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A STUDY OF THE
EFFECTS OF PLANT SPACING
AND
IRRIGATION ON SEED PRODUCTION
AND
SEED DEVELOPMENT IN SIRATRO
(Macroptilium atropurpureum)

A THESIS PRESENTED IN PARTIAL
FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY IN SEED TECHNOLOGY
AT MASSEY UNIVERSITY
PALMERSTON NORTH
NEW ZEALAND

SUNANTA JUNTAKOOL

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ABSTRACT

Since 1980 the Thai government has been interested and active in increasing livestock production by improving the productivity and quality of natural and sown grassland. The introduction of forage legumes, particularly Siratro (*Macroptilium atropurpureum*), is one of the ways in which this can and is being achieved.

The present study was carried out in two parts - the first involving two field trials conducted in Thailand during the wet and the dry season, and the second involving a controlled climate study at Palmerston North (N.Z.). The aim of the field trials was to investigate the effects of plant spacing, and during the dry season the effect of irrigation on Siratro seed production. In the controlled climate study a more detailed investigation was undertaken of the effects of water stress on plant growth and development and subsequent effects on seed yield. Particular attention was also given to relevant aspects of seed development in the latter study.

Irrigation during the dry season produced relatively small but significant increases in plant dry weight and LAI and led to a significant increase in seed yield by the final harvest 40 days after peak flowering. By comparison, plant spacing had a marked effect on plant components and seed yield showing a negative response on a per plant basis but a positive response on a per unit area basis with increasing plant density.

During the longer growing period of the wet season experiment, plant growth was substantial and again showed the same significant responses to increasing plant density stated above. Maximum seed yield per hectare was achieved at very high plant population densities approximately 15 x 15 cm spacings.

The major contributions to seed yield in both trials were inflorescence numbers and especially pod numbers, reflecting their sensitivity

to water stress and plant competition. Numbers of seeds per pod and individual seed weight were relatively insensitive to those environmental factors.

The growth room study clearly showed that early and extended soil moisture stress can cause a severe reduction in plant weight, branch development, leaf number and LAI, leading to a significant reduction in seed yield. However, soil moisture stress imposed at peak flowering resulted in a significant increase in seed yield compared with adequate moisture to final harvest. This beneficial effect was again due mainly to the increase in the number of inflorescences and pods formed on the primary and particularly the secondary branches. Numbers of seeds per pod and individual seed weight were again unaffected by water stress.

The development of Siratro seed followed two obvious phases viz the growth and food reserve accumulation phase and the ripening phase. Water stress reduced the time from anthesis to seed maturity and increased the percentage of hard seed^v when imposed early at the mid-vegetative stage. at harvest

Plant spacing and irrigation had little or no effect on seed quality characteristics of Siratro, as quality appeared to be more dependent on stage of maturity. High seed quality can be achieved by harvesting Siratro 20 - 30 days after peak flowering.

The possibility of growing Siratro for seed production in Thailand is also discussed.

* * * * *



SIRATRO

INFLORESCENCE

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INTRODUCTION

Although about half of the world's grazing animals are found in the tropics, most ruminant production is carried out on natural grasslands rather than on sown pastures. This is one reason why there is such a low animal output per unit area from many tropical pastures (Humphreys, 1978). In these natural grasslands, dominated by a wide range of graminaceous species, both the quantity and quality of the herbage sets a limit to production. The quantity produced is often severely limited by climate and by the low nitrogen availability of the soils, while pasture quality is influenced by both low crude protein content and the characteristic growth pattern of grasses which form the bulk of the diet. As a result, animal production is limited by the low nitrogen content and low digestibility of the feed for a considerable period of the year. Particularly during the dry period, this leads to low dry matter intake and low growth rates in grazing animals.

One reason for the poor nutritive value of many tropical pastures is the low proportion of high producing legumes in the sward. Although legumes may occur in abundance in some tropical grazing lands, edible herbaceous legumes do not usually improve yield or nitrogen status. For example, Humphreys (1978) stated that native legumes such as *Indigofera enneaphylla*, *Glycine* spp. and *Zornia diphylla* have been shown to contribute only 0.3 - 4.0% of the feed on offer in native grasslands and represent yields which seldom exceed 50 kg/ha.

Certainly the introduction of potentially high yielding legumes into natural grasslands can add nitrogen to the soil as well as providing herbage with an increased protein and nitrogen content (Jones *et al*, 1967), digestibility (Minson and Milford, 1966) and yield (Kretschmer, 1972). Such introductions have resulted in equally dramatic increases in animal production (Norman and Phillips, 1970). Shaw and 't Mannetje (1970) reported that the combination of fertilizers and a suitable tropical legume resulted in almost a doubling of liveweight gain per head and a sixfold increase in animal liveweight per hectare from

improved native grassland. This beneficial effect of the legume in promoting animal liveweight gains has been confirmed by many scientists (Norman and Stewart, 1964; Stobbs, 1965) even at relatively high stocking rates (Norman, 1970).

Perennial pasture legumes give a longer sequence of feed production than annual legumes. They are also often capable of fixing larger amounts of nitrogen than annuals. A number of perennial legumes have been found to produce acceptable amounts of high quality herbage in association with grasses and have shown persistence under grazing pressure. In Thailand generally, and in the North-east Region in particular, a number of perennial legumes have shown promise for pasture improvement. Amongst these, Siratro (*Macroptilium atropurpureum*) has been very successful. Although it is a relatively new pasture legume to Thailand, its use since it was first introduced in 1962 has greatly increased (Wickham, 1976). Since 1962 Siratro has been used in many pasture improvement projects particularly at Khon Kaen University (Annual Report 1976-1980) and in land development at Borabu, Mahasarakham province. Such early work provided important information on the value and potential of forage legumes for increasing animal production from native grasslands in Thailand and justified the associated and subsequent research on forage legume seed production (Wickham, 1976; Wickham *et al*, 1980; Hare and Waranyuwat, 1980).

An important aspect of the more general acceptance and usage of pasture legumes in Thailand is the extent to which reliable supplies of high quality seed can be maintained at reasonable prices. In many tropical countries seed supply has been a major constraint to pasture development. Accompanying this has been the need to develop seed production skills, commercial processing and seed quality controls as the basis of an efficient seed industry. Certainly with the wider use of tropical grasses and legumes by village farmers and government organisation in North-east Thailand, seed production has increased dramatically in importance. Currently seed and pasture production have a special place in nearly all livestock development projects in Thailand (Hare and Waranyuwat, 1980).

The present studies on Siratro seed production were therefore initiated in an attempt to add to the background of knowledge on the growth and development of this species. It was hoped that the results of such a study might be useful as the basis of recommendations and assistance to Thai farmers.

The study was divided into two main sections - a field experiment designed to study the effects of plant spacing on seed production following dry season and wet season plantings, and a controlled environment experiment designed to study Siratro growth and development under differing levels of water stress.

In particular, the objectives of the field study, carried out in Thailand, were:

1. to study the effects of plant spacing on seed production in terms of both seed quantity and quality;
2. to study the effects of irrigation on seed production with particular reference to a dry season planting;
3. to compare the performance of this crop sown at two different times of the year to determine the more suitable sowing time for Siratro seed production in Thailand.

The objectives of the controlled environment study, carried out in New Zealand, were:

1. to examine the role of water stress on plant growth and subsequent seed development and yield;
2. to study the effect of water stress imposed at different stages of growth on reproductive development and the components of seed yield;

3. to follow the sequence of seed development with particular reference to seed yield and quality.

* * * * *

SECTION A : LITERATURE REVIEW

Before reviewing the literature on factors affecting seed production in Siratro it is appropriate to present a general description of the species itself.

A.1 GENERAL DESCRIPTION OF SIRATRO (*Macroptilium atropurpureum*)

Macroptilium atropurpureum belongs to the sub-family Papilionoideae of the family Fabaceae. The plant is commonly known as 'Siratro' and was the first tropical pasture cultivar to be produced by the plant breeder, Dr E.M. Hutton of the C.S.I.R.O. in Australia. Siratro was bred by crossing two Mexican introductions of *Macroptilium atropurpureum* viz CPIs 16877 and 16879 and was released in 1960 (Hutton and Beall, 1977). It has proven to be a highly successful tropical pasture legume for the 700 - 1200 mm rainfall zone of the tropics and sub-tropics. Siratro spreads by creeping stems which may also behave as stolons and may root anywhere along their length. These roots, primarily in wet areas, aid persistence and nutrient uptake and provide further sites for nodule development. Siratro has a large seed with usually 40 - 70% hard seed, depending upon the age of the seeds and the method of harvesting. The production of hard seed allows the build-up of viable seed reserves in the soil (Tothill and Jones, 1977). The large seed size accompanied by rapid germination and strong seedling vigour make its establishment faster and possibly more certain than many other tropical legumes.

At present, Siratro is commonly used in tropical pasture in Australia and is rapidly gaining acceptance and use in many parts of the tropics and sub-tropics, e.g. Brazil, Mexico, Asia and some of the Pacific Islands (Hutton and Beall, 1977). Besides its relatively high productivity and palatability, important features in favour of Siratro are its good seed production and the relative ease of hand-harvesting seed pods. Shaw and Whiteman (1977) stated that the performance of Siratro outside Australia showed that the latitude does not seem to be important within the range 28°S to 28°N, provided the rainfall is between 700 and 2000 mm per annum. Siratro has not persisted in areas where

the dry season is virtually rainless and of more than four months' duration. Siratro is also somewhat limited in its value in the true humid tropics where it is subject to severe disease problems (Shaw and Whiteman, 1977; Jones and Jones, 1978). Persistence is also often poor in water-logged areas (Rees *et al.*, 1976). However, Siratro can persist under high rainfall conditions (2900 mm) provided soils are well drained and the climate is not continuously humid. As stated by Hopkinson (1977), Siratro has a wide adaptation to different soils both in terms of texture and pH provided they are free draining or adequately drained.

Low temperature can severely restrict the growth of Siratro. Jones (1969) and Whiteman (1968) found its optimum temperature range for growth to be between 27/22°C and 33/28°C (day/night). Siratro is a quantitative short day plant and has a cleistogamous habit (Hutton, 1962). Imrie (1973) found that low temperature tended to delay flowering but did not alter the basic short-day response. However, in the field, flowering can be stimulated by water stress (Hopkinson and Loch, 1973).

One of the special advantages of Siratro is its resistance to nematodes. Little leaf virus has been only rarely recorded. Bean fly, however, can attack young Siratro seedlings (Hutton, 1962) and seed dusting is a successful preventative measure (Jones, 1965). Siratro is one of the most vigorous pasture legumes and nodulates freely and effectively with a wide range of strains of Cowpea group Rhizobium (Date, 1977). It therefore provides an effective and productive legume base for many permanent high producing tropical pastures.

In reviewing the literature on seed production in Siratro, emphasis has been mainly restricted to those environmental factors studied in the current series of experiments, viz plant density and water stress. The many other important factors affecting seed yield were not the intention of this investigation.

A.2 EFFECT OF PLANT DENSITY ON VEGETATIVE GROWTH, REPRODUCTIVE DEVELOPMENT AND SEED YIELD

Variations in plant population density arise, generally, from variation in seeding rates and can lead to very different and severe levels of plant competition in the field. These competitive effects have been well documented over the years by many scientists including Donald (1963); Holliday (1960); Kirby (1977) and others and commence when the supply of a necessary resource falls below the combined demands of the population. The major factors involved in this competitive struggle are light, water and nutrients.

A.2.1 Effect of Plant Density on Vegetative Growth

A number of workers have reported increases in dry matter production with increasing seeding rates or plant densities, e.g. in barley (Aspinall and Milthorpe, 1959), in lucerne (Kowithayakorn, 1978), in Caribbean stylo (Topark-Ngarm, 1976) and in *Stylosanthes humilis* (Rickert and Humphreys, 1970). Similarly, Jones and Andrew (1967) found that the herbage yield of Siratro in mixtures with *S. sphacelata* cv. Nandi increased markedly with increasing sowing rates from 1 - 8 lb/ac. All of these investigations on vegetative growth and in particular, the classical work by Donald (1951) with Wimmera rye grass and subterranean clover and by Holliday (1960) with rape have highlighted the fact that total crop dry matter shows an asymptotic response with increasing plant density.

A.2.2 Effect of Plant Density on Plant Morphology

Plants show extreme plasticity, responding remarkably in size and form to environmental conditions. One variable which reflects this plasticity in the presence of competing neighbours is plant height. At high densities plants become taller due to the elongation of the internodes rather than an increase in the number of nodes (Hodgson and Blackman, 1956; Basnet *et al*, 1974; Tamaki *et al*, 1973). Along with this increase in plant height, the stems of plants in high population densities become thinner making them more susceptible to lodging. Hicks *et al* (1969), Cooper (1971) and Lueschen and Hicks (1977) working on soybean, found that highest plant density yields were

significantly reduced due to severe lodging. Similarly, Fontes and Ohlrogge (1972) reported that, above certain critical populations, lodging became very important and the yield gained from increasing the number of plants was smaller than the losses attributed to plant lodging.

The density of plants affects not only plant height, branch numbers or lodging but also the root system and plant mortality. For example, Rickert and Humphreys (1970) in work on Townsville stylo found poorer root growth with rising plant density. Tamaki *et al* (1973) showed that root dry weight per plant decreased as density increased due to poorer secondary and tertiary root formation. Haynes and Sayre (1956) stated that root patterns in individual corn plants at close-spacings changed from circular to oblong. Zaleski (1964) also noted that in dense crops, the majority of white clover plants had a tap root present, but in open swards the tap root was dead in most plants. In the latter situation the plant stolons had well developed adventitious roots, which were absent in plants grown in dense swards. In pigeon pea (*Cajanus cajan* L.) Ahlawat and Saraf (1981) reported that root length increased at higher densities due to the limited supply of inputs available per plant. Hence the roots grew at a much greater depth and utilized more inputs deeper in the soil.

Despite the great plasticity of plants, competition at high densities may be so severe that considerable numbers will die as reported by Palmer (1971) and Wynn-Williams and Palmer (1974) in studies on lucerne. The same result was found by Meadley and Milbourn (1970) with vining peas and Leakey (1972) reported increasing mortality of *Phaseolus vulgaris* L. (Savi) plants with increasing stand density.

A.2.3 Effect of Plant Density on Reproductive Growth

Carlos and Hume (1978) reported that the percentage of reproductive structures aborting in soybeans increased at high density. Work on *Vicia faba* by Hodgson and Blackman (1956) also showed that the number of podless stems increased with plant density and thus the number of productive stems per plant diminished more rapidly in high density

stands. Meadley and Milbourn (1970) compared vining peas at three plant densities, 43, 97 and 172 plants/m². They found no difference in the yield of green peas over these densities. Peak numbers of flowers and pods were found in the highest density, but there was a greater wastage (34%) by abscission than in the lower plant density which resulted in a similar number of pods per unit area for all densities. In lupin, Herbert and Hill (1978a) reported that at dense populations, plants produced fewer inflorescence orders, thus resulting in a shorter flowering period.

A.2.4 Effect of Plant Density on Seed Yield and Seed Components

As reported above, total yield of dry matter generally shows an asymptotic relationship with increasing plant density. By contrast, the relationship between reproductive yield and plant density shows a parabolic function (Holliday, 1960a). The relationship between seed yield and plant density is very complex because of the plasticity of yield components and the interaction with environment and genotype. Usually, as plant density increases seed yield increases, becoming maximal at an optimum density. Above this optimum density, further increases cause a reduction in seed yield (Willey and Heath, 1969; Shelton and Humphreys, 1971; Crothers and Westermann, 1976). Some workers, however, have not shown this parabolic relationship in their experiments even at very high population densities. One example is shown in work by Newton and Hill (1977) with broad beans grown at a population of up to 80 plants/m². It can only be assumed that had they gone even higher in density the expected decline would have occurred. However, this work does highlight the capacity of some species to adapt and continue to produce even under extremely high population pressures.

Seed yield is a complex character and built up from several yield components which in turn are determined by a combination of plant and environmental factors. These yield components have a relationship with plant structure as described by Adams (1975) in Figure A.2.4.

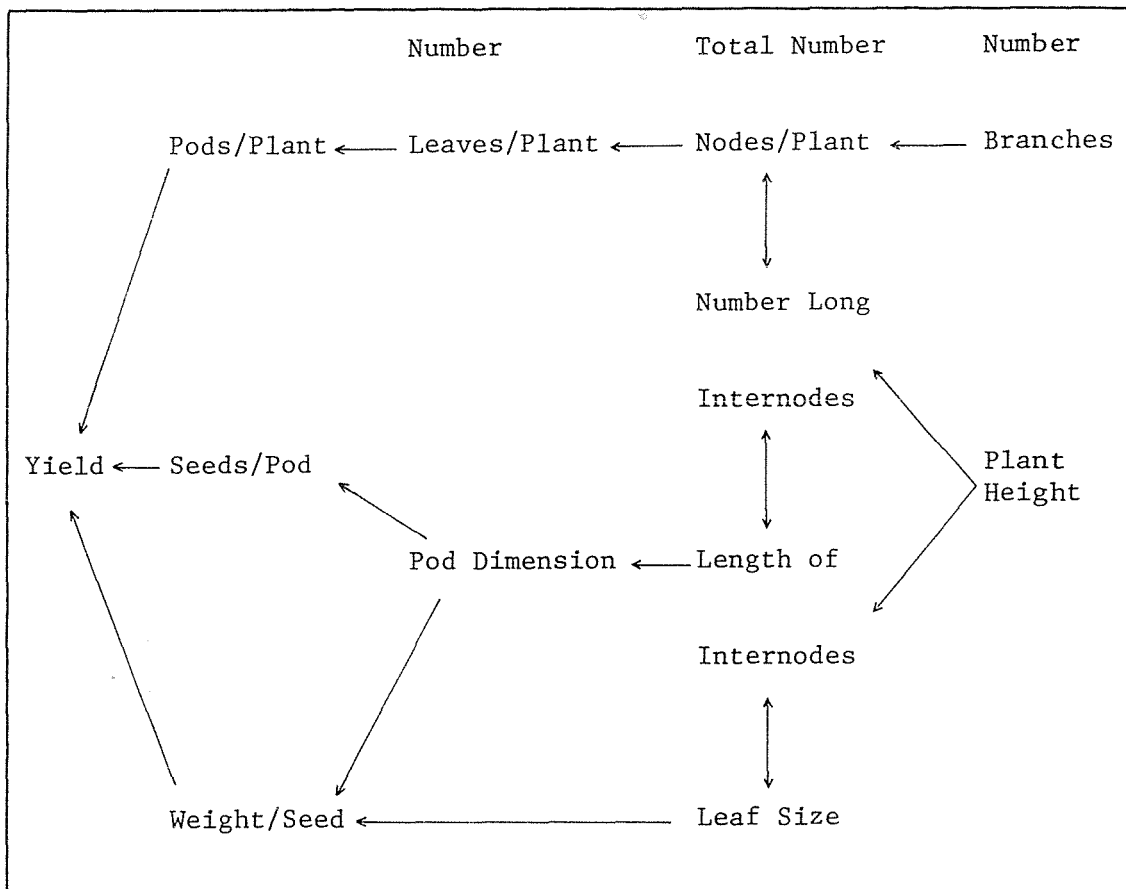


FIGURE A.2.4 DIAGRAM SUGGESTING THE DIRECT PATHS OF INFLUENCE
OF SEVERAL STRUCTURAL COMPONENTS OF PLANTS
UPON YIELD (ADAMS, 1975)

The number of pods per unit area or per plant is usually the main component influencing yield (Adams, 1975; Leakey, 1972; Crothers and Westermann, 1976; Bennett *et al*, 1977). This is usually the first seed yield component to be influenced by environmental and cultural practices (Bennett *et al*, 1977). Other components of yield viz number of seeds per pod and seed weight, tend to be less variable (Hodgson and Blackman, 1956; Gritton and Eastin, 1968; Crothers and Westermann, 1976). Ingram (1976) studied the effects of plant density on winter beans (*Vicia faba*) and reported that the number of

stems per plant and pods per stem were the components of yield most affected by plant density. In particular he showed that stems per plant were greatly decreased by increasing plant density but that pods per stem were slightly less affected. He also mentioned that changes in plant density generally produced only small changes in the number of seeds per pod and seed weight. Leakey (1972), working on *Phaseolus vulgaris* L., also confirmed that the number of pods per unit area increased at higher populations in spite of a reduction in the number of pods per plant as populations increased. Conversely, both mean seed weight and the number of seeds per pod were not significantly affected by changes in population. Bennett *et al* (1977), in a study on the same species, found that pod formation was highly sensitive to plant density and that both racemes per node and branches per plant were significantly reduced by higher planting density. These two components were shown to be positively correlated with pods per plant but negatively correlated with each other. However, Adams (1967) stated that seeds per pod and seed weight are capable of considerable compensation depending on the number of pods set on the plant. Such compensation was also found by Ishag (1973a). He reported an increase in the number of seeds per pod and in seed weight in response to low pod numbers per plant.

There are relatively few critical studies of the effects of plant density on seed yield and its components in tropical forage legumes, particularly Siratro. Some investigations by Shelton and Humphreys (1971) on Townsville stylo, however, have found that seed yield was related to plant density in a parabolic form which exhibited a maximum yield of 69 g/m² at a density of 850 plants/m² and slightly declined at a supra-optimal density of 3800 plants/m². They also reported that the primary control of seed yield was the number of inflorescences formed per unit area. The rate at which inflorescence numbers per plant decreased with density was more than compensated for by increased plant numbers. However, the major factor which caused a decrease in seed yield at the highest density was the proportion of florets setting seed which decreased sharply from 0.30 to 0.16. In the same species, Wilaipon (1976), using seeding rates of 6.2, 12.5,

37.5 and 50.0 kg/ha, reported that inflorescence numbers per plant decreased as the seeding rate increased and that seed yield tended to increase to a maximum of 1407 kg/ha at the 12.5 kg/ha seeding rate before declining at higher seeding rates. Javier *et al* (1978) studied seed production of Siratro sown in rows 20, 40 or 80 cm apart at rates of 3, 6 and 9 kg/ha and harvested by hand or machine. They reported that the highest seed yields were obtained from a 3 kg/ha sowing rate at 80 cm row spacing when hand harvested.

A.2.5 Effect of Plant Arrangement

In spacing experiments, the two major factors involved are plant density and plant arrangement. It is generally agreed, both on theoretical and experimental grounds, that the highest yield at a given density is obtained when the plant arrangement is square or approximately square. Mack and Hatch (1968) considered plant arrangement and plant density separately. They showed that densities of *Phaseolus vulgaris* L. ranging from 43 to 65 plants/m² planted in a square pattern produced 35% higher yields than the same densities in 91.4 cm rows. Rogers (1976) also confirmed that the square arrangement in *Phaseolus vulgaris* L. can give a higher seed yield. He suggested that 47 plants/m² was the approximate economic optimum density for this crop. Apparently a plant spacing with equal dimensions provides a more desirable environment for the spread and development of plants than those with a spacing of unequal dimensions (Mack and Varseveld, 1982).

A.3 EFFECT OF WATER STRESS ON PLANT GROWTH AND YIELD

The previous section has only considered the effect of plant density on seed production. This section considers the effect of water stress, a major environmental factor and specially selected for this study, on the vegetative and reproductive growth of plants.

A.3.1 Water Stress and Morphological Effects

The development of a soil moisture deficit can lead to a wide range of

morphological and physiological responses in the plant (Boyer and McPherson, 1975). For example, water deficit reduces cell turgor, causing closure of stomata and reduction in cell enlargement (Kramer, 1980). This is important since the growth and development of plants depends on a continuing process of cell division and cell enlargement (Salisbury and Ross, 1978). Both the initiation and differentiation of vegetative and reproductive primordia in the apical meristem and the enlargement of the cells are very sensitive to water stress and have been shown to be affected by even very mild levels of stress (Wardlaw, 1969; Hsiao, 1973). Cell division is generally regarded as less sensitive to water deficits than cell enlargement (Vaadia *et al.*, 1961; Slatyer, 1967; Salter and Goode, 1967; Hsiao, 1973). For example, Petinov (1965) observed that the leaves of plants which have undergone periods of stress may contain a similar number of cells as in unstressed controls but they are generally smaller in size. He also found that the differentiation of the leaf proceeds more rapidly leading to advanced maturation. The sensitivity of cell enlargement to water deficit was shown by Boyer (1970a) working with corn, soybean and sunflower. He reported that leaf enlargement was maximised at about -1.5 to -2.5 bars but was strongly inhibited at -4 to -5 bars. The work of Ludlow and Ng (1976) on *Panicum maximum* var. *trichoglume*, also reported an 80% reduction in leaf elongation rate when leaf water potential fell from -4 to -7 bars and that elongation actually ceased at -10 bars. One of the most important consequences of this sensitivity of cell enlargement to water deficits is the marked reduction in leaf area. Since the area and effectiveness of the leaf surface are primary factors determining seed yield, a reduction in leaf area can reduce crop growth rate and hence reduce potential yield per plant particularly during the early growth stage when there is incomplete light interception (Begg and Turner, 1976; Turner and Begg, 1981). However, Petinov (1965) commented that yield per unit area is influenced by the leaf area index of the plant community rather than the leaf area of individual plants, so that appropriate sowing rates can compensate for the reduction in leaf area per plant. This reduction in leaf area is considered to be most significant in forages, since the economic yield is determined by the proportion of above

ground dry matter rather than the reproductive yield (Turner and Begg, 1981). Water stress can also affect leaf area by reducing tillering and by hastening the death of leaves and tillers.

In summary, it can be stated that the effect of stress on growth tends to be most pronounced in those tissues which are in a rapid stage of development (Gates, 1955a; Salter and Goode, 1967). Primordial initiation and cell enlargement are particularly susceptible. Although cell enlargement does not appear to compensate following the removal of stress, cell initiation does show compensation as long as the stress has not been too severe. The developing tissues appear to enter a rejuvenating phase on relief of stress. The relative growth rate of previously stressed plants may then be more rapid than the unstressed control. This 'compensatory growth' has been shown by Gates (1955a, 1964) and Ludlow and Ng (1976). This rapid growth is aided by the continued, slow cell division which has occurred and by the availability of nutrients released from older tissues.

A.3.2 Water Stress and Physiological Effects

In addition to the effect of water deficit on plant morphology, a number of reports of physiological responses to water deficit have been published elsewhere (e.g. Slatyer, 1967; Hsiao, 1973; Boyer and McPherson, 1975; Begg and Turner, 1976; Day, 1981; Turner and Begg, 1981). In this section only some physiological processes such as photosynthesis and stomatal behaviour will be considered.

Turner and Begg (1981) stated that the deficit required to influence the rate of net photosynthesis is usually greater than that required to influence leaf elongation. However, a decrease in net photosynthesis always goes hand-in-hand with a decrease in stomatal conductance (Boyer, 1970b). The stomata occupy a key position in the pathway for gaseous exchange between plant and atmosphere, and thereby regulate both photosynthesis and water loss. The stomata of plants suffering from water stress normally respond by closing to some degree. This results from loss of turgor in the leaf and also

from hormonal effects in which water stress induces abscisic acid formation (Hsiao, 1973). It is now generally recognised that the stomata also act as 'humidity sensors' which may open or close even though leaf water content is constant (Lösch and Tenhunen, 1981).

Water stress can induce flowering and fruit set particularly in some tropical crops such as coffee, cacao and mango (Grierson *et al*, 1982). Alvim (1960) suggested that water deficits are not the cause of dormancy but rather the cause of breaking dormancy.

A.3.3 The Effect of Water Stress at Different Stages of Growth

The effect of different soil moisture levels occurring at the three main developmental stages on growth and yield of plants has been studied in many experiments. These three stages occur from sowing until the start of flowering; during flowering; and during the period of pod growth until harvesting (Salter and Goode, 1967).

The results from many experiments, for example Salter (1962), Kattan and Fleming (1956) and Salter (1963), have suggested that irrigation before flowering was often without effect apart from an increase in the amount of foliage produced.

The effect of irrigation during the flowering period has also been studied by several workers. Kattan and Fleming (1956) in their work on snap beans (*Phaseolus vulgaris*) found that irrigation applied during flowering and pod development resulted in the highest yield and largest pods, and for high quality beans irrigation during pod development was essential. They also concluded that drought injury became more pronounced at the more advanced stages of development. Dubetz and Mahalle (1969) in their work on bush beans (*Phaseolus vulgaris*) reported that when plants were subjected to a soil moisture stress of -8 bars at the flowering stage the total weight of green pods was reduced 71% compared with plants in the low-stress control treatment. They considered that this stage was the most susceptible to water stress and resulted in inhibition of subsequent flower initiation. Similarly, the work by Nelson (1962) showed that high

soil moisture stress during flowering and pod development produced the greatest reduction in yield, by an average of 22%. Robins and Domingo (1956) worked on a red Mexican variety of dry beans. The soil moisture treatments consisted of omitting irrigation at three different stages of growth, viz prior to flowering, during flowering and prior to harvest. Yields were reduced about 20% when soil moisture stress occurred at any of these growth stages. They also showed that stress before flowering reduced the number of pods and that it reduced both the number of pods and number of beans per pod when it was imposed during flowering; water stress occurring before harvest reduced bean weight. Plant development was retarded by moisture deficit before flowering and hastened during flowering and at later stages of growth. In a further experiment, Mack and Varseveld (1982) studied the response of bush snap bean to irrigation and density. Three soil water potential regimes (-0.6, -1.0 and -2.5 bars) were designated as low, medium and high water stress respectively. The two plant densities were low density (21.5 plants/m²) and high density (43.0 plants/m²). They found that no consistent interactions occurred between irrigation and density, but there was a trend for more rapid depletion of soil water at high density plantings than at low density. Pod yield increased with irrigation and plant density. Highest yields were obtained from the -0.6 bar soil water potential treatment and lowest yield in the -2.5 bar soil water potential regime.

Salter's (1962) studies on peas, showed that irrigation a few days before harvest greatly increased the yield of marketable pods and shelled peas. In a further experiment, Salter (1963) compared the effect of wet and dry soil conditions at different growth stages on a determinate variety of pea. Again, no increase in yield of peas resulted from irrigating before flowering, but irrigation at the start of flowering increased the yield by over 30% by increasing both the number of pods and the number of seeds per pod.

Many studies have been made on the response of soybeans at different stages of growth to different soil moisture conditions. Again, these stages are the period before flowering, during flowering and during

the fruiting period. By and large, adequate water supply during the main period of vegetative growth is of lesser importance than during flowering and fruiting. Certainly, water stress during flowering increases the abortion of both flowers and young pods (Whigham and Minor, 1978). Matson (1964), working on the irrigation of soybean in Missouri, reported that when irrigation was applied only from flowering until approximately four weeks before seed maturity, yields were not reduced over a three year period compared with those obtained from plants irrigated throughout their growth. Cartter and Hartwig (1962) also indicated that irrigation during the fruiting period was essential for maximum yields to be obtained, while Sionit and Kramer (1977) showed that stress at this stage produced the smallest seeds and shortened the length of the maturation period. Laohasiriwong (1982) reported that water stress during this stage caused significant pod abortion. He also commented that plants with a determinate growth habit were more sensitive to water stress during the early phase of reproductive growth, whereas indeterminate plant types were more sensitive during the later phase of reproductive growth.

There is limited information available on the effect of water on seed production of tropical forage legumes. Fisher and Campbell (1977) conducted an experiment which involved the effect of water stress on growth of Townsville stylo (*Stylosanthes humilis*). Five drought treatments were compared with an unstressed control (C). Treatments were: stress in early vegetative phase and rewatered (EV); stress in late vegetative phase and rewatered (LV); stress at flowering and rewatered (F); stress at late flowering with no further water (LF) and stress at seeding with no further water (S). The results indicated that stress during the vegetative stage reduced growth, but the relief of stress was followed by a period of rapid growth which largely compensated for the loss. However, unrelieved stress starting during flowering (LF) significantly reduced pod yield (by 37%) compared with the control. When stress during flowering was relieved by only one watering (F) pod yields were similar to the control. Stress during the vegetative growth hastened flowering by two weeks. They suggested that this earlier flowering was a direct effect of

water stress in stimulating initiation. Ahmed and Quilt (1980) studied the response of Siratro and *Desmodium intortum* cv. Green leaf subjected to four soil moisture treatments, 70%, 50%, 35% and 20% of water holding capacity (WHC) maintained for eight days and then rewatered to 70% WHC. They reported that the highest soil moisture stress (20% WHC) significantly reduced the top weight of plants but nitrogenase activity was not significantly affected by moisture stress, even at this high moisture stress level. They commented that either the root nodules of both legumes were not susceptible to moisture stress or that, under pot conditions, the moisture stress imposed was not high enough to inhibit nodulation and nitrogenase activity. They concluded that the growth of both Siratro and *Desmodium* is highly susceptible to moisture stress. Argel and Humphreys (1983b) studied the effects of moisture supply on seed development, hardseedness and seed yield in *Stylosanthes hamata* cv. Verano. They reported that yield of seed pods was significantly reduced by longer intervals between waterings. Severe water stress greatly reduced inflorescence density by a reduction in the differentiation of inflorescences. They also found that the less juvenile florets in the most stressed treatment showed a high percentage of floret abortion. However, individual pod weight was positively associated with the interval between irrigations, indicating the compensatory effect of this component of seed yield.

From literature reviews, it is apparent that the relative sensitivity of plants in terms of growth and development varies with the degree of water deficit (Hsiao, 1973). The growing tissues suffer the greatest check to growth but they are more tolerant to water deficits than older tissues and they can resume active growth again upon relief of water stress (Ludlow, 1975). Older tissues undergo accelerated senescence during periods of drought and may not recover following a severe water deficit (Hsiao, 1973).

A.4 ADAPTION AND ADAPTIVE MECHANISMS TO WATER DEFICITS

Water stress is probably the greatest environmental limitation to

pasture production. Such stress is caused by a deficiency of soil moisture or by an excessive transpiration of water from the leaves (Kramer, 1963; Turner and Begg, 1981). The amount of water lost in transpiration is proportional to the difference in water potential between plant and atmosphere. According to Ludlow (1980), plants can tackle water stress by escaping it, avoiding it or tolerating it. For example, Townsville stylo (*Stylosanthes humilis*) escapes water stress by germinating rapidly, growing quickly, flowering and producing seeds before the soil water supply is exhausted. Others avoid water stress by having especially deep roots, by having sensitive stomatal control or by the use of other mechanisms enabling them to survive the stress.

The adaptative mechanisms of Siratro to drought stress have been studied by a number of researchers, (Peake *et al*, 1975; Sheriff and Kaye, 1977; Ludlow and Ibaraki, 1979; Ludlow, 1980; Wilson *et al*, 1980 and Fisher *et al*, 1981). Peake *et al* (1975) found that in field conditions during dry periods, Siratro maintained a greater xylem water potential than grass species grown in association. They noticed that the older leaves of Siratro died progressively after several days of stress greater than -8 bars of leaf water potential. The maintenance of these higher leaf water potentials in the face of strong evaporative demand suggests that Siratro has a very efficient control of water loss. Ludlow and Ibaraki (1979) found that in controlled environments stomata of Siratro close when leaf water potential is below -6 bars and close to zero at approximately -10 bars. Sheriff and Kaye (1977) have shown that stomata of Siratro respond directly to humidity, independent of bulk leaf water potential. They suggested that the response to humidity and water potential have the same physiological base. The most obvious common base is the water status of the stomatal apparatus. As bulk water potential falls the water status of stomata declines and results in stomatal closure. In the case of

humidity, the combination of the relatively low conductance in the epidermis and the high rate of evaporation from the inner walls of the cells of the stomatal apparatus will produce a lowering of water potential in the stomatal apparatus and hence stomatal closure.

Siratro has developed not only the physiological mechanism, but also morphological mechanisms to enable it to withstand and adapt to water deficits. Since the rate of evapotranspiration is determined by leaf area, then the sensitivity of leaf expansion to water deficits is a useful adaptive mechanism. Any reduction in the evaporative surface will delay the development of further stress. By this mechanism, Siratro sheds its older leaves and may also orientate its leaves parallel to the rays of the sun to reduce the amount of energy absorbed. New leaves grown under increasing water stress are small, thick, dark green and hairy.

Ludlow (1980) concluded that Siratro has a low water stress tolerance but a high water stress avoidance involving the use of various mechanisms such as:

- (a) Rooting capacity : Siratro is a deep-rooted plant and can extract water from a considerable depth of soil (Peake *et al*, 1975).
- (b) Sensitive stomatal control which closes with either decrease in humidity (Sheriff and Kaye, 1977) or small changes in leaf water potential (Ludlow and Ibaraki, 1979).
- (c) Leaf movements allowing the movement of leaves parallel to the sun's rays (paraheliotrophy) to reduce the radiation load, leaf temperature and water loss.
- (d) Leaf area reduction by shedding older, larger leaves and producing smaller, dark green, thick and hairy leaves during stress.

A.5 SEED DEVELOPMENT

The term 'development' has been defined as the process of growth and differentiation of individual cells into recognisable tissue, organs and organism (Salisbury and Ross, 1978). Seed development commences following anthesis, fertilisation and seed set. Various physiological changes accompany this development. These changes include variation in seed moisture content, increase in seed weight, biochemical changes, colour changes and the onset and increase of seed germination capacity. In several studies on seed development in both grasses and legumes (Hyde, 1950; Hyde *et al*, 1959; Griffiths *et al*, 1967; Hill, 1971; Kowithayakorn, 1978 and Win Pe, 1978) most attention has been paid to two main phases of seed development viz the relationship of moisture content to dry weight and the development of viable seed from the time of anthesis to seed maturity. The term 'maturity' has been described as the point at which maximum seed development is first attained (Aldrich, 1943) or alternatively the point at which maximum dry weight is first obtained (Anderson, 1954). The latter definition has also been referred to as 'physiological' and 'morphological' maturity, terms which have been used by Shaw and Loomis (1950) and Anderson (1954) respectively. Andrews (1966) suggested that the term 'physiological maturity' should be judged in terms of maximum seed viability, vigour and dry weight rather than being considered only in terms of maximum seed dry weight.

The course of seed development in both grasses and legumes has been studied by many researchers (Hyde, 1950; Hill, 1971; Kowithayakorn, 1978; Win Pe, 1978; Mullett, 1981). Hyde (1950) and Hyde *et al* (1959) considered that three stages can be commonly distinguished in the development of the seed after anthesis both in grasses and legumes.

- (a) A growth stage : This stage lasts for approximately 10 days after pollination and is characterised by a rapid increase in seed weight. The moisture content of seed is high (75 - 80%) and the seed is non-viable.

- (b) A food reserve accumulation stage : This stage occupies a period of 10 to 14 days following the first stage. It is characterised by a uniform rate of growth which is presumably determined by the transfer rate of food reserves from the parent plant into the seed. During this second stage of development, the dry weight of the seed increases approximately three times or more, reaching a maximum at the end of the stage. The amount of water in the seed changes very little but the percentage water content falls rapidly. Any increase in the size of the embryo is due to enlargement of the cells formed in the first stage rather than to further cell division. At the end of this stage, the seed is structurally complete and attains full viability.
- (c) A ripening stage : This stage lasts for a further three to seven days. During this phase dry weight remains relatively constant, but the moisture content falls to somewhere between 10 and 20% which is in equilibrium with the relative humidity of the prevailing atmosphere. The time required for this stage is very dependent on weather conditions (Delouche, 1980).

Changes in moisture content, seed weight, biochemical substances, pod or seed colour and germination capacity during seed development are of particular importance and are closely related to seed maturity. Therefore changes in these parameters are commonly measured in seed development studies (Loewenberg, 1955; Hill, 1971; Chow and Crowder, 1974).

Generally, high moisture content in seed is characteristic of a young developing seed in the so-called growth stage. Moisture content of seed gradually decreases throughout this period of growth from an initial level of approximately 90% to approximately 35 - 40% (in forage legumes) as seed dry weight reaches its maximum. The relationship between the stage of seed development and seed moisture content

has been reported by many workers (Hyde, 1950; Hyde *et al*, 1959; Carr and Skene, 1961; Oliker *et al*, 1978; Win Pe, 1978; Kowithayakorn, 1978). With many species, the mature seeds reach a moisture content which is in equilibrium with that of the surrounding air. The equilibrium moisture content varies with species, but is little affected by temperature (Austin, 1972) and moisture content in the seed has been widely used as the parameter for determining seed maturity and correct harvest timing (Klein and Harmond, 1971). Hill and Watkin (1975) presented a 'drying curve' which involved both moisture content and percentage of seed viability to be used as an indicator to forecast the correct time of harvesting for attaining maximum viable seed yield.

Along with the high moisture content of the seed during growth stage, there is a slow increase in dry weight of seed followed by a rapid increase reaching a maximum at 'physiological maturity' (Andrews, 1966). The time to reach maximum dry weight varies with species and environment. For example, Hyde *et al* (1959) showed that white clover and red clover reached their maximum seed dry weight approximately 24 days after anthesis. Chow and Crowder (1974) investigating *Desmodium* species found that maximum seed weight was achieved about 28 days after anthesis. Flinn and Pate (1968) found that seed of *Pisum arvense* L. var. Black-eyed Susan gained maximum dry weight at about 55 days after anthesis when grown in the field while Oliker *et al* (1978) reported that seed of *Phaseolus vulgaris* took 36 days from pollination to reach maximum dry weight.

Protein and carbohydrate comprise the major storage reserves of most monocotyledon seeds, while many dicotyledons, particularly legumes, also accumulate lipids and free fatty acids. Changes in these substances during seed development have been reviewed in detail by Dure (1975), Oliker *et al* (1978) and also by Osborne (1981). Carr and Skene (1961) in *Phaseolus vulgaris*, Flinn and Pate (1968) in pea (*Pisum arvense* L.), Bils and Howell (1963) and Yazdi-Samadi *et al* (1977) in soybeans. Apparently, free sugars and amino acids are found in the early growth stage of the seed and rise sharply during the first phase of seed development, decreasing gradually

thereafter to a relatively stable level at seed ripening (Stoddart, 1964b). The reserve of starch in the seed is virtually complete by the end of the food reserve accumulation stage and most of this starch is laid down in the cotyledon of the seed (Flinn and Pate, 1968). At the same time, by the end of second phase of seed development, the progressive build up of globulins and reserve proteins in the cotyledons can be detected and reaches a maximum at seed ripening (Flinn and Pate, 1968).

Colour changes are an indication of approaching maturity and are helpful in judging the ripeness of grass and legume crops. Such colour changes have been traditionally used to determine the correct harvest date. In grasses, the mature caryopsis is often described as being largely free of green pigmentation. However, Hyde *et al* (1959) stated that in several grass species physiological ripeness was attained whilst the seed coat was still appreciably green. In legumes, loss of green pod colour was found to be a visual indication of physiological maturity (Gbikpi and Crookston, 1981). Rubel *et al* (1972) and TeKrony *et al* (1979) commented that soybean seed reaches physiological maturity when the seed coat turns completely yellow, regardless of the colour of the pod. Again TeKrony *et al* (1979), estimating physiological maturity of soybean in the field from seed weight data, found that this occurred when there was a relatively low percentage of brown pods and completely yellow seeds. Colour change of the pod has also been used as a guide to correct harvest timing of Siratro, e.g. when the upper surface of the majority of the pods (more than 50%) showed some brown coloration (Humphreys, 1978; Hare and Waranyuwat, 1980). According to Griffiths *et al* (1967), colour changes occurring in perennial ryegrass during seed development are due to variation in chlorophyll and anthocyanin content, and Oliker *et al* (1978) found that chlorophyll content in *Phaseolus vulgaris* L. was highest in the very young seed and had disappeared by 32 days after anthesis. In red clover and white clover, Hyde *et al* (1959) reported that colour changes commenced about 18 days after pollination. Reported pod colour change in lucerne occurred 34 days after pollination (Kowithayakorn, 1978). However, changes

in seed or pod colour are affected by environmental conditions during seed development, e.g. loss of green pigment in grass seed was quicker under hot dry conditions than under humid conditions (Hill, 1971).

Another seed character which shows a close relationship with seed maturity is 'hard seededness'. This form of seed dormancy is commonly found in the family Leguminosae (Anon, 1976a). Quinlivan (1971) defined the term 'hard seededness' as the dormancy mechanism which prevents the movement of water through the seed coat and the seeds concerned are known as 'impermeable seeds' or 'hard seed'. As legume seeds ripen their moisture content falls and seed coat impermeability develops. A report from Hyde (1954) showed that the hilum of the seed acted as a hygroscopically activated valve, which opened when the relative humidity of surrounding atmosphere was low allowing moisture loss from the seed, and closed when the ambient relative humidity was high. This relationship between seed moisture content and the development of impermeability has been recorded at approximately 14% (dry weight) by Hyde (1954). Quinlivan (1968b), researching *Lupinus varius*, confirmed that when the moisture content of the seed fell below approximately 8.5% the seeds were absolutely impermeable. The impermeability of seed coats to water is very common in pasture legumes. However, the rapidity with which hard seededness develops differs between genera and varieties and also depends on environmental conditions. For example, Argel and Humphreys (1983a) found that hard seededness in *Stylosanthes hamata* cv. Verano developed more rapidly in temperatures of 30°C day and 28°C night than in 20°C day and 16°C night and was decreased by low temperatures during flowering and seed formation. Cameron (1967) found that a selected line of *Stylosanthes humilis*, which flowered later in the growing season, had a higher level of hard seededness than early flowering lines. Seed coat impermeability of legumes is associated with longevity since it provides an important protection against rapid seed deterioration.

Hyde (1950) has listed three important aspects of seed quality which are greatly affected by the stage of seed development - viability,

seedling vigour, and storage life. Viability can be expressed as the ability or capacity of seed to germinate when placed in favourable conditions that allow germination to occur. According to Hyde *et al* (1959) seeds of most species have the ability to germinate at the beginning of the food reserve stage. However, Austin (1972) mentioned that maximum yield of viable seed and full germination capacity may not be achieved until the attainment of seed maturity. Again, Hyde *et al* (1959) pointed out that the lack of seedling vigour from immature seeds was due to inadequate food reserves at the early development stage, even though the seed acquired viability when translocation of food materials to the seeds was only just commencing. However, they also showed that seed viability and vigour both increased to their highest level near maximum seed dry weight. Similarly, it has been reported by a number of workers that immature seeds deteriorate more rapidly in storage than mature seeds (Hyde, 1950; Hill and Watkin, 1975; Kowithayakorn, 1978). This can be explained by the fact that seed harvested at this stage has not reached maximum dry weight. As a result, it lacks the maximum supply of food reserves and hence has a shortened storage life.

A.6 CURRENT FARMING PRACTICE

Although seedcrop management was not a major component of the present study it was nevertheless thought worthwhile to briefly review this subject, particularly in relation to Siratro seed production. Humphreys (1978), for example, has mentioned that in many tropical countries seed supply has been the main stumbling block to pasture development. Again, (Humphreys, 1979) he suggested that these problems may be partly overcome by careful selection of the site, good establishment practices and crop husbandry and by appropriate harvesting and seed processing techniques.

A.6.1 Site Selection

The location for Siratro seed production should have an adequately long growing season. According to Hopkinson (1977) this should be

at least three months in order to produce the necessary vegetative canopy to build a satisfactory seed yield potential. The growing of the crop under a suitable daylength and temperature to promote flowering should also be considered (Imrie, 1973). Similarly, dry and sunny conditions during seed maturation are highly desirable. Humphreys (1979) has commented that flower opening, pollination and photosynthetic rate during grain filling, are all favoured by sunny conditions.

Soil conditions are also important. Hare and Waranyuwat (1980) reported that free draining sandy loam soils are most suitable for Siratro seed production in Thailand. Clay soils or heavy, saline or waterlogged soils should be avoided. However, Hopkinson (1977) stated that most arable soils with good drainage are adequate for Siratro seed production provided any nutritional disorders have been rectified.

A.6.2 Crop Establishment

Successful crop establishment occurs when good quality seed receives the right conditions to germinate and grow. Therefore an understanding of the processes influencing crop establishment and the way in which they are influenced by such factors as cultivation, nutrient supply, rhizobium and pests and diseases is of importance (Leach *et al*, 1976).

Careful attention to seed-bed preparation is necessary. Skerman (1977) commented that the better the seed-bed preparation, the better the pasture establishment. Also, the smaller the seed to be established, the finer the seed-bed should be. Humphreys (1979) has, however, mentioned that a common fault in seed-bed preparation is to produce a fine seed-bed which is too fluffy and unconsolidated to provide good seed-soil contact and control of sowing depth. Hare and Waranyuwat (1980) recommended that one ploughing, two discings and one harrowing is usually required for suitable seed-bed preparation in Thailand. Levelling of the seed-bed may also be necessary on sloped areas (Skerman, 1977).

Good seed-bed preparation can also help to solve weed problems. However, weed control can also be done by using suitable herbicides. Since plants react differently to herbicides it is important to check the correct dosage required, as well as the time and method of application before use. A large proportion of the soils in the tropics are usually low in phosphorus (Uehara, 1977) and the greatest response in terms of legume dry matter yield is associated with the correction of this deficiency (Skerman, 1977). Very large responses to phosphatic fertilizer by tropical forage legumes have been measured (Andrew and Bryan, 1958; Ostrowski, 1970; Blunt and Humphreys, 1970). Similar responses have been reported by Wilaipon (1980). The addition of phosphorus is usually applied as superphosphate. However, not only phosphorus may be deficient, a requirement for potassium and perhaps sulphur and other elements may be needed as reported by Andrew and Bryan (1955). Fertilizer need in each location should follow recommendation from an agricultural adviser along with the results obtained from soil tests.

One difficulty in establishing many tropical legumes is the low percentage of germination which is obtained as a result of high levels of hard seededness (Gray, 1962). Increased germination percentages enhance successful establishment and allow the use of reduced seeding with a consequent reduction in establishment seed costs. Many workers have tried different methods of increasing the germination percentage of hardseeded tropical legumes (Gray, 1962; Hutton, 1962; Cameron, 1967). Gray (1962), Hutton (1962), Bogdan (1966) and Phipps (1973) have shown that immersion of hard seed in concentrated sulphuric acid increased the percentage germination of some tropical legumes. However this method is hazardous and impractical. Hot water treatments have been advocated by many workers (Gray, 1962; Bogdan, 1966; Phipps, 1973). Wickham (pers. com.) and Hare and Waranyuwat (1980) recommended hot water treatment of Siratro seed at 70°C for 10 minutes. However other methods can also be used to increase germination including immersion in liquid nitrogen and deep freezing (Phipps, 1973).

Most successful pasture legumes can nodulate effectively with a wide

range of *Rhizobium* strains. These are mainly of the 'Cowpea type' *Rhizobium* (Norris, 1967). Although Siratro can nodulate freely with native rhizobia, for ensuring satisfactory establishment, it is recommended that inoculation of seed with the Cowpea strain (CB 756) be carried out (Date, 1969).

In countries where the growing season is dependent on natural rainfall, such as Thailand and the Philippines, Siratro should be sown at the beginning of the wet season (Hare and Waranyuwat, 1980; Javier *et al*, 1978). Krestchmer (1972) recommended in the United States (Florida) that Siratro may be sown in spring or summer. In Australia, Middleton and Hickmott (1972) have suggested that planting in the November to January period is the best time to allow Siratro seedlings to be sufficiently advanced before winter and to at least minimize the effects of cold temperatures. Seed growers in some parts of Australia are able to manipulate Siratro seed production by the use of irrigation to provide the required wet and dry cycles, allowing the production of three or four seed crops annually (Humphreys, 1979; Hopkinson and Loch, 1973).

In general, it is advisable to use row planting for seed production of forage legumes (Skerman, 1977). In the Philippines, Javier *et al* (1978) reported that a sowing rate of 3 kg/ha or less in rows 80 - 100 cm apart is suitable for Siratro seed production, while Hare and Waranyuwat (1980) recommended a higher seeding rate of 12.5 kg/ha in Thailand. However, sward and trellis planting systems can also be used. Wickham (1976) and Hare and Waranyuwat (1980) have reported that a trellis growing system gave a higher seed yield than a sward planting (1125 vs 438 kg/ha). The big advantage of this trellis growing method is the ease of hand harvesting (Wickham *et al*, 1980).

Siratro, like other legumes, can be attacked by insects and diseases. During the seedling stage (3 to 4 weeks after sowing), Siratro seedlings are very susceptible to attack by bean fly (*Melanagromyza phasioli* (Hutton, 1962)). This insect is a major pest of many legumes grown for seed and serious losses have been recorded in species of

Phaseolus spp. such as French bean. However, attack by this pest can be prevented by seed treatment (Jones, 1965). Another insect that feeds on foliage and attacks Siratro leaves is bean leaf roller (*Urbanus proteus*). Kretschmer (1972) reported, in Florida, that damage by bean leaf roller on Siratro, particularly in late summer and autumn, can be important but is not generally a serious problem.

Amnemus weevil (*Amnemus quadrituberculatus*) can also damage Siratro roots as reported by Mears (1967). However, Mears (1967) and Braithwaite and Rand (1970) both reported that Siratro appeared to be relatively resistant to this root insect compared with *Desmodium* and *Glycine* species.

Insects that feed on seed or flowering parts of Siratro have been reported in many countries. In Thailand, Wickham *et al* (1977) and Hare and Waranyuwat (1980) reported that pod borers (*Bruchus spp*) were serious pests and caused damage to the young pods and seeds of Siratro.

Several species of aphids also injure forage legumes by sucking the plant juices. The most favoured sites of attack are the floral parts and the growing shoots. In severe infestations the leaves and stems are also attacked. Such effects have been reported by Wickham *et al* (1977), Jones and Jones (1978) and Kretschmer (1972). Generally, dry conditions promote aphids. However, if the crop is kept vigorous and healthy by an adequate water supply it can usually outgrow an aphid attack (Saunders, 1968). Growing forage plants for seed often creates an environment favourable for the development of many diseases. Dense leaf growth creates a natural moist "chamber", and if this coincides with a high humidity environment, the associated micro-climate is particularly favourable for infection by fungi and bacteria.

Rhizoctonia solani is the most important fungal pathogen of Siratro and certainly limits use of this cultivar in high rainfall areas (Shaw and Whiteman, 1977). This fungus causes foliar blight and can lead to almost complete leaf death, as recorded in Australia by Hutton

(1962), in Florida by Sonada *et al* (1971) and Kretschmer (1972), in Thailand by Wickham *et al* (1977) and in Malaysia by Dunsmore and Ong (1969). Sonada *et al* (1971) suggested that resistant varieties will need to be developed. The production of such resistant varieties is one of the aims in the improvement of Siratro (Hutton and Beall, 1977).

Rust (*Uromyces appendiculatus*) is the other fungus disease which can cause a reduction of Siratro seed yield. Jones (1982) reported that in Australia, rust was first noted on Siratro in 1978. Sonada (1976) also reported the occurrence of rust on Siratro in Florida. The pathogen has also been found in Brazil, West Indies, Fiji and Colombia (Jones, 1982). Again, Jones (1982) noticed that disease attack was most severe in the cooler, drier months and lowest in the wetter summer months. He also recommended that the development of resistant lines of Siratro was the best way to combat this disease.

The only root disease reported on Siratro is violet root rot, caused by *Rhizoctonia crocorum*. However, Jones *et al* (1969) commented that, it is generally not an important problem in Siratro.

Bacteria can also attack the Siratro plant. Among these, halo blight disease caused by the bacteria *Pseudomonas phaseolicola* was recorded and claimed to be seed transmitted in Siratro by Moffett (1973). She explained that the extent and intensity of halo blight depends upon temperature and becomes less obvious over 27°C. MacSwan and Koepsell (1975) suggested that halo blight can be controlled by cultural practices such as crop rotation, avoidance of over-irrigation by sprinklers and using disease free seed.

A relatively common virus of legumes is 'little leaf'. However, Hutton and Grylis (1956) found that plants in the genera *Arachis*, *Centrosema*, *Dolichos*, *Glycine*, *Phaseolus* and *Vigna* show a relatively high degree of resistance to this virus. Hutton (1962) reported that Siratro is highly resistant to 'little leaf' virus.

Colbran (1964) found that Siratro was susceptible to attack by the root nematode *Helicotylenchus dihystrera* but was resistant to *Meloidogyne* spp. This resistance character of Siratro was also confirmed by Hutton and Beall (1977).

A.6.3 Harvesting

Humphreys (1979) mentioned that judging the correct harvesting time of many tropical pasture seed crops is often difficult since many species have an indeterminate plant growth habit and flower over a long period. This results in the production of inflorescences with seed which ripens unevenly and subsequent pod shattering with loss of ripe seed. As a result, hand harvesting is often considered to be the best method to get high seed yields of good quality seed because only mature pods are harvested. This method is particularly suitable for countries where labour is cheap. However, in many of the so-called developed countries, mechanical harvesting is generally adapted to the use of header harvesting machines. In some situations this may be followed by suction harvesting (Hopkinson and Loch, 1973; Humphreys, 1979) which can often provide an additional 200 - 300 kg of seed per hectare.

* * * * *

SECTION B : FIELD EXPERIMENT

B.1 THE EFFECT OF PLANT SPACING AND IRRIGATION ON SEED PRODUCTION OF SIRATRO (*Macroptilium atropurpureum*) IN DRY SEASON PLANTING

B.1.1 MATERIALS AND METHODS

B.1.1.1 Experimental site and land preparation

The field experiment was conducted during the dry season in 1979 - 1980 at 'The Dairy Farming Promotion Organisation of Thailand' Tambol Mittapab, Amphoe Muak Lek, Saraburi province, Thailand. This area has a latitude of 14°, a longitude of 101° and an elevation of 230 metres above sea level. The experiment covered 1.04 hectares of Wang Saphung soil series (silty clay loam) on a 2.5% slope. The Wang Saphung series are reddish-brown lateritic soils derived from sandy shale and phyllite and developed on dissected erosion surfaces. They are composed of moderately deep loams or clay loams and are moderately well to well drained, dark brown or very dark greyish brown in colour and very strong to medium acid soils (Appendix Table 1). The relief is gently undulating to rolling with slopes ranging from 0 - 16%, permeability is moderate and runoff is rapid (Land Development Report, 1979).

The trial site was ploughed and cultivated in August 1979, and divided into a series of plots which varied in size according to plant spacing (Figure B.1.1 and Plate B.1.1). An application of 500 kg per hectare of 17:17:17 fertiliser was broadcast before sowing.

B.1.1.2 Field procedures

Experimental design

The experiment utilised a split block design with three replications. Main plots were irrigated and non-irrigated with sub-plots of the following plant spacings:

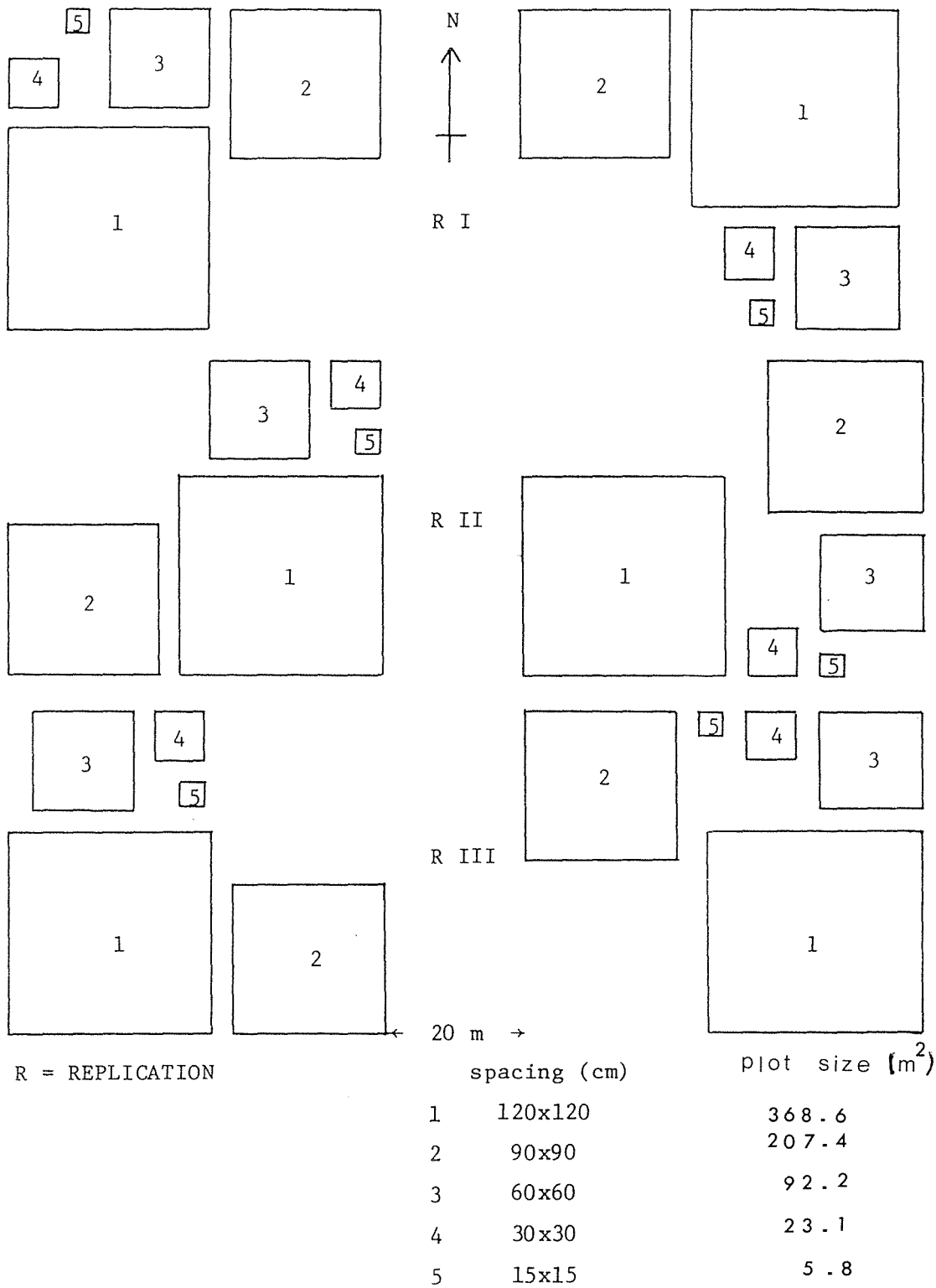


FIGURE B.1.1 FIELD LAYOUT (DRY SEASON PLANTING).



PLATE B.1.1 FIELD LAYOUT (DRY SEASON PLANTING).

120 x 120 cm spacing (6,944 plants per hectare)
90 x 90 cm spacing (12,345 plants per hectare)
60 x 60 cm spacing (27,777 plants per hectare)
30 x 30 cm spacing (111,111 plants per hectare)
15 x 15 cm spacing (444,444 plants per hectare)

Planting procedure

Strings marked at the required spacing were used to obtain the square planting employed in this experiment. Siratro (*Macroptilium atropurpureum*) seeds were scarified, using sandpaper to break hard seededness, and treated with rhizobial inoculum (Cowpea strain) to ensure satisfactory nodulation. Seeds were sown by hand at the required distances on October 6, 1979, with approximately five seeds per hole being sown at a depth of about 2 cm. Sowing was completed within one day. Thinning to one plant per hole was made seven days after emergence. In the case of missing plants, these were replaced by transplanting seedlings of the same age from a small seedling nursery area nearby. Plots were hand-weeded as required to control weed invasion and the area between plots rotary-hoed.

Plant protection

Before sowing, Aldicarb¹ was used as a basal insecticide treatment applied into the planting hole at the rate of 1 kg a.i. or 20 kg per hectare. During plant establishment a weekly spraying of Fenvalerate² was applied at the rate of 0.25 litres of product per hectare in 500 litres of water in order to control insects, particularly *Lampides boetricus* Linn., which causes severe damage to buds, flowers and pods.

¹ 2 - Methyl - 2 (methylthio) propionaldehyde o - (methylearbamoyl) oxime 5%.

² Cyano (S - phenoxyphenyl) methyl 4-chloro-alpha-(1 - methylethyl) benzeneacetate 20%.

Irrigation procedure

The appropriate time and amount of water applied to irrigated plots in the dry season experiment was calculated from evapotranspiration and soil moisture data obtained from the Soil Science Department at Khon Kaen University. Starting with a soil moisture content at field capacity in the 0 - 25 cm depth, (assumed to be the root zone of the plant) it was possible to calculate an acceptable level of soil moisture deficit which could be allowed to develop between irrigations but which would not be detrimental to plant growth. This was calculated to be an approximately 12 mm soil moisture deficit from an estimated total of 30 mm. This meant in practice, that irrigation was necessary every four to five days, sufficient water being applied to return soil moisture levels to field capacity. In order to simplify the procedure, the rim of marked tins (showing a 12 mm line) was buried to ground level and water level allowed to vary through evaporation and irrigation over a 0 to 12 mm deficit range. Irrigation was applied using an overhead sprinkler system (Plate B.1.2).

During the first three weeks after sowing water was applied to both irrigated and non-irrigated plots to ensure good plant establishment. Watering was then discontinued in the non-irrigated treatment. Water was applied to the irrigated treatment until peak flowering and then discontinued.

Harvesting

Six plants were harvested by hand from each plot at each of eight harvests. The eight harvests were:

- Harvest 1: 28 days after sowing
- Harvest 2: At floral initiation
- Harvest 3: At peak flowering
- Harvest 4: At 5 days after peak flowering
- Harvest 5: At 10 days after peak flowering
- Harvest 6: At 20 days after peak flowering



PLATE B.1.2

IRRIGATION SYSTEM USING OVERHEAD SPRINKLER
DURING DRY SEASON EXPERIMENT.

- Harvest 7: At 30 days after peak flowering
 Harvest 8: At 40 days after peak flowering

The samples taken at each of the eight harvests were used for the following measurements.

B.1.1.3 Plant measurements

At four selected harvests (1, 2, 3 and 8) measurements of total plant dry weight and leaf area were made using six plant samples. Each plant was separated into leaf and stem components and leaf area determined on an automatic leaf area meter (Hayashi Denko Model AAM-7). Both leaf and non-leaf components were then oven dried at 80°C to constant dry weight.

Plants harvested after peak flowering were measured as follows:

- | | | |
|-------------------------|---|------------------------------------|
| Seed yield per plant | - | total seed dry weight per plant |
| Seed yield components | - | number of inflorescences per plant |
| | - | number of pods per plant |
| | - | number of seeds per pod |
| | - | 100 seed dry weight |
| Seed quality components | - | seed moisture content |
| | - | germination percentage |
| | - | hard seed percentage |
| | - | abnormal seedling percentage |

Seed yield was determined from six plants in each treatment in the last five harvests after peak flowering (harvests 4, 5, 6, 7 and 8). Seed moisture was determined by using four lots of 100 seeds, dried at 103°C for 17 hours and weighed (ISTA Rules 1976). In order to determine the germination percentage, four lots of 50 seeds were placed on germination blotters immediately after each harvest and kept at 25°C constant for 10 days. Seedling counts were made at

four and 10 days according to the ISTA Rules (1976). Normal seedlings, abnormal seedlings, hard seeds, fresh ungerminated seeds and dead seeds were counted and germination percentage calculated.

Statistical analysis

Plot means of all traits were used for statistical analysis. Data collected from dry season planting were analysed according to the procedure of a split-plot design (Little and Hills, 1975). The analysis was done by Genstat program (Alvey *et al*, 1977).

B.1.1.4 Definitions

The following definitions have been adopted in this study:

- Inflorescence: A flowerhead with one or more open flower or seed pod containing seed (see Plate B.1.3).
- Flower: A single flower with the corolla exerted (see Plate B.1.4).
- Pod: Pods were divided into three categories, depending on size and colour viz: (see Plate B.1.5)
 - small green pods, less than 5 cm long
 - big green pods, more than 5 cm long
 - brown pods of variable length
 - shattered pods
- Floral initiation: When flower buds were first observed (see Plate B.1.6). . .
Flower emergence

- Peak flowering: When the number of newly fully opened flowers reached a maximum as determined by daily counting (see Plate B.1.7).



PLATE B.1.3 INFLORESCENCE.



PLATE B.1.4 SINGLE OPEN FLOWER.



PLATE B.1.5 CATEGORIES OF PODS.

SMALL GREEN
PODS

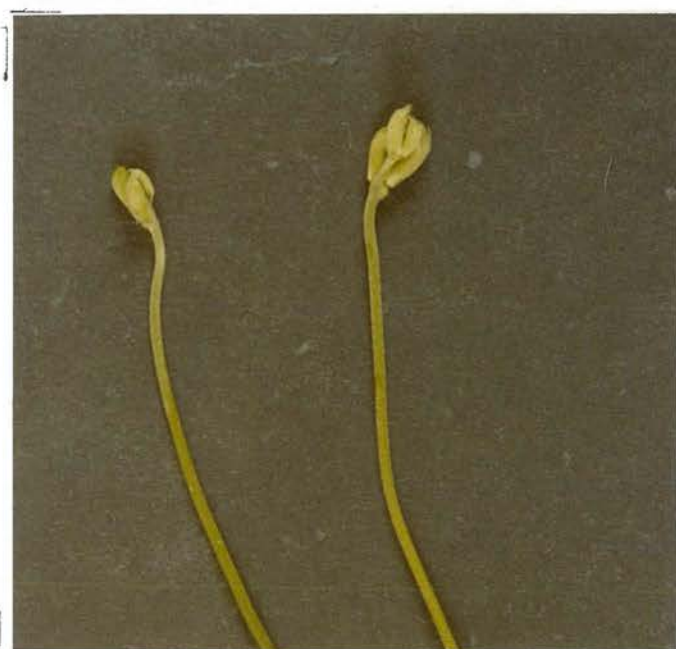
LARGE GREEN
PODS

BROWN
PODS

SHATTERED
PODS



(a) WHOLE PLANT



(b) FLORAL BUD
DETAIL

PLATE B.1.6 FLORAL INITIATION STAGE.



(a) WHOLE PLANT



(b) SINGLE FLOWER
DETAIL

PLATE B.1.7 PEAK FLOWERING STAGE.

B.1.2 RESULTS

B.1.2.1 Plant growth and development

The effect of irrigation and plant spacing treatments on total plant dry weight and leaf area development throughout the vegetative and reproductive stages of Siratro in the dry season experiment are presented in Tables B.1.1, B.1.2, B.1.3 and B.1.4 on both a per plant and per unit area basis.

Plant Dry Weight

Plant growth throughout the dry season, even with irrigation, was extremely poor compared with the wet season experiment reported in the next section. It was also rather surprising to see (Table B.1.1) that the beneficial effect of irrigation on plant dry weight was only apparent at the harvest 40 days after peak flowering, i.e. 40 days after irrigation ceased. Apparently during the early and mid stages of the experiment, the non-irrigated plants (which received water during the first 30 days after sowing to ensure establishment) were able to draw sufficient water for growth from the relatively 'heavy soil' and did not suffer significant moisture stress until the post peak flowering stage. Certainly plant size was small and presumably water demand relatively low up to peak flowering. Another possibility is that the basis of irrigation determined from the limited climatic and soil water data available may have been inappropriate in terms of frequency or intensity (or both) for this particular soil type.

Total dry weight per plant was, however, significantly affected by plant spacing at most harvests, reflecting the amount of space available per plant, i.e. the closer the plant spacing the lower the plant weight. This effect was noticeable between extreme spacing treatments even at the first harvest, 40 days after planting, and was most striking at the final harvest, 40 days after peak flowering. By this stage the different levels of competition between plants had produced a ten-fold difference in plant weight.

There was also a significant interaction between irrigation and plant

TABLE B.1.1 EFFECT OF IRRIGATION AND PLANT SPACING ON TOTAL PLANT DRY WEIGHT (GM/PLANT) AT EACH HARVEST.

<u>Water Treatment</u>	<u>HARVESTING</u>					
	<u>40 days after planting</u>	<u>Floral initiation</u>	<u>Peak flowering</u>	<u>40 days after peak flowering</u>		
Irrigated	0.78	1.74	5.15	37.30		
Non-irrigated	1.00	2.70	4.57	19.10		
Significance	N.S.	*	N.S.	*		
				(at 10% level)		
L.S.D.	.10			17.23		
	.05	0.80		-		
	.01	-		-		
<u>Plant spacing</u>						
120 x 120 cm	1.15	3.08	6.24	62.70		
90 x 90 cm	0.84	2.11	6.41	34.40		
60 x 60 cm	0.90	2.01	4.65	24.50		
30 x 30 cm	0.97	2.33	3.99	12.80		
15 x 15 cm	0.60	1.58	3.00	6.50		
Significance	*	**	N.S.	**		
L.S.D.	.05	0.33	0.71	8.20		
	.01	-	0.97	11.30		
<u>Significant Interactions</u>						
<u>Irrigation x spacing</u>	<u>40 days after planting</u>		<u>Floral initiation</u>		<u>40 days after peak flowering</u>	
	I	NI	I	NI	I	NI
120 x 120 cm	0.96	1.34	2.50	3.65	87.70	37.70
90 x 90 cm	0.51	1.16	1.34	2.88	38.30	30.60
60 x 60 cm	0.79	1.00	1.17	2.86	35.30	13.80
30 x 30 cm	0.59	1.35	1.61	3.05	15.80	9.90
15 x 15 cm	1.05	0.15	2.09	1.08	9.30	3.60
Significance	**		**		**	
L.S.D.	.05	.01	.05	.01	.05	.01
(1)	0.57	0.98	1.14	1.86	26.13	54.13
(2)	0.46	0.64	1.00	1.38	11.60	15.98

(1) When comparing means with the different levels of mainplot.

(2) When comparing means with the same levels of mainplot.

TABLE B.1.2 EFFECT OF IRRIGATION AND PLANT SPACING ON TOTAL PLANT DRY WEIGHT PER UNIT AREA (KG/HA).

<u>Water treatment</u>	<u>HARVESTING</u>					
	<u>40 days after planting</u>	<u>Floral initiation</u>	<u>Peak flowering</u>	<u>40 days after peak flowering</u>		
Irrigated	114	235	389	1592		
Non-irrigated	53	192	388	743		
Significance	*	**	N.S.	N.S.		
L.S.D. .05	37	11				
.01	-	26				
 <u>Plant spacing</u>						
120 x 120 cm	8	21	43	436		
90 x 90 cm	10	26	79	425		
60 x 60 cm	25	56	129	681		
30 x 30 cm	108	259	444	1428		
15 x 15 cm	266	704	1248	2867		
Significance	**	**	**	**		
L.S.D. .05	44	101	180	822		
.01	61	139	248	1133		
 <u>Significant Interactions</u>						
<u>Irrigation x spacing</u>	<u>40 days after planting</u>		<u>Floral initiation</u>		<u>40 days after peak flowering</u>	
	I	NI	I	NI	I	NI
120 x 120 cm	6.7	9.3	17.0	25.0	609.0	262.0
90 x 90 cm	6.3	14.3	16.0	36.0	473.0	377.0
60 x 60 cm	22.0	27.9	32.0	79.0	981.0	382.0
30 x 30 cm	65.9	149.6	179.0	339.0	1760.0	1095.0
15 x 15 cm	466.7	64.8	929.0	478.0	4136.0	1599.0
Significance	**		**		*	
L.S.D.	.05	.01	.05	.01	.05	.01
(1)	64.6	99.5	127.7	176.3	1637.8	-
(2)	62.2	85.7	142.3	196.0	1163.0	-

- (1) *When comparing means with the different levels of mainplot.*
 (2) *When comparing means with the same levels of mainplot.*

spacing due to the greater depressive effect of close spacing on plant weight in the non-irrigated treatment compared with that in the irrigated plots.

In terms of total dry weight on a per unit area basis, irrigation (Table B.1.2) only had a significant effect on plant growth during the early part of the experimental period. However it was responsible for producing a substantially bigger plant than in the non-irrigated treatment at the final harvest, although just failing to reach statistical significance. Plant spacing also had a significant effect on plant weight per unit area with total plant dry weight reaching a maximum at the closest spacing. The greater increase in plant weight per unit area with closer spacing plus irrigation, compared with closer spacing minus irrigation caused a significant interaction between irrigation and plant spacing at most harvests.

Leaf Area

The beneficial effect of irrigation on leaf area per plant was, again, only evident after peak flowering and reached a highly significant advantage at the final harvest, 40 days after peak flowering (Table B.1.3). The effect of plant spacing on leaf area was first evident at floral initiation and continued to be expressed through to the final harvest, i.e. plants at wide spacings had a larger leaf area than plants at narrow spacings. The significant interactions recorded between irrigation and plant spacing are difficult to explain in the earlier harvests but by the final harvest the advantage of wider spacing between plants in allowing irrigated plants to develop larger leaf area compared with non-irrigated plants was clearly apparent.

In terms of leaf area index (Table B.1.4) irrigation appeared to have only a small but positive effect throughout much of the experiment. Close plant spacing showed a highly significant increase in LAI compared with wide plant spacing at all harvests. Obviously the increase in plant numbers more than compensated for the smaller leaf area per plant and resulted in the highest leaf area index being

TABLE B.1.3 EFFECT OF IRRIGATION AND PLANT SPACING ON LEAF AREA
(CM²) PER PLANT AT EACH HARVEST TIME.

<u>Water treatment</u>	<u>HARVESTING</u>					
	<u>40 days after planting</u>	<u>Floral initiation</u>	<u>Peak flowering</u>	<u>40 days after peak flowering</u>		
Irrigated	97	238	592	1852		
Non-irrigated	142	324	489	835		
Significance	N.S.	N.S.	N.S.	**		
L.S.D. .05				394		
.01				908		
 <u>Plant spacing</u>						
120 x 120 cm	156	361	743	3067		
90 x 90 cm	108	289	658	1604		
60 x 60 cm	98	258	486	977		
30 x 30 cm	132	283	472	726		
15 x 15 cm	105	213	344	343		
Significance	N.S.	**	N.S.	**		
L.S.D. .05		74		509		
.01		102		701		
 <u>Significant Interactions</u>						
<u>Irrigation x spacing</u>	<u>40 days after planting</u>		<u>Floral initiation</u>		<u>40 days after peak flowering</u>	
	I	NI	I	NI	I	NI
120 x 120 cm	138.0	174.7	318.0	404.0	4628.0	1506.0
90 x 90 cm	60.3	156.0	226.0	352.0	1819.0	1388.0
60 x 60 cm	74.3	121.0	178.0	339.0	1413.0	541.0
30 x 30 cm	58.3	204.7	209.0	357.0	938.0	514.0
15 x 15 cm	156.0	53.0	257.0	169.0	460.0	226.0
Significance	**		*		**	
L.S.D.	.05	.01	.05	.01	.05	.01
(1)	116.2	210.4	180.9	-	729.5	1110.7
(2)	83.0	114.3	104.5	-	719.0	990.8

- (1) When comparing means with the different levels of mainplot.
 (2) When comparing means with the same levels of mainplot.

TABLE B.1.4 EFFECT OF IRRIGATION AND PLANT SPACING ON LEAF AREA INDEX (LAI) AT EACH HARVEST.

<u>Water Treatment</u>	<u>HARVESTING</u>			
	<u>40 days after planting</u>	<u>Floral initiation</u>	<u>Peak flowering</u>	<u>40 days after peak flowering</u>
Irrigated	0.16	0.29	0.45	0.81
Non-irrigated	0.11	0.26	0.48	0.40
Significance	N.S.	*	N.S.	N.S.
L.S.D.	.05	.031		
	.01	-		
 <u>Plant spacing</u>				
120 x 120 cm	0.011	0.025	0.052	0.213
90 x 90 cm	0.013	0.036	0.081	0.198
60 x 60 cm	0.027	0.072	0.135	0.271
30 x 30 cm	0.146	0.315	0.524	0.807
15 x 15 cm	0.465	0.948	1.531	1.525
Significance	**	**	**	**
L.S.D.	.05	0.076	0.111	0.293
	.01	0.105	0.153	0.404
 <u>Significant Interactions</u>				
<u>Irrigation x spacing</u>	<u>40 days after planting</u>		<u>Floral initiation</u>	
	I	NI	I	NI
120 x 120 cm	0.010	0.012	0.022	0.028
90 x 90 cm	0.007	0.019	0.028	0.044
60 x 60 cm	0.020	0.034	0.049	0.094
30 x 30 cm	0.065	0.227	0.233	0.396
15 x 15 cm	0.694	0.236	1.145	0.750
Significance	**		**	
L.S.D.	.05	.01	.05	.01
(1)	0.114	0.179	0.143	0.200
(2)	0.108	0.148	0.157	0.216

(1) When comparing means with the different levels of mainplot.

(2) When comparing means with the same levels of mainplot.

recorded at the closest spacing. Highly significant interactions between irrigation and plant spacing were due to the greater leaf area index at close spacing with water than without water. This effect however was only apparent during the first two harvests and had disappeared by the time plants had reached peak flowering.

B.1.2.2 Seed yield and yield components

Seed Yield

The effects of irrigation and plant spacing on seed yield are presented in Tables B.1.5 and B.1.6 on a per plant and per unit area basis respectively. As shown in Table B.1.5, irrigation had no significant beneficial effect on seed yield per plant until the final harvest 40 days after peak flowering, that is 40 days after irrigation was discontinued. However in terms of seed yield per hectare the benefit from irrigation was recorded 30 days after peak flowering, with the advantage increasing substantially by the final harvest (Table B.1.6) due to a doubling in seed yield per hectare from irrigation in these 10 days, and a halving in seed yield over the same period in the non-irrigated treatment.

Plant spacing was also shown to have no significant effect on seed yield per plant in the first three harvests followed by a significant depression per plant due to closer spacing in the last two harvests, 30 and 40 days after peak flowering. This effect was more apparent with increasing size of plant (Table B.1.1) with the bigger plants at wide spacings producing higher seed yields than the smaller plants at close spacings. However, low seed yield per plant was more than compensated for by increasing numbers of plants per unit area. For example as shown in Table B.1.6 seed yield per hectare actually increased as plant spacing decreased with maximum yields at each harvest being obtained from the closest spacing (15 x 15 cm). It appears that plants in the irrigated treatments were still benefiting from the 'stored' soil moisture available throughout the harvesting period to 40 days after peak flowering. Even though irrigation ceased at peak flowering those plants produced significantly higher

TABLE B.1.5 EFFECT OF IRRIGATION AND PLANT SPACING ON SEED YIELD
(GM/PLANT) AT EACH HARVEST.

		<u>HARVESTING</u>				
		<u>Days after peak flowering</u>				
<u>Water treatment</u>		<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
Irrigated		0.023	0.164	1.112	2.898	5.265
Non-irrigated		0.028	0.189	0.972	1.640	2.457
Significance		N.S.	N.S.	N.S.	N.S.	* (at 10% level)
L.S.D.	.10					2.669
	.05					-
	.01					-
		<u>Plant spacing</u>				
120 x 120 cm		0.020	0.172	0.968	3.770	6.280
90 x 90 cm		0.017	0.175	0.938	3.350	5.240
60 x 60 cm		0.028	0.133	1.080	1.980	4.850
30 x 30 cm		0.023	0.145	1.243	1.400	2.020
15 x 15 cm		0.040	0.258	0.980	0.850	0.920
Significance		N.S.	N.S.	N.S.	**	**
L.S.D.	.05				1.075	1.427
	.01				1.481	1.966

TABLE B.1.6 EFFECT OF IRRIGATION AND PLANT SPACING ON SEED YIELD PER UNIT AREA (KG/HA) AT EACH HARVEST.

<u>HARVESTING</u>					
<u>Days after peak flowering</u>					
<u>Water treatment</u>	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
Irrigated	3.6	32.2	130.8	156.8	298.4
Non-irrigated	4.7	22.6	117.9	105.7	52.3
Significance	N.S.	N.S.	N.S.	**	**
L.S.D. .05				20.7	110.0
.01				47.6	256.1
 <u>Plant spacing</u>					
120 x 120 cm	0.2	1.2	6.7	26.2	44.0
90 x 90 cm	0.2	2.1	11.6	41.3	65.0
60 x 60 cm	0.8	3.7	30.0	54.9	135.0
30 x 30 cm	2.3	16.2	138.1	155.1	224.0
15 x 15 cm	17.3	113.8	435.2	378.5	410.0
Significance	**	**	**	**	**
L.S.D. .05	6.4	38.4	28.0	66.5	87.1
.01	8.8	53.0	38.6	91.6	120.0
 <u>Significant Interactions</u>					
<u>40 days after peak flowering</u>					
<u>Irrigation x spacing</u>	<u>I</u>		<u>NI</u>		
120 x 120 cm	53.0		34.0		
90 x 90 cm	73.0		56.0		
60 x 60 cm	209.0		60.0		
30 x 30 cm	392.0		56.0		
15 x 15 cm	764.0		55.0		
Significance			**		
L.S.D.	.05		.01		
(1)	148.2		249.9		
(2)	123.4		170.0		

(1) When comparing means with the different levels of mainplot.

(2) When comparing means with the same levels of mainplot.

seed yield than their non-irrigated counterparts. It is also possible that the water stress imposed by stopping irrigation allowed the larger plants to be stressed and 'thrown' into more intense reproductive development than smaller non-irrigated plants. On the other hand, seed yields in non-irrigated plots declined noticeably by 30 days after peak flowering compared with 20 days after peak flowering. This effect was presumably due to water stress which also influenced seed shattering. A significant interaction between irrigation and plant spacing appeared in the final harvest due to the continuing 'seed' response to close spacing in the presence of added water but not in the absence of irrigation.

Yield components

Since differences in seed yield were detected as a result of both irrigation and spacing treatments, further investigations were carried out to determine the effect of these treatments on those components which influenced seed yield. Four yield components, inflorescence numbers, pod numbers, number of seeds per pod and seed weight were given attention.

Inflorescence number

As shown in Table B.1.7, irrigation had no significant effect on inflorescence number although the trend towards an irrigation response at later harvests was again apparent.

In terms of plant spacing, the beneficial effect of wide spacing on inflorescence number per plant was strikingly evident and decreased to a minimum number at the narrowest spacing, presumably due to plant competition. The interaction between irrigation and plant spacing appeared only at 20 days after peak flowering due to the greater competitive effects of close spacing in the presence of irrigation than in the absence of irrigation.

TABLE B.1.7 EFFECT OF IRRIGATION AND PLANT SPACING ON INFLORESCENCE NUMBER PER PLANT AT EACH HARVEST TIME.

<u>Water treatment</u>	<u>HARVESTING</u>				
	<u>Days after peak flowering</u>				
	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
Irrigated	5.9	12.1	22.6	25.1	31.3
Non-irrigated	6.8	11.8	16.9	20.3	19.7
Significance	N.S.	N.S.	N.S.	N.S.	N.S.
 <u>Plant spacing</u>					
120 x 120 cm	6.5	15.5	28.7	37.5	47.8
90 x 90 cm	7.3	14.8	19.7	33.2	35.5
60 x 60 cm	7.3	12.2	23.0	24.0	25.2
30 x 30 cm	5.5	10.0	18.2	13.0	12.5
15 x 15 cm	5.0	7.3	9.2	5.7	6.3
Significance	N.S.	*	**	**	**
L.S.D. .05		5.6	7.0	10.0	10.2
.01		-	9.6	13.7	14.0

Significant Interactions

<u>Irrigation x spacing</u>	<u>20 days after peak flowering</u>	
	<u>I</u>	<u>NI</u>
120 x 120 cm	38.3	19.0
90 x 90 cm	15.7	23.7
60 x 60 cm	27.0	19.0
30 x 30 cm	22.3	14.0
15 x 15 cm	9.7	8.7
Significance		*
L.S.D.	.05	.01
(1)	11.7	-
(2)	9.9	-

(1) When comparing means with the different levels of mainplot.

(2) When comparing means with the same levels of mainplot.

Pod number

Although not statistically significant, irrigation seemed to stimulate pod numbers per plant with the effect becoming most pronounced at the last harvest (Table B.1.8). However, plant spacing, while it had no effect on the number of pods in the first 10 days after peak flowering, reached a highly significant effect on this yield component in subsequent harvests. Again, it was found that pod numbers per plant increased as plant spacing increased, the maximum being recorded from the widest spacing. A significant interaction was recorded at 20 days after peak flowering, again due to the greater depression of close plant spacing on pod number in the irrigated treatment than in the non-irrigated treatment.

Seed per pod

Seed numbers per pod were generally unresponsive to both water treatment and plant spacing (see Table B.1.9), with the average number of seeds per pod ranging from 10 - 12.

Seed weight

No significant effect from either irrigation or plant spacing occurred until the final harvest when a small but significant reduction in seed weight was recorded at the narrowest spacing and in the non-irrigated treatment (Table B.1.10). Possibly this effect was due to loss of more mature and therefore heavier seeds through seed shattering during the ripening stage, 40 days after peak flowering. The only significant interaction was also recorded 40 days after peak flowering and was due to a noticeable decrease in seed weight in the non-irrigated plots which was not noticeable in the irrigated plots.

B.1.2.3 Seed quality

Apart from yield and yield component effects, the influence of water and plant spacing was also investigated in terms of seed quality attributes, i.e. seed moisture content, the percentage of normal germination, abnormal seedlings and hard seed.

TABLE B.1.8 EFFECT OF IRRIGATION AND PLANT SPACING ON POD NUMBERS PER PLANT AT EACH HARVEST TIME.

<u>Water treatment</u>	<u>HARVESTING</u>				
	<u>Days after peak flowering</u>				
	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
Irrigated	3.9	9.0	34.2	51.7	63.7
Non-irrigated	5.9	9.9	24.1	39.8	33.5
Significance	N.S.	N.S.	N.S.	N.S.	N.S.

Plant spacing

120 x 120 cm	3.5	6.7	41.3	80.3	90.5
90 x 90 cm	5.0	9.8	28.3	66.0	66.7
60 x 60 cm	5.8	9.7	32.7	45.0	56.0
30 x 30 cm	4.7	10.3	28.7	27.0	17.3
15 x 15 cm	5.5	10.8	14.8	10.5	12.3
Significance	N.S.	N.S.	**	**	**
L.S.D. .05			11.9	25.2	28.9
.01			16.4	34.7	39.9

Significant Interactions

20 days after peak flowering

<u>Irrigation</u> <u>x spacing</u>	<u>I</u>	<u>NI</u>
120 x 120 cm	56.7	26.0
90 x 90 cm	23.7	33.0
60 x 60 cm	39.7	25.7
30 x 30 cm	31.3	26.0
15 x 15 cm	19.7	10.0
Significance		*
L.S.D.	.05	.01
(1)	18.1	-
(2)	16.9	-

- (1) When comparing means with the different levels of mainplot.
 (2) When comparing means with the same levels of mainplot.

TABLE B.1.9 EFFECT OF IRRIGATION AND PLANT SPACING ON NUMBER OF SEEDS PER POD AT EACH HARVEST.

<u>HARVESTING</u>				
<u>Days after peak flowering</u>				
<u>Water treatment</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
Irrigated	11.2	11.3	11.5	11.2
Non-irrigated	11.9	11.5	11.8	11.3
Significance	*	N.S.	N.S.	N.S.
L.S.D. .05	0.6			
.01	-			
 <u>Plant spacing</u>				
120 x 120 cm	12.2	10.7	11.7	10.7
90 x 90 cm	11.3	11.5	11.8	11.7
60 x 60 cm	11.3	11.7	11.3	11.5
30 x 30 cm	11.0	11.8	11.0	11.3
15 x 15 cm	12.0	11.2	12.5	11.2
Significance	N.S.	N.S.	N.S.	N.S.

TABLE B.1.10 EFFECT OF IRRIGATION AND PLANT SPACING ON SEED WEIGHT
(GM/100 SEEDS) AT EACH HARVEST TIME.

<u>Water treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
Irrigated	0.374	0.876	1.059	1.112
Non-irrigated	0.381	0.983	0.941	0.963
Significance	N.S.	N.S.	N.S.	**
L.S.D. .05				0.061
.01				0.140

<u>Plant spacing</u>				
120 x 120 cm	0.362	0.998	1.022	1.080
90 x 90 cm	0.400	0.818	0.968	1.017
60 x 60 cm	0.372	0.927	1.128	1.097
30 x 30 cm	0.323	0.967	1.012	1.015
15 x 15 cm	0.430	0.937	0.868	0.978
Significance	N.S.	N.S.	N.S.	**
L.S.D. .05				0.070
.01				0.097

Significant Interactions

<u>Irrigation</u> <u>x spacing</u>	<u>40 days after peak flowering</u>	
	<u>I</u>	<u>NI</u>
120 x 120 cm	1.133	1.027
90 x 90 cm	1.053	0.980
60 x 60 cm	1.127	1.067
30 x 30 cm	1.077	0.953
15 x 15 cm	1.170	0.787
Significance		**
L.S.D.	.05	.01
(1)	0.108	0.165
(2)	0.100	0.137

- (1) When comparing means with the different levels of mainplot.
(2) When comparing means with the same levels of mainplot.

Seed moisture content

The effect of irrigation and plant spacing on seed moisture content was only significant at the final harvest (Table B.1.11). Seed moisture content was initially high (76 - 81%) in the early harvest and gradually declined as seed increased in maturity to approximately 45 - 53% at the final harvest 40 days after peak flowering. The higher moisture content in seed from non-irrigated plots, particularly those from closer spacings, was due to the higher proportion of young green pods than older brown pods which lead to a significant interaction at this harvest.

Germination percentage

Neither irrigation nor plant spacing affected the germination capacity of seed (Table B.1.12). The percentage of normal seedlings increased with increasing seed maturity and reached a maximum (95%) approximately 30 days after peak flowering and then decreased slightly. This latter effect probably occurred as a result of the increasing hard seed content, as shown in Table B.1.14.

As can be seen from Table B.1.13, the percentage of abnormal seedlings was not significantly affected by the application of irrigation or by changes in plant spacing. The main types of abnormalities were seedlings in which the primary root was short and stunted, or short and weak or where the primary root had no root hairs. These abnormalities however were generally few in number with a maximum of less than 5%.

Although not statistically significant, the figures on hard seededness (Table B.1.14) suggest a tendency towards increased hard seed development occurring under irrigation and at close plant spacings.

TABLE B.1.11 EFFECT OF IRRIGATION AND PLANT SPACING ON PERCENTAGE OF SEED MOISTURE CONTENT AT EACH HARVEST TIME.

<u>Water treatment</u>	<u>HARVESTING</u>				
	<u>Days after peak flowering</u>				
	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
Irrigated	80.8	71.7	55.4	51.6	45.0
Non-irrigated	76.4	61.5	56.3	55.4	53.4
Significance	N.S.	N.S.	N.S.	N.S.	*
L.S.D. .05					6.2
.01					-

Plant spacing

120 x 120 cm	80.3	64.4	56.5	54.0	53.2
90 x 90 cm	80.1	65.7	59.5	56.4	53.4
60 x 60 cm	78.7	72.4	57.5	52.7	47.8
30 x 30 cm	79.4	70.1	52.2	50.3	45.7
15 x 15 cm	74.8	60.5	53.5	54.2	45.9
Significance	N.S.	N.S.	N.S.	N.S.	**
L.S.D. .05					4.1
.01					5.7

Significant Interactions

<u>Irrigation</u> <u>x spacing</u>	<u>40 days after peak flowering</u>	
	<u>I</u>	<u>NI</u>
120 x 120 cm	52.1	54.2
90 x 90 cm	54.9	51.9
60 x 60 cm	46.5	49.1
30 x 30 cm	39.9	51.4
15 x 15 cm	31.4	60.5
Significance		**
L.S.D.	.05	.01
(1)	7.6	13.4
(2)	5.8	8.0

(1) *When comparing means with the different levels of mainplot.*

(2) *When comparing means with the same levels of mainplot.*

TABLE B.1.12 EFFECT OF IRRIGATION AND PLANT SPACING ON THE GERMINATION PERCENTAGE OF SEED (NORMAL SEEDLINGS) AT EACH HARVEST TIME.

<u>Water treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
Irrigated	27.0	60.4	87.7	75.4
Non-irrigated	18.1	64.7	82.8	73.0
Significance	N.S.	N.S.	N.S.	N.S.
<u>Plant spacing</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
120 x 120 cm	22.8	63.5	76.5	75.6
90 x 90 cm	28.4	54.1	80.0	78.1
60 x 60 cm	16.5	60.7	83.8	76.8
30 x 30 cm	19.1	70.6	94.7	67.9
15 x 15 cm	26.1	63.8	91.1	72.7
Significance	N.S.	N.S.	N.S.	N.S.

TABLE B.1.13 EFFECT OF IRRIGATION AND PLANT SPACING ON THE ABNORMAL SEEDLING PERCENTAGE AT EACH HARVEST TIME.

<u>HARVESTING</u>				
<u>Days after peak flowering</u>				
<u>Water treatment</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
Irrigated	2.3	2.1	0.4	3.6
Non-irrigated	1.6	2.1	2.8	1.8
Significance	N.S.	N.S.	*	N.S.
L.S.D. .05			2.17	
.01			-	
<u>Plant spacing</u>				
120 x 120 cm	3.2	1.3	2.5	4.6
90 x 90 cm	1.9	2.5	2.3	2.1
60 x 60 cm	1.4	2.9	1.3	2.3
30 x 30 cm	1.1	1.7	0.5	3.2
15 x 15 cm	2.1	2.0	1.3	1.2
Significance	N.S.	N.S.	N.S.	N.S.

TABLE B.1.14 EFFECT OF IRRIGATION AND PLANT SPACING ON THE HARD SEED PERCENTAGE AT EACH HARVEST TIME.

<u>HARVESTING</u>			
<u>Days after peak flowering</u>			
<u>Water treatment</u>	<u>20</u>	<u>30</u>	<u>40</u>
Irrigated	0.7	3.4	10.4
Non-irrigated	0.1	0.1	5.7
Significance	N.S.	N.S.	N.S.
<u>Plant spacing</u>			
120 x 120 cm	0.2	1.3	5.2
90 x 90 cm	0.5	3.7	3.5
60 x 60 cm	0.5	1.7	8.2
30 x 30 cm	0.4	0.4	12.6
15 x 15 cm	0.4	1.4	10.6
Significance	N.S.	N.S.	N.S.

B.1.3 DISCUSSION

The most striking feature in this dry season experiment was the extremely poor growth response recorded with irrigation. As mentioned earlier this may have been due to inappropriate watering and even over-watering, as the advantage from watering was only evident after irrigation ceased at peak flowering. A further factor limiting plant response was no doubt the relatively short vegetative period of Siratro (a short-day plant) growing under the slightly shorter days of October and November compared with the long vegetative period recorded in earlier and slightly longer days of the wet season experiment (Appendix Figure 1). Nevertheless 'irrigation' did finally produce a plant almost twice the size and leaf area of non-irrigated plants. This subsequently led to a doubling of the seed yield per plant and a six-fold increase per hectare when calculated across the different plant populations.

Although the data fails to show statistically significant responses, it is nevertheless considered that the major contributors to this response to irrigation were inflorescence numbers and especially pod numbers. Numbers of seeds per pod, 100 seed weight and the various seed quality characteristics were all generally unresponsive to the presence or absence of irrigation.

Increasing plant density clearly decreased dry weight and leaf area per plant, reflecting the level of plant competition occurring, particularly at the final harvest. Nevertheless when expressed on a per unit area basis the increase in plant population more than compensated for the declining plant size as also reported by Kowithayakorn (1978), although such differences due to population were less obvious by the final harvest. It was also apparent that at very high plant densities, irrigation was of particular importance in aiding the early growth and development of the plant, as indicated by the significant spacing x irrigation interactions.

In terms of seed production, increasing plant density depressed yield per plant as reported by Salter and Williams (1967), but significantly

increased yield per hectare at all harvest times, although the differences due to plant spacing became progressively less at each successive harvest. This was due to the earlier competitive stress occurring at the highest plant density causing a "levelling off" in seed yield per plant following the harvest 20 days after peak flowering. By comparison seed yield per plant and also per hectare continued to increase at all other plant densities, particularly at the widest spacing, right through to the final harvest.

In terms of plant spacing effects, inflorescence number and pod number were clearly (in this case) the major contributors to the differences recorded, as also reported by Shelton and Humphreys (1971) and Ishag (1973a, b). However the number of seeds per pod, seed weight and seed quality components were little affected even by such large differences in plant density. However, it is of interest to note that seed moisture content did differ quite markedly between treatments at the final harvest. It appears that plant population stress lowered seed moisture content appreciably, particularly in previously irrigated plants, due to an increased proportion of brown to green pods remaining on the plant.

Hard seed formation has been shown to be a function of progressive dehydration in hardseeded legumes (Hyde, 1954). It is therefore likely that the generally higher hard seed content in irrigated plants 40 days after peak flowering reflected the more rapid loss of water from seed during the latter stages of seed ripening. Certainly such a suggestion also supports the observation that non-irrigated plants had more shattered pods than those in irrigated plots, since losses only occur after seed has become dry.

B.2 THE EFFECT OF PLANT SPACING ON SIRATRO SEED PRODUCTION DURING THE WET SEASON

B.2.1 MATERIALS AND METHODS

The wet season experiment was conducted at the same site as the dry season experiment. Land was cultivated and levelled in March 1980. Before planting, 'paraquat'¹ was applied to control weeds, at the rate of 1.5 litres of herbicide in 350 litres of water/hectare.

The wet season experiment utilised a randomised complete block design with three replications. Plant spacings compared were the same as in the previous experiment, plus the addition of a closer spacing treatment, 10 x 10 cm (Figure B.2.1 and Plate B.2.1). Being sown in the wet season no irrigation treatment was imposed. Seeds were scarified and treated with rhizobial inoculum (Cowpea strain) before planting. Seeds were sown on 30 April 1980 and plants thinned to a single plant seven days after plant emergence (approximately 12 days after sowing).

Crop husbandry was as previously described in the dry season experiment, except for the further application of Mancozeb 80%² at the rate of 1 kg product per hectare in 500 litres of water at fortnightly intervals to protect plants from fungal diseases.

In the wet season experiment, because of the larger plant size and the increased twining habit, single plant harvests were impossible. Instead, quadrats of varying sizes to cover four plants/plot were used for sampling the crop at each harvest. Harvesting times and plant measurements were the same as in the dry season experiment.

Data collected from wet season planting were analysed according to the common procedure of a randomized complete block design (Little and Hills, 1975). Again, the analysis was done by Genstat program (Alvey *et al*, 1977).

¹ 1,1 - dimethyl - 4,4' bipyridilium.

² A co-ordination product of zinc ion and manganese ethylene bisdithiocarbamate 80%.

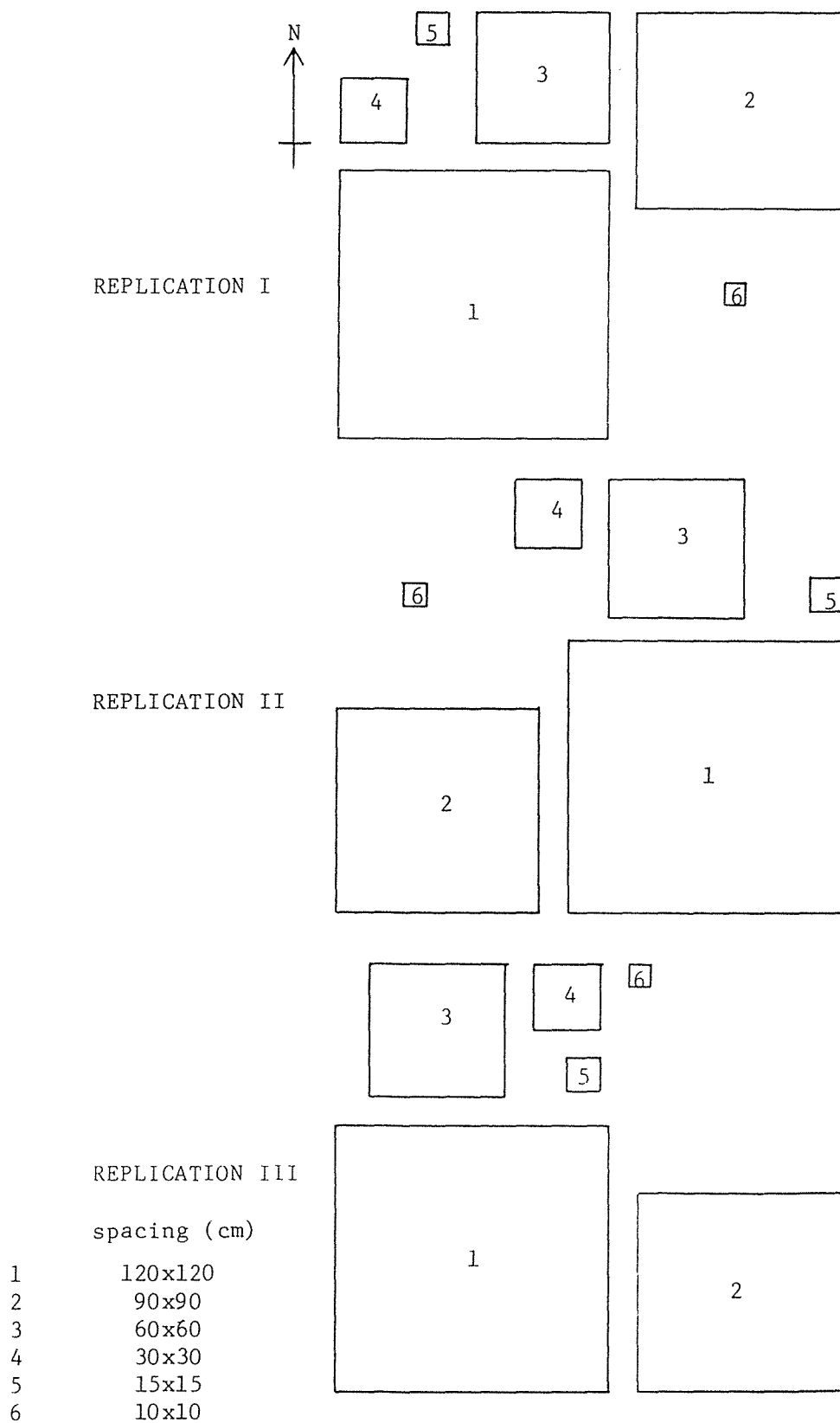


FIGURE B.2.1 FIELD LAYOUT (WET SEASON PLANTING).



PLATE B.2.1 FIELD TRIAL LAYOUT (WET SEASON PLANTING).

B.2.2 RESULTS

B.2.2.1 Plant growth and development

Results showing the effects of plant spacing on plant dry weight and leaf area throughout the vegetative and reproductive stages of growth of Siratro in a wet season planting are presented in Tables B.2.1 - B.2.4. Results are presented on both a per plant and a per unit area basis.

Plant Dry Weight

As shown in Table B.2.1, plant dry weight generally reached a maximum at floral initiation and then declined due to plant senescence. In the case of the widest spacing however, maximum plant dry weight was delayed until peak flowering.

Plant spacing had a highly significant effect on total dry weight per plant, i.e. by increasing the space between plants during this rainy season there was a marked expansion in plant size which began as early as 40 days from sowing.

TABLE B.2.1 EFFECT OF PLANT SPACING ON TOTAL PLANT DRY WEIGHT (GM/PLANT) AT EACH HARVEST.

<u>Plant spacing</u>	<u>HARVESTING</u>				
	<u>40 days after planting</u>	<u>60 days after planting</u>	<u>Floral initiation</u>	<u>Peak flowering</u>	<u>40 days after peak flowering</u>
120 x 120 cm	14.3	109.2	657.1	797.8	627.8
90 x 90 cm	6.5	84.6	480.9	414.4	368.4
60 x 60 cm	4.8	49.8	195.9	171.9	175.7
30 x 30 cm	6.0	22.7	53.9	48.2	37.4
15 x 15 cm	4.6	8.6	15.4	11.3	14.3
10 x 10 cm	2.9	6.8	9.2	5.2	5.9
Mean	6.5	47.0	235.4	241.5	204.9
Significance	N.S.	**	**	**	**
L.S.D.	.05 .01	20.70 29.02	91.95 128.92	91.52 128.31	66.66 93.45

TABLE B.2.2 EFFECT OF PLANT SPACING ON TOTAL PLANT DRY WEIGHT
(KG/HA) AT EACH HARVEST.

<u>Plant spacing</u>	<u>HARVESTING</u>				
	<u>40 days after planting</u>	<u>60 days after planting</u>	<u>Floral initiation</u>	<u>Peak flowering</u>	<u>40 days after peak flowering</u>
120 x 120 cm	99	758	4563	5540	4463
90 x 90 cm	80	1045	5937	5116	4548
60 x 60 cm	134	1384	5441	4776	4882
30 x 30 cm	668	2521	5990	5354	4155
15 x 15 cm	2047	3837	6830	5024	6364
10 x 10 cm	2910	6840	9157	5170	5853
Mean	990	2731	6319	5163	5044
Significance	**	**	**	N.S.	**
L.S.D.	.05 1096	1773	1758		1151
	.01 1537	2486	2464		1614

When expressed on a unit area (hectare) basis plant dry weight again increased rapidly, particularly at the wider spacing, from establishment to floral initiation. Maximum yield per hectare was again delayed at the widest spacing until peak flowering (Table B.2.2). Subsequently dry weight per hectare generally declined and showed much smaller differences between plant spacing treatments at and following the peak flowering stage.

Leaf Area

As shown in Table B.2.3 leaf area increased as plants developed and generally reached a maximum at floral initiation or peak flowering. Leaf area then declined substantially by the final harvest due to leaf senescence. As plant density increased leaf area per plant declined, this effect being apparent and highly significant at all but the first harvest.

TABLE B.2.3 EFFECT OF PLANT SPACING ON LEAF AREA (CM²/PLANT)
AT EACH HARVEST.

<u>HARVESTING</u>						
<u>Plant spacing</u>	<u>40 days after planting</u>	<u>60 days after planting</u>	<u>Floral initiation</u>	<u>Peak flowering</u>	<u>40 days after peak flowering</u>	
120 x 120 cm	1676	16291	74246	75450	23850	
90 x 90 cm	777	13865	27335	30459	18147	
60 x 60 cm	729	8976	16242	15719	7629	
30 x 30 cm	1004	4141	4131	4163	1476	
15 x 15 cm	754	1534	888	917	651	
10 x 10 cm	358	1065	617	451	360	
Mean	883	7645	20576	21193	8686	
Significance	N.S.	**	**	**	**	**
L.S.D.	.05	3921.33	21176.83	8755.44	9838.84	
	.01	5497.78	29690.32	12275.30	13794.24	

In terms of leaf area index (LAI) (Table B.2.4) differences between plant spacings were only apparent during the vegetative stage, reaching significance at 60 days after sowing. Throughout the reproductive stage, from floral initiation to the final harvest 40 days after peak flowering, differences in LAI were relatively small and non-significant.

TABLE B.2.4 EFFECT OF PLANT SPACING ON LEAF AREA INDEX AT EACH HARVEST.

<u>HARVESTING</u>						
<u>Plant spacing</u>	<u>40 days after planting</u>	<u>60 days after planting</u>	<u>Floral initiation</u>	<u>Peak flowering</u>	<u>40 days after peak flowering</u>	
120 x 120 cm	0.12	1.13	5.16	5.24	1.66	
90 x 90 cm	0.09	1.71	3.38	3.76	2.24	
60 x 60 cm	0.20	2.49	4.51	4.37	2.12	
30 x 30 cm	1.12	4.60	4.59	4.63	1.64	
15 x 15 cm	3.35	6.82	3.95	4.08	2.89	
10 x 10 cm	3.58	10.64	6.17	4.51	3.60	
Mean	1.41	4.57	4.62	4.43	2.36	
Significance	N.S.	**	N.S.	N.S.	N.S.	N.S.
L.S.D.	.05	2.74				
	.01	3.84				

B.2.2.2 Seed yield and components

Seed Yields

Significant differences in seed yield per plant were recorded at all harvests (Table B.2.5), from a maximum at the widest spacing (29.2 g) to a minimum at the closest spacing (0.17 g). It is interesting that differences in seed yield between the wider spacings (i.e. 120, 90 and 60 cm) were observed as early as five days after peak flowering whereas no significance differences occurred at the closer spacings throughout the entire harvest period.

TABLE B.2.5 EFFECT OF PLANT SPACING ON SEED YIELD (GM/PLANT) AT EACH HARVEST.

<u>Plant spacing</u>	<u>HARVESTING</u>				
	<u>Days after peak flowering</u>				
	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
120 x 120 cm	9.660	9.133	27.420	29.180	19.780
90 x 90 cm	6.163	7.897	11.800	12.283	18.913
60 x 60 cm	2.083	4.827	7.343	9.540	7.770
30 x 30 cm	1.027	1.260	3.057	2.327	1.547
15 x 15 cm	0.253	0.657	0.297	1.533	0.530
10 x 10 cm	0.170	0.553	0.327	0.510	0.293
Mean	3.226	4.054	8.374	9.229	8.139
Significance	**	**	**	**	**
L.S.D. .05	3.179	3.632	6.215	3.203	6.469
.01	4.457	5.093	8.713	4.491	9.070

In terms of mean seed yield per unit area (kg/ha) (Figure B.2.2), there was a strong asymptotic trend in the relationship between plant density and seed yield with the asymptote around the 15 cm square plant spacing. However, when considered in relation to different harvest times (Table B.2.6) this trend virtually disappeared by the final harvest reflecting the considerable seed losses, through shattering particularly at the very close spacings (15 and 10 cm).

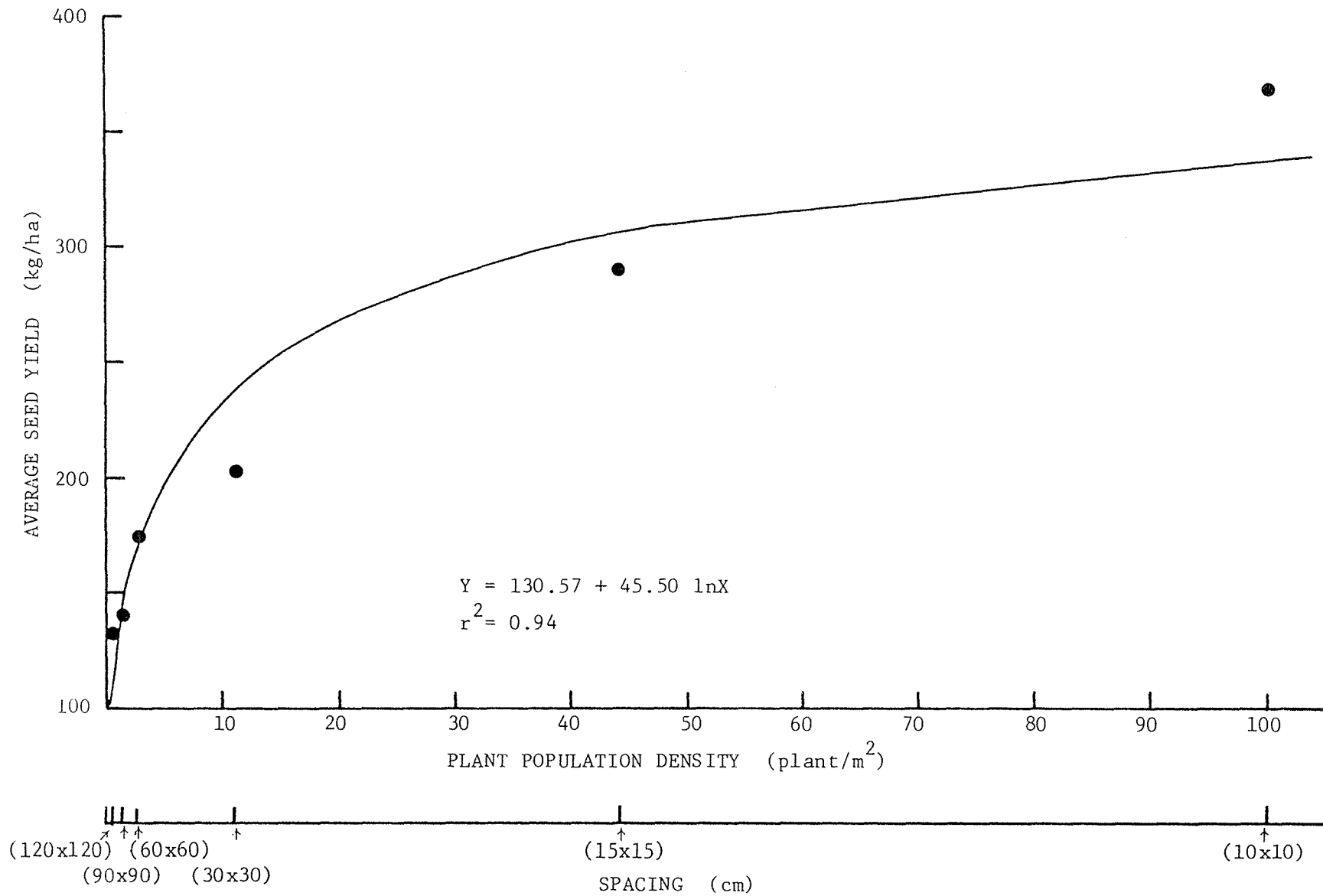


FIGURE B.2.2 THE RELATIONSHIP BETWEEN AVERAGE SEED YIELD (KG/HA) AND PLANT POPULATION DENSITY.

TABLE B.2.6 EFFECT OF PLANT SPACING ON SEED YIELD (KG/HA)
AT EACH HARVEST.

<u>Plant spacing</u>	<u>HARVESTING</u>					
	<u>Days after peak flowering</u>					
	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>	
120 x 120 cm	67.1	63.4	190.4	202.6	137.4	
90 x 90 cm	76.1	97.5	145.7	151.6	233.5	
60 x 60 cm	57.9	134.1	204.0	265.0	215.8	
30 x 30 cm	114.1	140.0	339.6	258.5	171.8	
15 x 15 cm	112.6	291.9	131.9	681.5	235.6	
10 x 10 cm	170.0	553.3	326.7	510.0	293.3	
Mean	99.6	213.4	223.0	344.9	214.6	
Significance	N.S.	*	N.S.	**	N.S.	
L.S.D.	.05	-	265.0	-	263.3	-
	.01	-	371.5	-	369.4	-

In terms of harvest times the highest mean seed yield was recorded 30 days after peak flowering with the 15 cm square plant spacing being the most productive. The results also highlight the problems associated with such studies when very small per plant differences are 'exploded' into large per unit area differences due to big differences in plant density and therefore in the conversion factor. The fluctuation in seed yield during this wet season was probably due to the indeterminate growth habit of Siratro and the production of massive vegetative growth resulting in uneven flowering patterns.

Inflorescence Number

As shown in Table B.2.7, plant spacing had a tremendous effect on inflorescence numbers per plant. Plants at the widest spacing (120 x 120 cm) produced the greatest number of inflorescences and declined as plant spacing decreased. The highly significant effect caused by plant density was only apparent at the wider spacings (120, 90 and 60 cm) at each harvest. Maximum numbers of inflorescences

were generally recorded 20 to 30 days after peak flowering and then declined at the last harvest.

TABLE B.2.7 EFFECT OF PLANT SPACING ON INFLORESCENCE NUMBER PER PLANT AT EACH HARVEST.

<u>Plant spacing</u>	<u>HARVESTING</u>				
	<u>Days after peak flowering</u>				
	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
120 x 120 cm	104.7	92.3	235.0	256.0	158.3
90 x 90 cm	60.0	56.0	115.7	83.7	107.3
60 x 60 cm	20.3	46.0	60.7	62.0	57.3
30 x 30 cm	9.0	11.3	19.3	19.3	8.3
15 x 15 cm	2.3	5.0	3.7	7.7	2.3
10 x 10 cm	2.7	4.0	3.0	3.0	2.3
Mean	33.2	35.8	72.9	71.9	56.0
Significance	**	**	**	**	**
L.S.D. .05	19.28	47.96	46.02	53.60	61.88
.01	27.04	67.24	64.52	75.15	86.76

Pod Numbers

The number of pods per plant was also found to be most sensitive to variation in spacing. As seen in Table B.2.8, pod numbers generally reached a maximum 30 days after peak flowering and then declined. A decline in the number of pods per plant as density increased was recorded as early as five days after peak flowering and continued to the final harvest. Again the highly significant differences recorded were greatest among plants at the wider spacings (120, 90 and 60 cm) rather than in plants grown at high population densities.

TABLE B.2.8 EFFECT OF PLANT SPACING ON POD NUMBER PER PLANT
AT EACH HARVEST.

<u>Plant spacing</u>	<u>HARVESTING</u>				
	<u>Days after peak flowering</u>				
	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
120 x 120 cm	164.3	133.0	333.0	341.0	261.0
90 x 90 cm	105.0	84.7	140.7	141.3	212.3
60 x 60 cm	33.3	52.7	91.7	112.0	97.7
30 x 30 cm	15.3	15.0	24.7	34.3	16.7
15 x 15 cm	4.7	7.3	5.0	12.3	5.0
10 x 10 cm	3.3	6.0	4.0	4.3	3.7
Mean	54.3	49.8	99.8	107.6	99.4
Significance	**	**	**	**	**
L.S.D. .05	47.57	47.74	79.10	34.25	99.36
.01	66.69	66.93	110.90	48.03	139.31

Number of Seeds per Pod

Plant spacing had little or no effect on the number of seeds per pod (Table B.2.9). The results suggest that this component is relatively insensitive to environmental factors. Number of seeds per pod varied from only 11 - 12 at every spacing and at every harvest.

TABLE B.2.9 EFFECT OF PLANT SPACING ON NUMBER OF SEEDS PER POD
AT EACH HARVEST.

<u>Plant spacing</u>	<u>HARVESTING</u>				
	<u>Days after peak flowering</u>				
	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
120 x 120 cm	11.98	11.97	12.01	11.99	12.00
90 x 90 cm	11.90	11.89	11.98	12.00	12.00
60 x 60 cm	11.83	11.97	11.99	12.02	12.05
30 x 30 cm	12.18	12.12	11.85	11.92	11.93
15 x 15 cm	11.00	11.95	12.13	12.01	11.59
10 x 10 cm	12.35	11.92	12.25	12.70	12.25
Mean	11.88	11.97	12.03	12.10	11.97
Significance	N.S.	N.S.	N.S.	**	N.S.
L.S.D. .05				0.305	
.01				0.427	

Seed Weight

Hundred seed dry weight measurements, as shown in Table B.2.10, indicate that alteration in plant spacing has little or no effect on seed weight. Seed weight, however, increased as the seed matured generally reaching a maximum 30 to 40 days after peak flowering. A decline in 100 seed dry weight at the final harvest at most spacings was probably due to the loss of dry heavy seeds from brown pods, resulting in a higher proportion of green lighter seeds being sampled for measurement. Such a decline was most evident at high plant densities, presumably reflecting the previously observed heavy seed loss due to shattering found at high plant populations.

TABLE B.2.10 EFFECT OF PLANT SPACING ON SEED DRY WEIGHT (100 SEEDS) AT EACH HARVEST.

<u>Plant spacing</u>	<u>HARVESTING</u>				
	<u>Days after peak flowering</u>				
	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
120 x 120 cm	0.505	0.582	0.697	0.714	0.661
90 x 90 cm	0.486	0.797	0.708	0.725	0.751
60 x 60 cm	0.544	0.754	0.656	0.710	0.656
30 x 30 cm	0.534	0.713	1.219	0.569	0.787
15 x 15 cm	0.487	0.674	0.471	1.133	0.916
10 x 10 cm	0.485	0.766	0.667	0.822	0.691
Mean	0.507	0.714	0.736	0.779	0.744
Significance	N.S.	N.S.	N.S.	N.S.	**
L.S.D. .05					0.131
.01					0.183

B.2.2.3 Seed quality

The quality of seed in terms of moisture content, germination percentage, abnormal seedling percentage and hard seed content was also examined. Results are presented in Tables B.2.11 - B.2.14.

Moisture Content

The effect of plant spacing on moisture content of seed was small and erratic. However, there was a gradual but steady decline in mean seed moisture content across harvests as the seed ripened (Table B.2.11). The rate of dehydration was surprisingly low considering seed lost less than 8% moisture over a period of 35 days. Such a slow rate of moisture change presumably reflected the unsuitability of the wet season environment for seed drying.

TABLE B.2.11 EFFECT OF PLANT SPACING ON SEED MOISTURE CONTENT AT EACH HARVEST.

<u>Plant spacing</u>	<u>HARVESTING</u>				
	<u>Days after peak flowering</u>				
	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
120 x 120 cm	63.0	62.8	51.6	56.2	56.1
90 x 90 cm	61.8	57.7	53.8	56.3	49.3
60 x 60 cm	63.2	57.8	53.8	55.3	59.9
30 x 30 cm	60.3	58.3	58.5	55.0	57.2
15 x 15 cm	61.5	59.2	58.7	54.3	47.7
10 x 10 cm	63.0	54.8	58.5	55.1	57.5
Mean	62.2	58.4	55.8	55.4	54.6
Significance	N.S.	**	*	N.S.	**
L.S.D.	.05	2.21	4.49		4.05
	.01	3.09	-		5.68

Germination Percentage

Seed germination percentages obtained on samples tested immediately after harvest are presented in Table B.2.12. It was noticed that changes in plant spacing generally had little effect on the germination ability of seed and appeared to be more dependent on the stage of maturity of the seed. Over all spacings seed germination increased from 36% to 72% as seed matured, reaching a maximum 30 to 40 days after peaking flowering.

TABLE B.2.12 EFFECT OF PLANT SPACING ON PERCENTAGE OF SEED GERMINATION AT EACH HARVEST.

<u>Plant spacing</u>	<u>HARVESTING</u>				
	<u>Days after peak flowering</u>				
	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
120 x 120 cm	52.5	49.8	61.8	66.0	64.3
90 x 90 cm	30.2	54.3	48.0	61.3	80.0
60 x 60 cm	40.5	63.3	61.8	79.2	62.3
30 x 30 cm	39.3	38.3	55.0	78.7	68.7
15 x 15 cm	23.0	56.0	47.5	74.7	77.7
10 x 10 cm	30.5	51.9	58.7	72.0	75.3
Mean	36.0	52.3	55.5	72.0	71.4
Significance	N.S.	N.S.	N.S.	N.S.	*
L.S.D. .05					10.53
.01					-

Again, plant spacing had little effect on seedling abnormality in most harvests (Table B.2.13). The main types of abnormality detected, however, included root damage with the primary root being short and stunted or with no root hairs. Unbalanced development, particularly of seedlings with short and weak roots, was also common. The level of seedling abnormality was low in all cases (less than 9%).

The level of hard seededness reached a peak 10 to 20 days after peak flowering and then declined (Table B.2.14). The generally low percentage of hard seeds formed was presumably a reflection of the mild drying capacity of the wet season environment since hard seed formation is generally associated with dehydration.

TABLE B.2.13 EFFECT OF PLANT SPACING ON ABNORMAL SEEDLING PERCENTAGE AT EACH HARVEST.

<u>Plant spacing</u>	<u>HARVESTING</u>				
	<u>Days after peak flowering</u>				
	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
120 x 120 cm	3.50	5.83	5.67	4.50	2.67
90 x 90 cm	2.33	4.83	6.67	3.17	2.17
60 x 60 cm	3.67	5.17	8.83	3.33	5.50
30 x 30 cm	3.83	6.00	6.33	4.67	4.83
15 x 15 cm	6.33	5.50	4.67	5.00	1.50
10 x 10 cm	3.33	6.10	3.83	5.17	6.50
Mean	3.83	5.57	6.00	4.31	3.86
Significance	N.S.	N.S.	*	N.S.	*
L.S.D. .05			2.72		3.02
.01			-		-

TABLE B.2.14 EFFECT OF PLANT SPACING ON HARD SEED PERCENTAGE AT EACH HARVEST.

<u>Plant spacing</u>	<u>HARVESTING</u>				
	<u>Days after peak flowering</u>				
	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>
120 x 120 cm	3.33	10.17	7.83	4.67	1.17
90 x 90 cm	0.17	10.17	8.50	6.00	2.67
60 x 60 cm	3.33	7.00	8.17	0.67	0.17
30 x 30 cm	2.67	6.17	4.83	1.83	1.33
15 x 15 cm	3.17	5.00	8.33	1.33	0.83
10 x 10 cm	4.67	5.50	14.83	1.83	1.17
Mean	2.89	7.33	8.75	2.72	1.22
Significance	N.S.	N.S.	N.S.	*	*
L.S.D. .05				3.28	1.03
.01				-	-

B.2.3 DISCUSSION

Although individual plant dry weight was markedly depressed by increasing plant density, as found by other workers (Ishag, 1973a; Rickert and Humphreys, 1970), this effect was more than compensated for by increasing plant populations, particularly at the closer spacings, resulting in a greater total plant yield per unit area at the higher population densities. This effect was also reported by Rickert and Humphreys (1970) and Kowithayakorn (1978). It is important to note that this dominating population effect was most evident at the earlier vegetative stage before widely-spaced plants had fully exploited their more extensive environment. However, as plants developed, the differences in plant yield per unit area due to spacing, became less and less. The stress from intra-specific plant competition was first evident at floral initiation in all but the widest spacing. Plants in the widest spacing treatment were apparently able to continue their growth and development without serious impediment until after peak flowering.

As expected, leaf area per plant was severely depressed by increasing plant population as reported by Ishag (1973a). This effect was due to intra-specific competition (Tamaki *et al*, 1973), but again increasing populations compensated for the lower leaf area per plant resulting in relatively similar leaf area index (LAI) between treatments. Similar results have been reported by Meadley and Milbourn (1970) and Appadurai *et al* (1966). However, it is also interesting that LAI in the closer spacing treatments (30, 15 and 10 cm) reached a maximum considerably earlier than in the wider spaced treatments, by 23 weeks. This again reflects the high plant density and therefore the high leaf number and area in high density treatments. It also shows the consequent ability of close spaced plants to better exploit the environment for early growth. It is suggested that competition for light during this wet season experiment, may be the main reason for the subsequent decline in leaf area due to leaf senescence and leaf drop. These effects certainly occurred earlier in the high populations due to earlier competitive stress. However, the possibility of nutrient stress being involved in this reaction cannot be discarded,

although every attempt was made to maintain adequate soil nutrient levels by 'topdressing'.

The results from this experiment show that the widest plant spacing produced the highest seed yield per plant as found by Withers (1975) in lupin and Kowithayakorn (1978) in lucerne. This was due largely to high inflorescence and pod numbers. This advantage was also sufficient to achieve seed yields per hectare equal to that from a 16-fold difference in plant density (e.g. 120 cm v 30 cm spacings). However, when plant population increased 64-fold and 145-fold (i.e. to 15 and 10 cm spacings) the advantages from the larger more fully developed plants at the wider-spacing was overshadowed by the sheer number of plants. Even at the closest spacings plants were apparently still capable of producing at least some viable seed.

It appears that a harvest around 30 days after peak flowering is probably the most approximate time to achieve maximum seed yields irrespective of plant population. Beyond that time seed shattering losses are likely to be substantial. This is supported by the production of maximum inflorescence numbers and pod numbers, the major determinants of seed yield at about this time (Ishag, 1973a, b; Adams, 1975). It is also important to recognise that numbers of seeds per pod and seed dry weight were relatively unaffected by plant competition, the experimental data showing little variation in these yield components due to plant spacing. These results serve to highlight the strong genetic control of these characters by the plant, particularly when one considers the extreme differences between plants in the widest and closest spacings. Similar results have also been reported by Lehman and Lambert (1960).

In terms of seed quality components, there were only minor differences recorded between the plant-spacing treatments, except perhaps in the level of hard-seededness. As also found by Aitken (1939) there was a significantly lower level of hard-seededness recorded from plants grown under high competitive stress than in seed produced on wider-spaced plants, however the trends were less clear than the situation stated by Aitken (1939). * * * * *

SECTION C : CONTROLLED ENVIRONMENT EXPERIMENT

C.1 THE EFFECT OF WATER STRESS ON VEGETATIVE GROWTH, SEED YIELD AND SEED DEVELOPMENT IN SIRATRO (*Macroptilium atropurpureum*)

C.1.1 INTRODUCTION

Results from the field study in Thailand showed that plant growth and development in Siratro was markedly affected by soil moisture conditions. Depending on the time of sowing, the field experiment presented three quite distinct and different soil moisture regimes. Firstly, in the dry season experiment all plants received sufficient moisture for good initial vegetative growth, up to four weeks from sowing. Some were then subjected to increasing water stress right through to seed ripeness. Secondly, in the dry season experiment some plants obtained sufficient moisture for growth during the vegetative stage and up to peak flowering and were then subjected to drought conditions during the period of seed development through to seed ripeness. Thirdly, by sowing Siratro at the start of the wet season, plants were exposed to a long period (7 months) of good moisture conditions before the natural dry season occurred. The differences recorded in the plant's reaction to water stress suggest that Siratro seed production depends on the stage of growth of the plant when drought conditions occur and on the severity and duration of the stress, as stated by Hsiao and Acevedo (1974).

From the literature (Salter and Goode, 1967) it appears that water stress before flowering can reduce vegetative growth of the plant but has little effect on pod and seed yields provided the soil does not reach permanent wilting point. However, water stress during the reproductive period can cause a marked reduction in seed yield (Salter, 1963; Hiler *et al*, 1972; Soinit and Kramer, 1977), through a reduction in pod number (Biddiscombe, 1975), seed size (Soinit and Kramer, 1977) and number of seeds per pod (Momen *et al*, 1979).

However, with particular reference to Siratro, there is only limited information on the vegetative and reproductive responses to water stress, particularly relating to its effects on seed development and seed quality. Therefore this experiment was carried out to examine the effects of water stress imposed at three different stages of growth on vegetative and reproductive growth and on seed development.

C.2 EFFECT OF WATER STRESS IMPOSED AT DIFFERENT GROWTH STAGES ON VEGETATIVE AND REPRODUCTIVE DEVELOPMENT

C.2.1 MATERIALS AND METHODS

C.2.1.1 Environmental conditions

Siratro plants were grown from seed in the climate controlled rooms at the Plant Physiology Division, DSIR, Palmerston North, New Zealand. The conditions in the controlled environment room were: temperature $30/20 \pm 0.5^{\circ}\text{C}$ (day/night), humidity $70/90 \pm 5\%$ R.H. (day/night) and 12 hour photoperiod (Appendix Table 2). CO_2 level was monitored during the experiment and ranged from 290 - 350 ppm during day conditions and from 320 - 390 ppm during night conditions.

This environment was chosen, following reference to climatic records for the North-East region of Thailand, to simulate as closely as possible the climate prevailing during the previous field experiments. Siratro seeds were scarified in order to overcome hard seededness, and six seeds sown at a 1.5 cm depth in one gallon containers filled with a sterilised North Carolina soil mixture. Each pot was connected to a watering tube and watered automatically with N.C.S.U. (Appendix Table 3) nutrient solution throughout the experiment. Duration and time of watering were adjusted to maintain soil moisture above 80% field capacity. Water stress was imposed at different growth stages by removing the automatic watering tubes and subsequently watering by hand to maintain soil moisture content and leaf relative water content at the required stress level.

C.2.1.2 Treatments

Plant water deficits were induced at two different growth stages and were defined as follows:

W1: An initial 'high' water level,^{*} followed by a 'low' water level^{**} which commenced approximately half-way through the vegetative stage (18 days after sowing) and continued until final harvest.

W2: An initial 'high' water level maintained from sowing until peak flowering (54 days after sowing) followed by a 'low' water level until final harvest.

Control treatment:

W3: A 'high' water level was supplied to the plants throughout the experiment from sowing until final seed harvest.

* *The 'high' water level was established and maintained by keeping the soil moisture level at 80 - 100% field capacity by an automatic feeding system. Such a level ensured adequate moisture for plant growth and development throughout the experimental period.*

** *The 'low' water level maintained a soil moisture tension of pF 2.8 - 3.0, equivalent to a leaf relative water content (RWC) of 75 - 80%. Such a level ensured a degree of water stress on the plant throughout the periods concerned.*

The schedule of treatments is shown in Table C.2.1.

TABLE C.2.1

SCHEDULE OF TREATMENTS

<u>GROWTH STAGE</u>	Days from sowing	<u>TREATMENT</u>		
		W1	W2	Control (W3)
From sowing until half vegetative growth (approximately 18 days)	18	+	+	+
From half vegetative until floral initiation (approximately 8 days)	26	-	+	+
From floral initiation until peak flowering (approximately 24 days)	50	-	+	+
From peak flowering until seed harvest (approximately 25 days)	75	-	-	+

+ = *adequate watering*

- = *restricted watering*

C.2.1.3 Measurements

Soil Water Potential

The relationship between soil water potential and soil moisture content (SMC) is shown in the soil moisture retention curve (Figure C.2.1), determined by using a pressure plate membrane apparatus. Gypsum blocks (2 x 7 cm) were buried in the middle of a number of selected pots and soil water potential readings obtained from gypsum

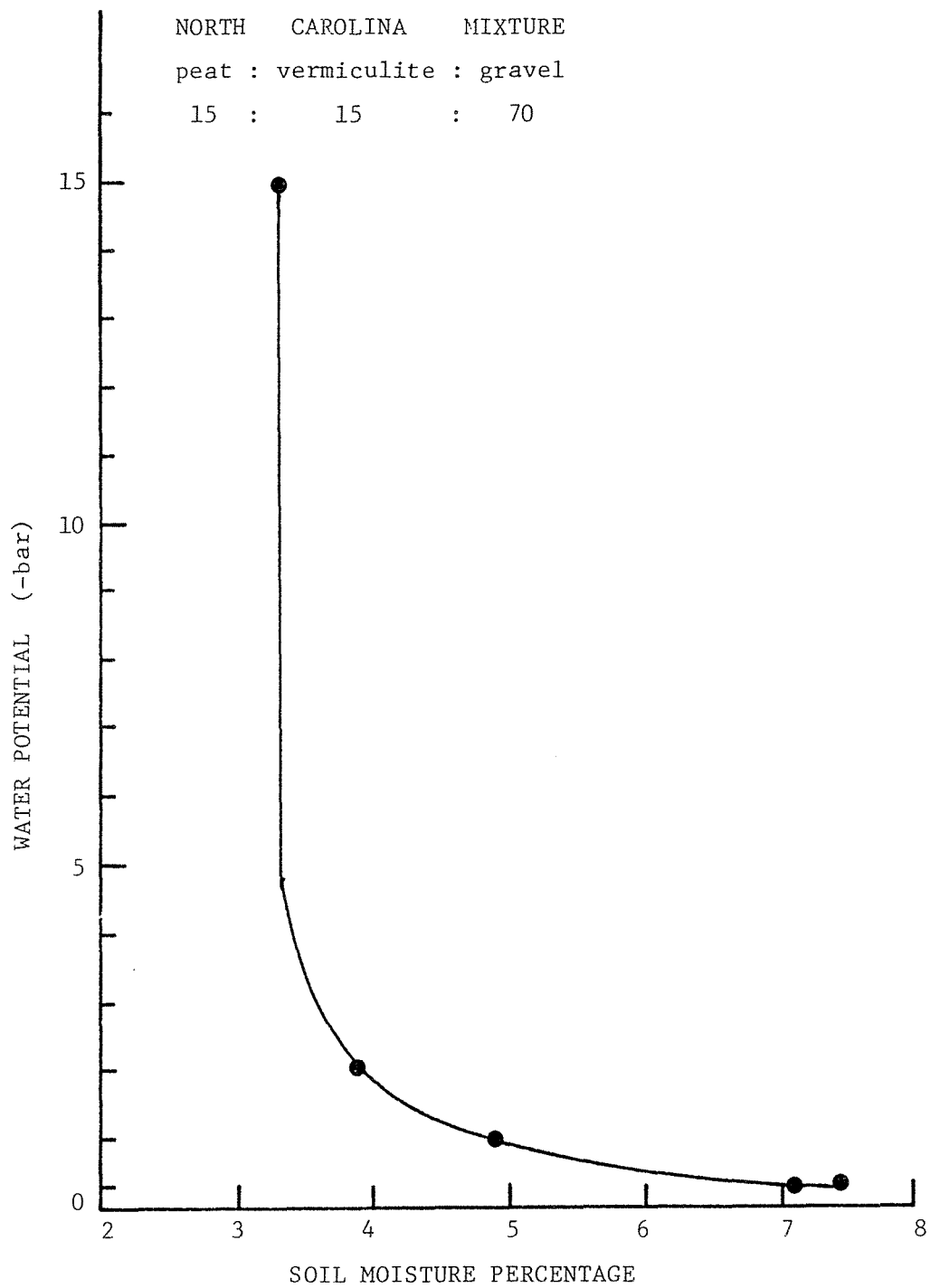


FIGURE C.2.1

SOIL WATER RETENTION CURVE OF NORTH CAROLINA MIXTURE.

blocks using a 'Wheatstone Bridge". Restricted watering treatments were imposed by measuring soil water potential daily from gypsum blocks and applying only sufficient water to maintain a mean soil water potential in the pF range 2.8 - 3.0. Soil moisture tension in well watered containers cycled below pF 2.5.

Plant Water Potential

During the water stress period leaf relative water content (RWC) was determined immediately before hand watering from 10 - 15 leaf discs (1 cm diameter). These were taken from newly expanded leaves so that sample leaves were of a similar physiological age. The leaf samples were then weighed to determine fresh weight and floated upside down in distilled water for three hours until they became fully turgid. Turgid weight was determined and dry weight was recorded after oven drying at 85°C for three hours.

Relative water content of leaf was calculated by using the following formula:

$$\text{RWC} = \frac{\text{Fresh wt} - \text{Dry wt}}{\text{Turgid wt} - \text{Dry wt}} \times 100$$

Leaf RWC was determined for each treatment and presented in Figure C.2.2.

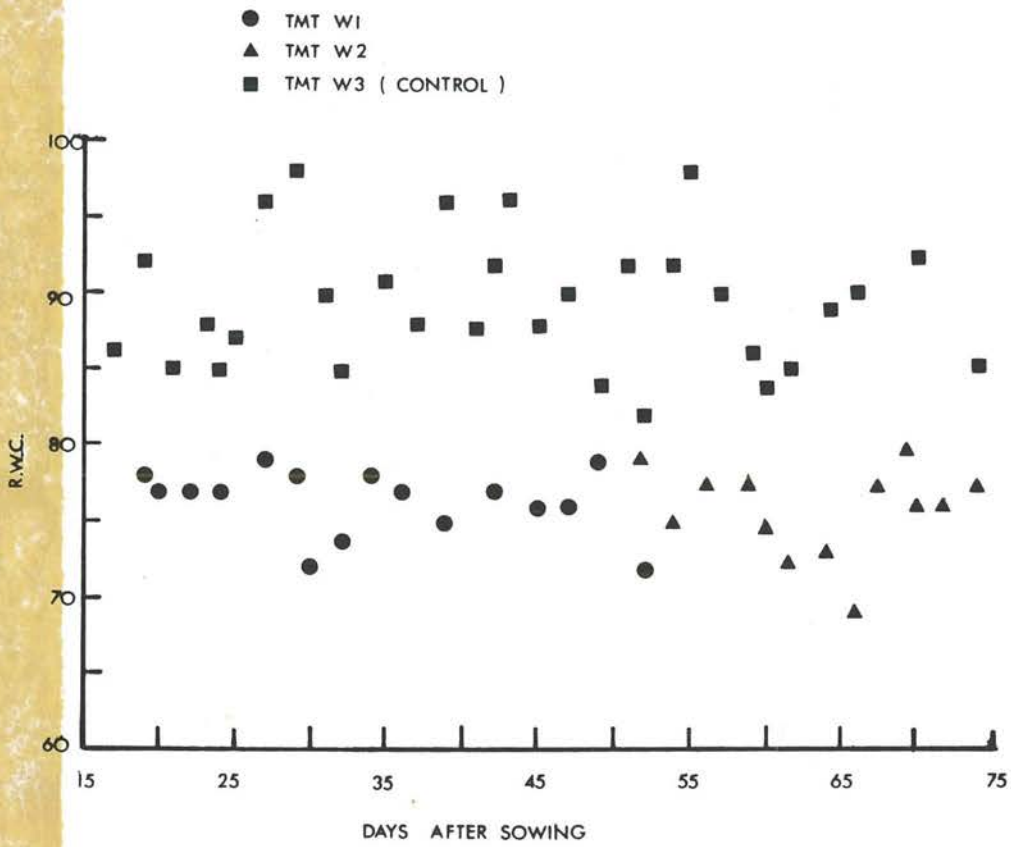


FIGURE C.2.2. RELATIVE WATER CONTENT (RWC) MEASUREMENTS.

C.2.1.4 Harvesting

The schedule of harvests involving three plants at each of seven harvest times is summarised in Table C.2.2. The stages of plant growth in each harvesting time are presented in Appendix Plates 1 - 7.

TABLE C.2.2 SCHEDULE OF HARVESTS

<u>TIME OF HARVEST</u>	W1	W2	Control (W3)
At half vegetative stage (H1)	-	-	+
At floral initiation (H2)	+	-	+
At peak flowering (H3)	+	-	+
10 days after peak flowering (H4)	+	+	+
15 days after peak flowering (H5)	+	+	+
20 days after peak flowering (H6)	+	+	+
25 days after peak flowering (H7)	+	+	+

+ = *harvested*

- = *not harvested*

At each harvest, the plants were dissected into leaf and non-leaf components with subsequent measurement of leaf area, and branch and pod numbers. The dry weight of each component was determined following drying in a vacuum oven.

Seed yield and components were obtained from each harvest after peak flowering. Number of inflorescences and pods were counted and pods were grouped into length categories, i.e. 1.1 - 3.0 cm (A), 3.1 - 5.0 cm (B), 5.1 - 7.0 cm (C), 7.1 - 9.0 cm (D). Brown pods were separated and placed in Group E. Numbers of pods in each group were recorded.

Seed yields were only collected from pods which were sufficiently formed to allow seed to be extracted easily without damage. A minimum pod length of 5 cm was chosen to meet this criterion. Seed moisture content and germination were carried out as prescribed in the ISTA Rules (1976) and previously described in SECTION B.

C.2.1.5 Statistical analysis

Data collected from controlled environment experiment were analysed according to the common procedure of a randomized complete block design for all plant characters (Little and Hills, 1975). The analysis was done by Genstat program (Alvey *et al*, 1977).

C.2.2 RESULTS

C.2.2.1 Growth and development

The effects of water stress on vegetative growth throughout the experimental period under a controlled environment are presented in terms of plant dry weight, leaf number, leaf area, and branch number. Under such controlled environmental conditions the total growth period (sowing to final harvest) varied from 75 - 79 days according to treatment, which was considerably shorter than in the field study (110 - 267 days).

Total Plant Dry Weight

The data presented in Table C.2.3 compares total plant dry weight of each treatment at the same stage of growth and highlights the severe depression in plant dry weight when water stress was applied early

($\frac{1}{2}$ vegetative stage). Plants in this treatment (W1) showed only slow growth throughout the growth period and little beyond peak flowering compared with plants in the watered control (W3) treatment. When stress was not applied until peak flowering (W2), growth continued at a relatively high rate for approximately 10 days and finally 'plateaued' about 15 days after stress was applied. The well watered plants continued to increase in dry weight through to the final harvest 25 days after peak flowering. The plant responses in the different treatments on a simple time basis, i.e. days from sowing, are also presented in Figure C.2.3. Although the trends presented were not able to be analysed statistically, as measurements were only taken on a stage of growth basis, the differences between treatments are clearly substantial and of agronomic significance. It is interesting that plants under early water stress reached the floral initiation stage six days earlier than well-watered plants. However, the period between floral initiation and peak flowering was only one day different between treatments. The differences on final plant size are shown in Plate C.2.1 - C.2.3

TABLE C.2.3 EFFECT OF WATER TREATMENTS ON TOTAL PLANT DRY WEIGHT (GM/PLANT)

<u>Treatment</u>	<u>$\frac{1}{2}$V</u>	<u>F.I.</u>	<u>HARVESTING</u>				
			<u>P.F.</u>	<u>10D</u>	<u>15D</u>	<u>20D</u>	<u>25D</u>
W1	(0.33)	1.86	6.75	7.07	6.72	7.28	7.98
W2	(0.33)	(3.59)	(22.71)	38.01	43.79	40.20	44.72
W3	0.33	3.59	22.71	43.27	53.27	65.56	74.21
Mean	0.33	3.01	17.39	29.45	34.59	37.68	42.30
Significance	N.S.	**	**	**	**	**	**
L.S.D.	.05	0.87	9.57	11.84	9.05	10.38	9.45
	.01	1.32	14.49	17.94	13.72	15.72	14.31

(Figures in brackets in this and subsequent tables reflect the data from the W3 treatment which was identical to W1 and W2 at those harvests, i.e. W1 treatment commenced at half vegetative stage, W2 commenced at peak flowering).

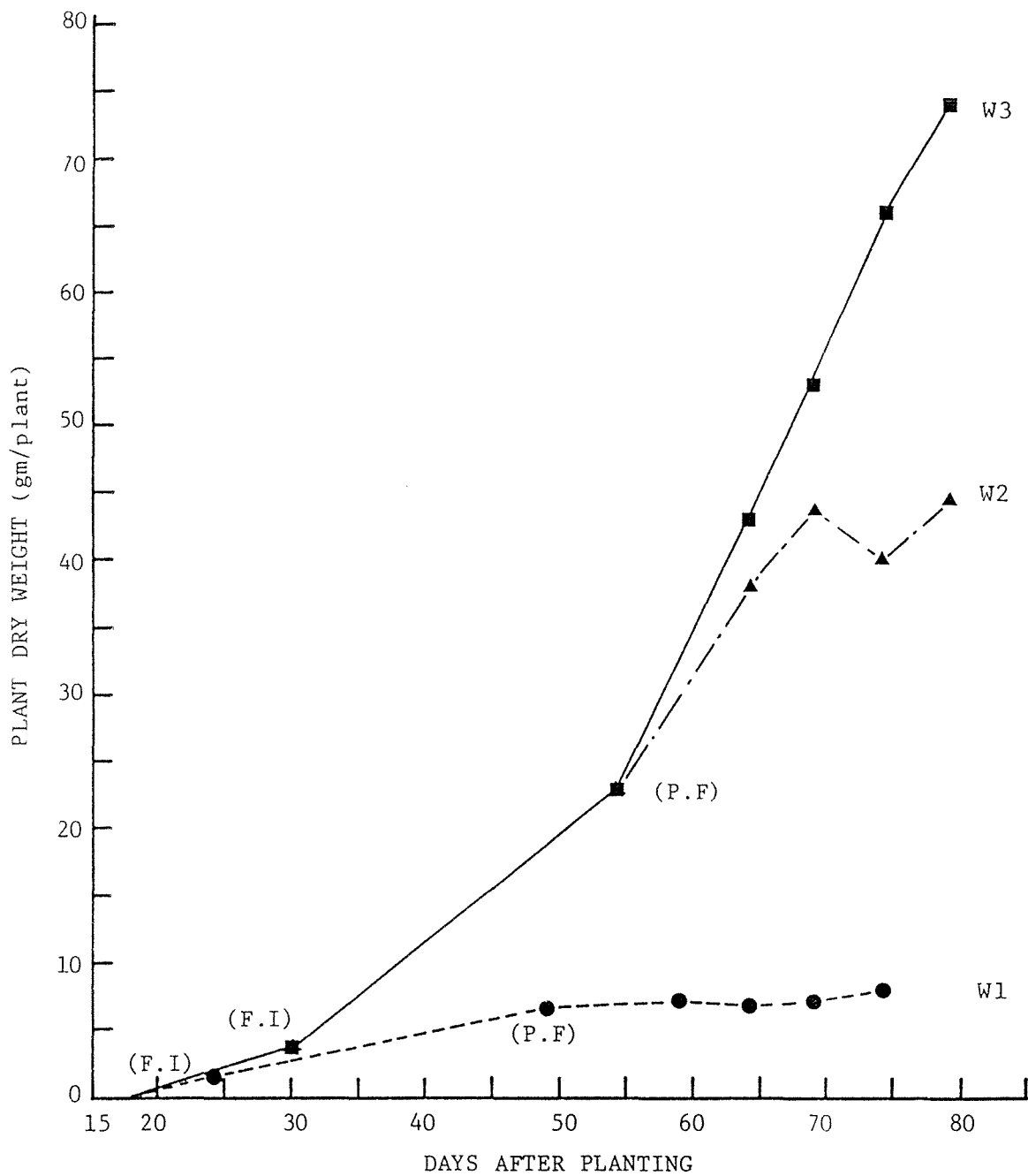


FIGURE C.2.3 EFFECT OF WATER TREATMENTS ON TOTAL PLANT DRY WEIGHT.



PLATE C.2.1 WHOLE PLANT FROM TREATMENT W1
AT FINAL HARVEST (25 DAYS
AFTER PEAK FLOWERING).



PLATE C.2.2 WHOLE PLANT FROM TREATMENT W2
 AT FINAL HARVEST (25 DAYS
 AFTER PEAK FLOWERING).

Green Leaf Number per Plant

The numbers of green leaves per plant recorded throughout the experimental period in the three treatments are presented in Table C.2.4 and Figure C.2.4. Highly significant effects due to the water treatments were found in all but the earliest harvest. Well watered plants (W3) showed the greatest number of green leaves which increased from three leaves per plant at the first harvest (18 days after sowing) up to 318 leaves by the final harvest (79 days after sowing). Water stress applied at the half vegetative stage of growth (W1) resulted in the lowest number of green leaves per plant compared with the W3 and W2 treatments. This effect (W1) was reflected in a slow rate of increase in leaf number through to the peak flowering stage and thereafter the number remained virtually static. New leaf appearance and leaf shedding tended to counteract each other, resulting in a relatively constant leaf number per plant until the final harvest. Water stress applied at peak flowering (W2 treatment) resulted in a gradual decrease in leaf numbers from approximately 10 days after peak flowering until the final harvest.

TABLE C.2.4 EFFECT OF WATER TREATMENTS ON NUMBER OF GREEN LEAVES PER PLANT

<u>Treatment</u>	<u>½V</u>	<u>F.I.</u>	<u>HARVESTING</u>				
			<u>P.F.</u>	<u>10D</u>	<u>15D</u>	<u>20D</u>	<u>25D</u>
W1	(3)	12	44	47	49	54	52
W2	(3)	(21)	(145)	167	158	129	137
W3	3	21	145	204	246	304	318
Mean	3	18	111	139	151	162	169
Significance	N.S.	**	**	**	**	**	**
L.S.D.	.05	3	44	56	50	32	28
	.01	4	66	85	76	48	41

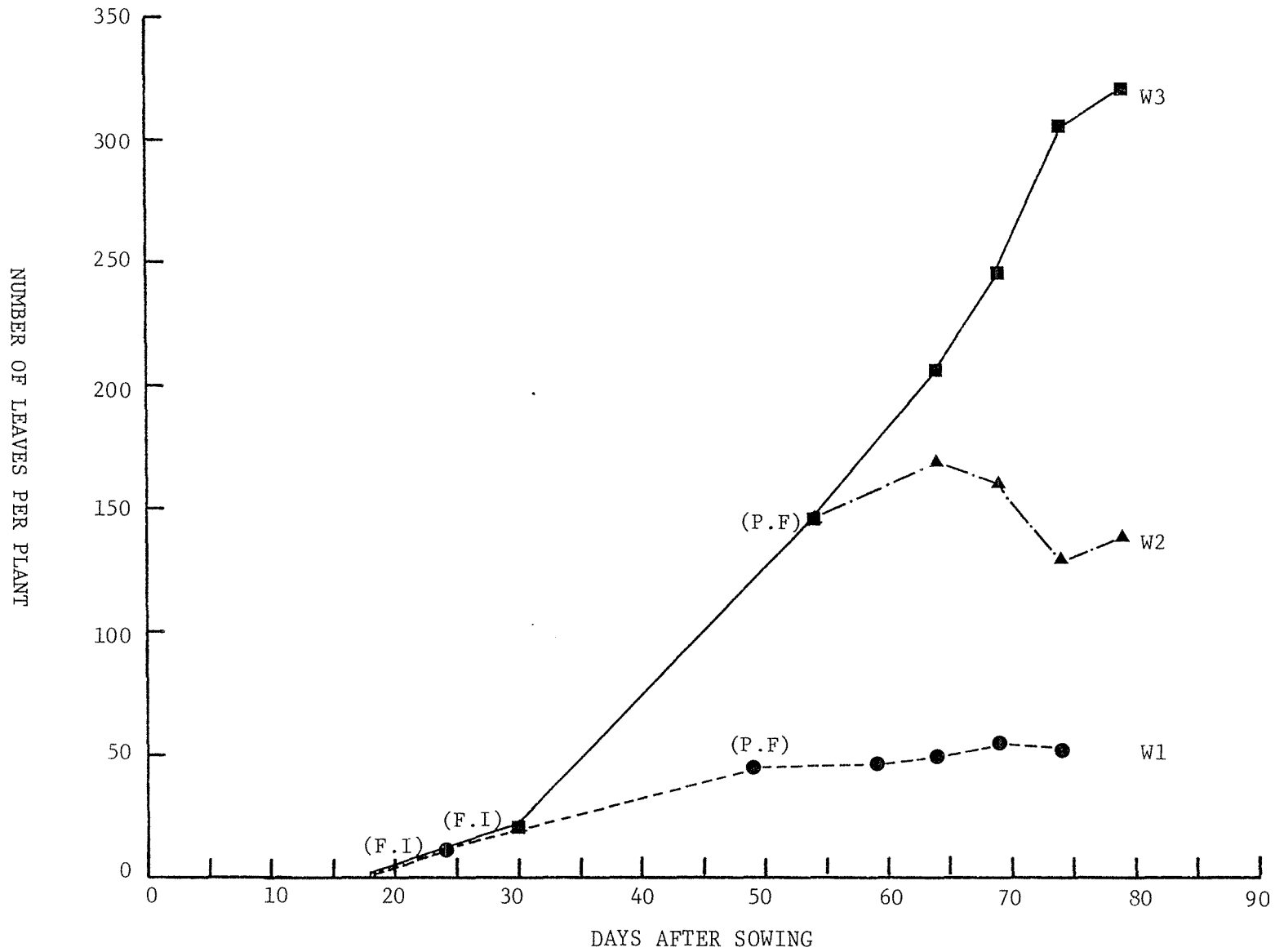


FIGURE C.2.4 EFFECT OF WATER TREATMENTS ON NUMBER OF GREEN LEAVES PER PLANT.

Leaf Area (cm²/plant)

Leaf area per plant showed the same trend as leaf number. From Table C.2.5 and Figure C.2.5, it can be seen that greatest leaf area per plant was obtained from plants in treatment W3 which were well watered throughout the experiment. The maximum leaf area per plant in treatment W3 was obtained 20 days after peak flowering whereas plants in treatment (W1), with their very low leaf area throughout, showed little increase beyond peak flowering. Plants in the W2 treatment showed the same rapid effect of water stress as W1, with little increase in leaf area occurring after watering was reduced at peak flowering.

TABLE C.2.5 EFFECT OF WATER TREATMENTS ON LEAF AREA (CM²) PER PLANT

<u>Treatment</u>	<u>½V</u>	<u>HARVESTING</u>					
		<u>F.I.</u>	<u>P.F.</u>	<u>10D</u>	<u>15D</u>	<u>20D</u>	<u>25D</u>
W1	(90)	302	505	495	494	528	488
W2	(90)	(735)	(5249)	5318	5355	4124	4259
W3	90	735	5249	7661	9990	12293	11888
Mean	90	591	3668	4479	5280	5648	5545
Significance	N.S.	**	**	**	**	**	**
L.S.D.	.05	144	2113	1599	2897	1822	1497
	.01	219	3201	2422	4389	2760	2268

Branch Number per Plant

Water stress imposed halfway through the vegetative stage of growth (W1) or at peak flowering (W2) subsequently depressed total branch numbers per plant throughout the remainder of the experiment (Table C.2.6a and Figure C.2.6). The results highlight the sensitivity of new branch production to reduced watering with the final harvest,

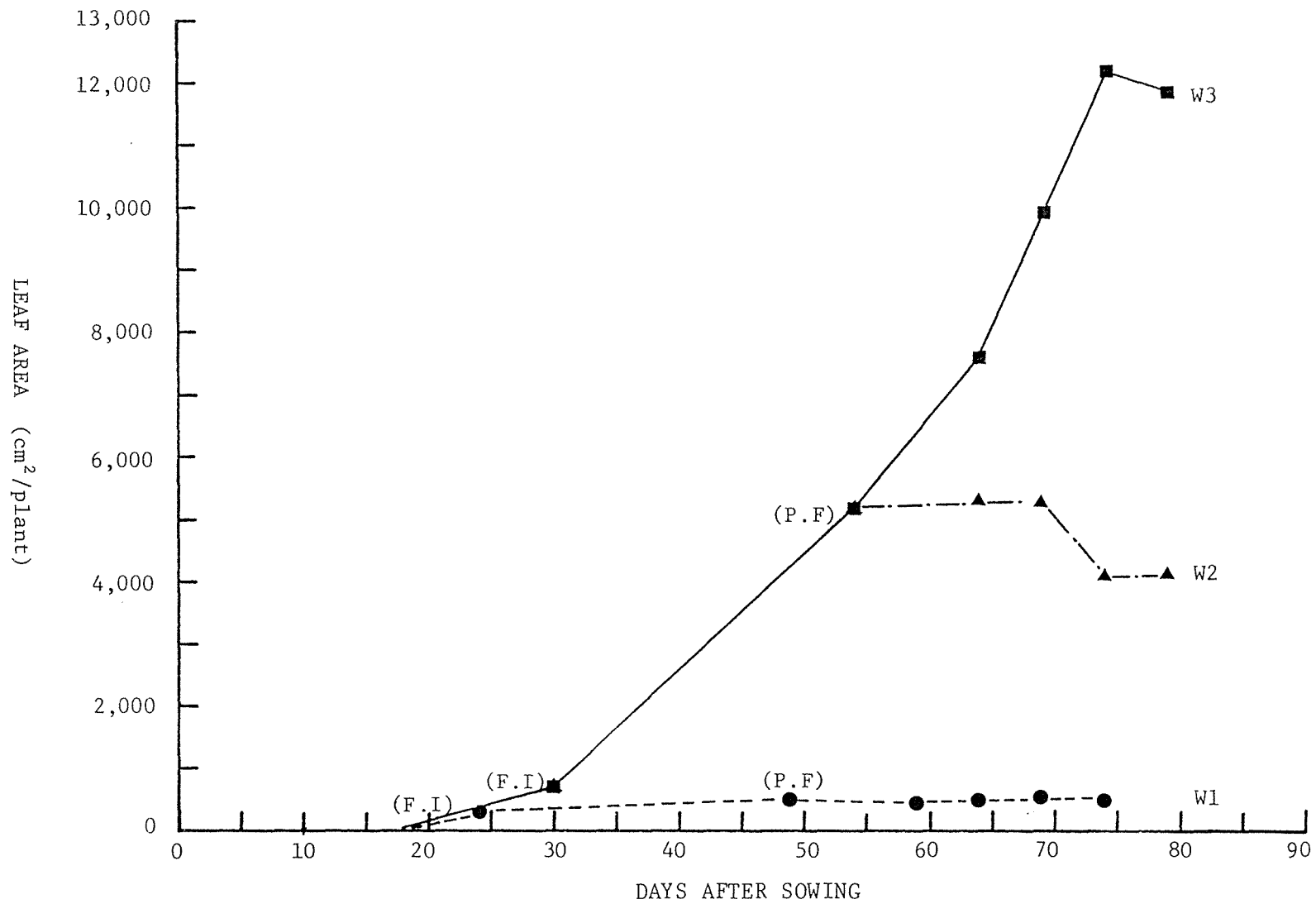


FIGURE C.2.5 EFFECT OF WATER TREATMENTS ON LEAF AREA PER PLANT.

taken 25 days after peak flowering, showing a six-fold difference in branch numbers between early-stressed (W1) and continuously watered (W3) plants. It is also interesting to note that, irrespective of the watering treatment, significant differences in total branch numbers per plant were not obtained until 10 days after peak flowering.

The results in Table C.2.6b show the mean number of primary, secondary and tertiary branches respectively on plants from the different water treatments. In the early stressed treatment (W1) primary branch numbers remained relatively constant (5 - 7) throughout the experiment. Plants also showed a severe depression in their ability to produce secondary branches (maximum 2) and no capacity for tertiary branch formation. In contrast, plants in the W2 and W3 treatments both reached a maximum number of primary branches 10 days after peak flowering (11 - 14). No significant change in primary branch numbers subsequently occurred. A similar pattern of secondary branch formation was apparent, plants in both W2 and W3 treatments producing 21 - 24 secondary branches. It appears that the imposition of water stress at peak flowering (W2) was not important in influencing subsequent secondary branch formation. Tertiary branch production on plants in treatments W2 and W3 was, however, affected by the duration of watering. Plants which were continuously watered (W3) continued to form tertiary branches throughout the experiment, reaching a maximum of 14 at 20 days after peak flowering. However, plants water stressed from peak flowering showed an initial capacity to produce tertiary branches but this ability 'ran out' during the later stages of seed development.

TABLE C.2.6a EFFECT OF WATER TREATMENTS ON TOTAL BRANCH NUMBERS PER PLANT

Treatment	$\frac{1}{2}V$	F.I.	HARVESTING				
			P.F.	10D	15D	20D	25D
W1	(6)	5	8	8	9	8	8
W2	(6)	(7)	(9)	39	37	32	33
W3	6	7	9	39	38	49	47
Mean	6	6	9	29	28	30	29
Significance	N.S.	N.S.	N.S.	**	**	**	**
L.S.D.	.05			5	6	6	8
	.01			9	11	11	13

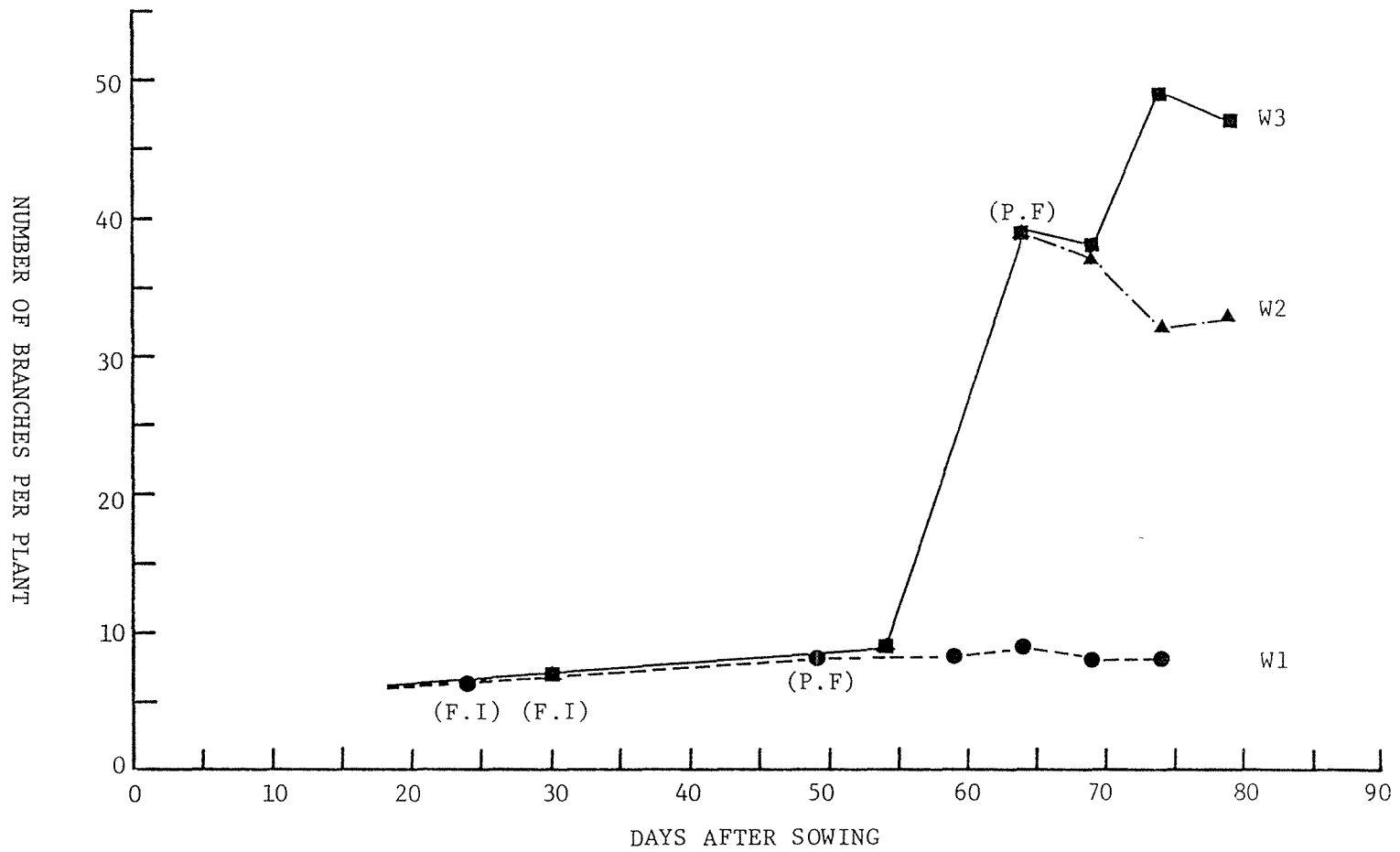


FIGURE C.2.6 EFFECT OF WATER TREATMENTS ON TOTAL BRANCH NUMBERS PER PLANT.

TABLE C.2.6b EFFECT OF WATER TREATMENTS ON PRIMARY, SECONDARY AND TERTIARY BRANCHES PER PLANT

PRIMARY BRANCH

<u>Treatment</u>	<u>½V</u>	<u>HARVESTING</u>					
		<u>F.I.</u>	<u>P.F.</u>	<u>10D</u>	<u>15D</u>	<u>20D</u>	<u>25D</u>
W1	(6)	5	6	6	7	5	6
W2	(6)	(7)	(9)	12	13	11	12
W3	6	7	9	14	12	11	13
Mean	6	6	8	11	11	9	10
Significance	N.S.	*	*	**	*	**	**
L.S.D.	.05	1	2	2	2	1	2
	.01	-	-	3	4	2	4

SECONDARY BRANCH

<u>Treatment</u>	<u>½V</u>	<u>HARVESTING</u>					
		<u>F.I.</u>	<u>P.F.</u>	<u>10D</u>	<u>15D</u>	<u>20D</u>	<u>25D</u>
W1	(0)	0	2	2	2	2	2
W2	(0)	(0)	(0)	24	22	21	22
W3	0	0	0	24	24	24	23
Mean	0	0	0.7	17	16	16	16
Significance	N.S.	N.S.	**	**	**	**	**
L.S.D.	.05		1	5	5	8	5
	.01		2	8	8	13	7

TERTIARY BRANCH

<u>Treatment</u>	<u>½V</u>	<u>HARVESTING</u>					
		<u>F.I.</u>	<u>P.F.</u>	<u>10D</u>	<u>15D</u>	<u>20D</u>	<u>25D</u>
W1	(0)	0	0	0	0	0	0
W2	(0)	(0)	(0)	4	1	1	0
W3	0	0	0	1	2	14	11
Mean	0	0	0	2	1	5	4
Significance	N.S.	N.S.	N.S.	N.S.	*	**	**
L.S.D.	.05				1	4	3
	.01				-	7	5

C.2.2.2 Seed yield and components

Seed Yield

As shown in Tables C.2.7a and C.2.7b, water stress had a most contrasting and interesting effect on seed yield with maximum production occurring where the plants were subjected to late water stress, beginning at peak flowering. By comparison, well watered plants with a continuous supply of water failed to achieve as high a level of seed production and, along with those plants stressed early (at $\frac{1}{2}$ vegetative stage), produced significantly less and similar seed yields. These effects were particularly evident at the 20 and 25 day harvests after peak flowering. These results clearly show that continuous watering throughout the experimental period, and the imposition of a water stress as early as half-way through the vegetative stage, were equally deleterious to maximum seed yield. However, when plants were provided with adequate water during the period from sowing to peak flowering and then subjected to a degree of water stress seed yield was more than doubled. In this situation a maximum seed yield of 11.94 gm/plant (equivalent to 5307 kg/ha) is extremely high by commercial standards and represents a yield approximately three times higher than that obtained in the other two treatments.

TABLE C.2.7a EFFECT OF WATER TREATMENTS ON SEED YIELD (GM/PLANT)

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	0.79	2.17	3.12	3.44
W2	1.15	3.12	7.31	11.94
W3	1.01	2.46	3.14	4.49
Mean	0.99	2.58	4.52	6.62
Significance	N.S.	N.S.	**	**
L.S.D. .05			2.44	2.99
.01			3.70	4.54

TABLE C.2.7b EFFECT OF WATER TREATMENTS ON SEED YIELD (KG/HA)

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	351	964	1387	1529
W2	511	1387	3249	5307
W3	449	1093	1395	1995
Mean	440	1147	2009	2942
Significance	N.S.	N.S.	**	**
L.S.D. .05			1084	1329
.01			1644	2017

Inflorescence Number

Water stress applied half-way through the vegetative growth of the plant and maintained for the remainder of the experiment (W1) significantly reduced the number of inflorescences (Table C.2.8a) compared with the 'better' and well watered treatments W2 and W3. The reduction in inflorescence numbers was shown to occur mainly as a result of almost complete suppression of secondary branch inflorescence production (Table C.2.8c) and to a lesser extent reduction in primary inflorescence formation (Table C.2.8c). Nevertheless, the mean main stem framework was not affected although the number of inflorescences formed on the main stem in all treatments was very low (maximum 2 - 3) (Table C.2.8b).

As can be seen from Table C.2.8c, the major contribution to high inflorescence number in the late stressed (W2) treatment came from primary and particularly secondary branches. The number of inflorescences formed on tertiary branches was insignificant irrespective of the watering treatment. From this point of view the stimulation of tertiary branches by continuous watering was a 'non-productive' feature of seed yield in Siratro.

TABLE C.2.8a EFFECT OF WATER TREATMENTS ON TOTAL INFLORESCENCE
NUMBERS PER PLANT

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	9	12	13	15
W2	30	37	37	43
W3	14	22	25	36
Mean	18	24	25	31
Significance	*	*	**	**
L.S.D. .05	12	16	8	7
.01	-	-	12	11

TABLE C.2.8b EFFECT OF WATER TREATMENTS ON INFLORESCENCE NUMBERS
ON THE MAIN STEM PER PLANT

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	3	3	3	3
W2	3	2	3	2
W3	2	1	1	2
Mean	3	2	2	2
Significance	N.S.	*	N.S.	N.S.
L.S.D. .05		1		
.01		-		

TABLE C.2.8c EFFECT OF WATER TREATMENTS ON INFLORESCENCE NUMBERS
ON THE PRIMARY, SECONDARY AND TERTIARY BRANCHES
PER PLANT

PRIMARY BRANCH

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	5	8	8	11
W2	16	21	18	19
W3	11	14	13	18
Mean	11	14	13	16
Significance	N.S.	N.S.	**	*
L.S.D. .05			4	6
.01			6	-

SECONDARY BRANCH

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	1	1	1	1
W2	11	14	16	22
W3	1	6	11	14
Mean	4	7	9	12
Significance	*	**	**	**
L.S.D. .05	8	6	5	8
.01	-	9	8	12

TERTIARY BRANCH

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	0	0	0	0
W2	0	0	0	0
W3	0	0	0	3
Mean	0	0	0	1

Pod Number

The total numbers of pods per plant and per branch order in each treatment are presented in Tables C.2.9a, C.2.9b and C.2.9c. The number of pods produced on early water stressed plants (W1) was significantly reduced at harvests 20 and 25 days after peak flowering (mean 23 - 28 pods/plant) compared with the number of pods formed on plants which had not been water stressed until peak flowering (W2) (mean 57 - 77). Surprisingly, however, the number of pods on plants which had received continuous watering was only greater than the number of pods on early stressed plants at the final harvest 25 days after peak flowering. This difference, however, was not significant. It appears that these differences in pod numbers generally reflect the influence of water stress on inflorescence numbers described previously (Table C.2.8a).

As with inflorescence number, the mean number of pods per plant was mainly affected by primary and secondary branch pod production (Table C.2.9c). Again, there was no significant difference in the number of pods formed on the main stem of each plant (4 - 10) (Table C.2.9b) or on the tertiary branches (0 - 5) (Table C.2.9c) irrespective of the watering treatment.

Early stressed plants only produced approximately half as many pods (24) on primary branches as later stressed (47) or continuously watered plants (49) (Table C.2.9c). Similarly, secondary branch pod formation in early stressed plants was almost absent (maximum 2) compared with maximum values of 48 pods in late stressed plants and 37 pods in continuously watered plants. As with inflorescence formation, secondary pod formation was less under continuous watering than under late water stress. This reinforces the previous suggestion that Siratro plants appear to benefit from a level of water stress applied in the early reproductive phase which "strengthens" reproductive development and enables the plant to express its full seeding potential.

TABLE C.2.9a EFFECT OF WATER TREATMENTS ON NUMBERS OF POD WHICH CONTRIBUTED TO SEED YIELD PER PLANT

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	7	18	23	28
W2	13	30	57	77
W3	9	23	28	42
Mean	10	24	36	49
Significance	N.S.	N.S.	**	**
L.S.D. .05			17	25
.01			26	38

TABLE C.2.9b EFFECT OF WATER TREATMENTS ON NUMBERS OF POD ON THE MAIN STEM PER PLANT

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	9	8	9	10
W2	6	7	8	6
W3	8	4	4	4
Mean	8	6	7	7
Significance	N.S.	N.S.	N.S.	N.S.

TABLE C.2.9c EFFECT OF WATER TREATMENTS ON NUMBERS OF POD ON THE
PRIMARY, SECONDARY AND TERTIARY BRANCHES PER PLANT

PRIMARY BRANCH

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	9	17	19	24
W2	33	46	46	47
W3	23	33	30	49
Mean	22	32	32	40
Significance	N.S.	N.S.	*	*
L.S.D. .05			16	16
.01			-	-

SECONDARY BRANCH

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	0.3	1	2	2
W2	19	21	39	48
W3	1	10	31	37
Mean	7	11	24	29
Significance	*	**	**	**
L.S.D. .05	14	10	11	18
.01	-	16	15	27

TERTIARY BRANCH

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	0	0	0	0
W2	0	0	0	0
W3	0	0	0	5
Mean	0	0	0	2

Number of Seeds per Pod

The different water treatments had no significant effect on the number of seeds per pod (Table C.2.10), reflecting the insensitivity of this plant component to water stress. The average seed numbers per pod remained relatively constant around 10 - 12.

TABLE C.2.10 EFFECT OF WATER TREATMENTS ON THE NUMBERS OF SEED PER POD

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	10	12	12	11
W2	12	9	11	13
W3	12	10	11	11
Mean	11	10	11	12
Significance	N.S.	N.S.	N.S.	N.S.

Seed Weight

The water treatments compared had little effect on 100 seed weight, although the benefit from a period of water stress, particularly when applied late (W2 treatment) was again observed. The average seed weight over all water treatments show that maximum seed weight was obtained from plants harvested approximately 20 days after peak flowering (Table C.2.11), at which stage there was no significant difference in seed weight between treatments. However, by the final harvest five days later, the superior weight of seeds from the W2 treatment was particularly evident. This reinforces the previously observed advantage of higher seed yield obtained from plants in this treatment.

TABLE C.2.11 EFFECT OF WATER TREATMENTS ON THE 100 SEED WEIGHT (GM)

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	1.020	1.003	1.097	1.090
W2	0.710	1.087	1.137	1.223
W3	0.900	1.057	1.047	0.960
Mean	0.877	1.049	1.093	1.091
Significance	**	N.S.	N.S.	**
L.S.D. .05	0.150			0.132
.01	0.226			0.199

C.2.2.3 Seed quality

Seed quality results are presented here in terms of seed moisture content, germination percentage (normal seedlings), hard seed content, abnormal seedling percentage and seed viability.

Moisture Content

Changes in seed moisture expressed as a percentage are presented in Table C.2.12. Water stress applied before flowering (W1) showed a significant depressing effect on seed moisture content compared with the later or non-stressed treatments. Seeds from treatment W2 show a similar level of moisture to those from the control treatment even though the former plants were placed under water stress at peak flowering.

TABLE C.2.12 EFFECT OF WATER TREATMENTS ON SEED MOISTURE CONTENT PERCENTAGE

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	46.90	51.13	41.37	40.03
W2	67.97	57.13	47.10	45.10
W3	68.03	56.80	49.00	46.90
Mean	60.97	55.02	45.82	44.01
Significance	**	N.S.	*	**
L.S.D. .05	2.12		4.76	2.10
.01	3.21		-	3.18

Germination

The germination capacity of seed measured immediately after each harvest is presented in Table C.2.13. Water treatments had no significant effect on the germination capacity of seed except at the first harvest. The percentage germination in the control and W2 treatments was lower than in treatment W1 in the first two harvests due to the different proportions of immature and mature seeds present at that stage. It was noticed that germination percentage generally increased as seeds matured. However, germination capacity of seed in treatment W1 decreased after the 15 day harvest due to an increase in hard seed content, as shown in Table C.2.14.

TABLE C.2.13 EFFECT OF WATER TREATMENTS ON GERMINATION
PERCENTAGE (NORMAL SEEDLING)

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	78.0	80.0	64.0	74.7
W2	46.7	57.0	60.7	74.3
W3	52.0	47.3	68.7	72.3
Mean	58.9	61.4	64.4	73.8
Significance	**	N.S.	N.S.	N.S.
L.S.D. .05	16.2			
.01	24.5			

Hard Seed

Water treatments had no significant effect on the percentage of hard seed at the first two harvests due to immaturity of seed (Table C.2.14). Stress applied early (W1) appeared to lift the percentage of hard seed in the later harvests, being significantly higher than in the control (W3) and W2 treatments. However, hard seed content was generally low in all treatments, reaching a maximum of only 5.3%.

TABLE C.2.14 EFFECT OF WATER TREATMENTS ON HARD SEED PERCENTAGE

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	0.0	0.0	5.3	5.3
W2	0.0	0.0	0.0	0.0
W3	0.0	0.7	0.0	0.7
Mean	0.0	0.2	1.8	2.0
Significance	N.S.	N.S.	**	**
L.S.D. .05	-	-	2.6	1.5
.01	-	-	4.0	2.3

Abnormal Seedlings

The effect of water treatments on the percentage of abnormal seedlings (Table C.2.15) was significant only at the final harvest due to the comparatively high level of abnormality in treatment W1. The relatively large but non-significant differences in seed abnormality recorded at the earlier harvest, particularly in treatments W2 and W3, disappeared as the seed matured. It is possible that the higher percentage of abnormal seedlings found in early harvests may have been due in part to physical damage occurring during depodding of young seeds for subsequent germination tests. However, it is also possible that Siratro seeds were exhibiting the commonly observed higher levels of seedling abnormality found in situations where germination tests are carried out immediately after harvest on immature seeds. The main category of seedling abnormality found in germination tests involved root damage, particularly seedlings where the primary root was unduly shortened and stunted. Weak root development or the development of roots with no root hairs was also observed (Plate C.2.4).

TABLE C.2.15 EFFECT OF WATER TREATMENTS ON ABNORMAL SEEDLING PERCENTAGE

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	6.0	10.0	4.0	8.0
W2	13.0	7.7	3.0	3.3
W3	17.3	12.7	6.3	1.7
Mean	12.2	10.1	4.4	4.3
Significance	N.S.	N.S.	N.S.	*
L.S.D.	.05			4.4
	.01			-



(a) NORMAL SEEDLINGS



(b) ABNORMAL SEEDLINGS

SPLIT HYPOCOTYL, PRIMARY ROOT BROWN IN
COLOUR, TWISTED EPICOTYL.

PLATE C.2.4 NORMAL AND ABNORMAL SEEDLINGS FOUND IN
GERMINATION TESTS.

Viability

The data presented in Table C.2.16 refers to the percentage of viable i.e. live seed, including hard seed and fresh ungerminated seed, recorded in each treatment. Seed viability tended to depend on the level and time of maturity of the seed in the different treatments, with later stressed plants (W2) appearing to reflect a later maximum seed viability level than those in the other treatments.

TABLE C.2.16 EFFECT OF WATER TREATMENTS ON SEED VIABILITY PERCENTAGE

<u>Treatment</u>	<u>HARVESTING</u>			
	<u>Days after peak flowering</u>			
	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>
W1	90.0	93.3	80.0	94.7
W2	72.0	75.7	89.3	92.3
W3	92.0	88.7	87.7	83.0
Mean	84.7	85.9	85.7	90.0
Significance	*	*	N.S.	N.S.
L.S.D.	.05	15.5	10.6	
	.01	-	-	

C.2.3 DISCUSSION

EFFECT OF WATER STRESS ON VEGETATIVE GROWTH

The importance of an adequate supply of soil moisture for maximum plant growth was clearly highlighted in this experiment. Plants in the well-watered control treatment (W3) continued to increase in dry weight at a relatively high rate right up to final harvest, although there was the suggestion that growth rate was beginning to decline in the last week. The same response was reflected in the number of green leaves per plant, leaf area per plant and branch numbers, although these components declined increasingly in their rate of development during the late reproductive stages approaching the final harvest. In contrast, the early restriction of soil moisture (W1) led to a severe reduction in plant growth indicating that Siratro is highly sensitive to water stress applied early in its life, as reported by Ludlow (1980) and Ahmed and Quilt (1980). Such plants struggled throughout the entire experimental period with little chance to develop and support any real number of green leaves, a worthwhile area of leaf or adequate numbers of branches, as also reported by Gates (1955b); Salter and Goode (1967); Boyer and McPherson (1975) and others.

Plants receiving adequate water up to peak flowering (W2) continued to increase in dry weight for some 10 - 15 days after the water restriction was imposed before showing any marked reduction in growth rate. However, leaf number and leaf area were much more sensitive to water restriction and were affected almost immediately. Such responses were also reported in the same species by Peake *et al* (1975). Branching, on the other hand, was much less sensitive to late water stress and developed dramatically in number over the 10 days following peak flowering before presumably suffering the effects of stress. The reduction in branch numbers recorded over the last two weeks was due to the 'death' of a significant number of very small tertiary branches as indicated in Table C.2.6b.

EFFECT OF WATER STRESS ON REPRODUCTIVE GROWTH

The importance of adequate soil moisture in determining seed yield was again clearly evident. When plants were subjected to water stress early in their life (W1 treatment) seed yields were severely depressed, by some 23%, compared with plants well watered throughout their life span (W3) or, by some 72%, when compared with plants well watered through to peak flowering. The effects of water stress on seed yield were expressed mainly through the number of inflorescences and the number of pods produced per plant. However, it is interesting that surprisingly good yields of seed were obtained from such small and highly stressed plants (W1) which must have been highly efficient in their productive processes. Such efficiency probably resulted from the plant's capacity to survive by shedding old leaves which effectively reduced the total demand for water, enabling some available water to be conserved for limited growth and seed development. The reproductive tissues seemed to compete effectively for available assimilates and then showed less sensitivity to water stress during seed filling than during the vegetative phase as suggested by Hsiao and Acevedo (1974).

Of even greater interest and significance was the very high seed yield obtained from plants subjected to late water stress. At the final harvest the W2 plants produced 3 folds more than the well watered control plants. This reflected the importance of providing appropriate environmental conditions favouring reproductive development. Such an effect was largely due to an increase in the number of inflorescences and number of pods formed particularly on the secondary branches and to a lesser extent on primary branches in the late stressed plants. As expected, plants well watered throughout their life span (W3) produced a vigorous vegetative frame, but did not produce a higher seed yield when compared with plants in the W2 treatment and only 23% higher than plants in the W1 treatment at the final harvest. This effect was probably due to the competition for assimilates between the vegetative and reproductive components as also reported by Herbert and Hill (1978b) and Kattan and Fleming (1956). The number of seeds per pod was relatively unaffected by water

treatments, reflecting their insensitivity to water stress, while seed weight appeared to be slightly advantaged by moisture stress.

As expected, moisture content was lowest in those seeds from plants under early water stress but little affected under late water stress, compared with those from the well-watered control. Early water stress also induced a recordable level of hard-seededness, while none of the water treatments had any serious or lasting effect on seed germination or seed viability. Seedling abnormalities were, however, quite apparent from seed taken from the early stressed plants at the final harvest.

The results of this experiment clearly show the importance of correct sowing date in relation to local rainfall pattern in determining both the vegetative and seed yield of Siratro. Certainly they suggest that a sowing date which provides adequate rainfall or irrigation to allow the production of a well grown plant with high leaf and branch numbers is important. Subsequently however, a period of water stress is advantageous in stimulating a large number of inflorescences and hence a large number of pods and thereby achieving a high seed yield.

C.3 EFFECT OF WATER STRESS ON SIRATRO SEED DEVELOPMENT

C.3.1 MATERIALS AND METHODS

The environmental conditions and water treatments for seed development study are the same as previously described in C.2.1.

Newly-opened flowers were labelled every alternate day on six plants in each treatment. This labelling continued until the first sign of pod shattering. At this point, plants were harvested and labelled pods were separated into different age groups (days from labelling). In this way seeds of known age were obtained. Some seeds were used to determine the changes in various seed development components, viz

average seed fresh weight, average seed dry weight, seed moisture content and germination percentage.

C.3.2 RESULTS

Results showing the effects of water stress on physiological changes during seed development are presented in terms of moisture content, seed weight, germination capacity and seed and pod colour changes. These physiological changes will be considered under two headings which describe the major stages occurring during seed development as reported by Mullett (1981), viz the 'growth and food reserve accumulation stage' and the 'maturation or ripening stage'.

Growth and Food Reserve Accumulation Stage

This first phase of Siratro seed development lasted for 16 - 18 days after anthesis in the water treatment (Figure C.3.1). The growth of the seed in terms of fresh weight increased rapidly and reached a maximum at 18 and 16 days after anthesis in the control treatment W3 and stressed treatments (W1 and W2) respectively. Mean moisture content of seed in each treatment remained relatively high (77 - 85%) initially and declined only slowly to around 60% by the end of the phase (Appendix Table 4). The accumulation of food reserves, as reflected in seed dry weight, increased rapidly over the stage and almost to a maximum by 16 - 18 days after anthesis in treatments W1 and W2. However, in the well watered treatment (W3), food reserves continued to increase appreciably beyond this so-called growth and food accumulation stage to a maximum at 22 days after anthesis.

Seed harvested prior to 12 - 14 days after anthesis were immature and incapable of producing well developed normal seedlings although a measure of seed viability was evident two days earlier (Figure C.3.2). Seed harvested 12 - 14 days post-anthesis showed a rapid increase in germination capacity with time, presumably as food reserves increased. Onset of seed viability and germination capacity commenced earlier in

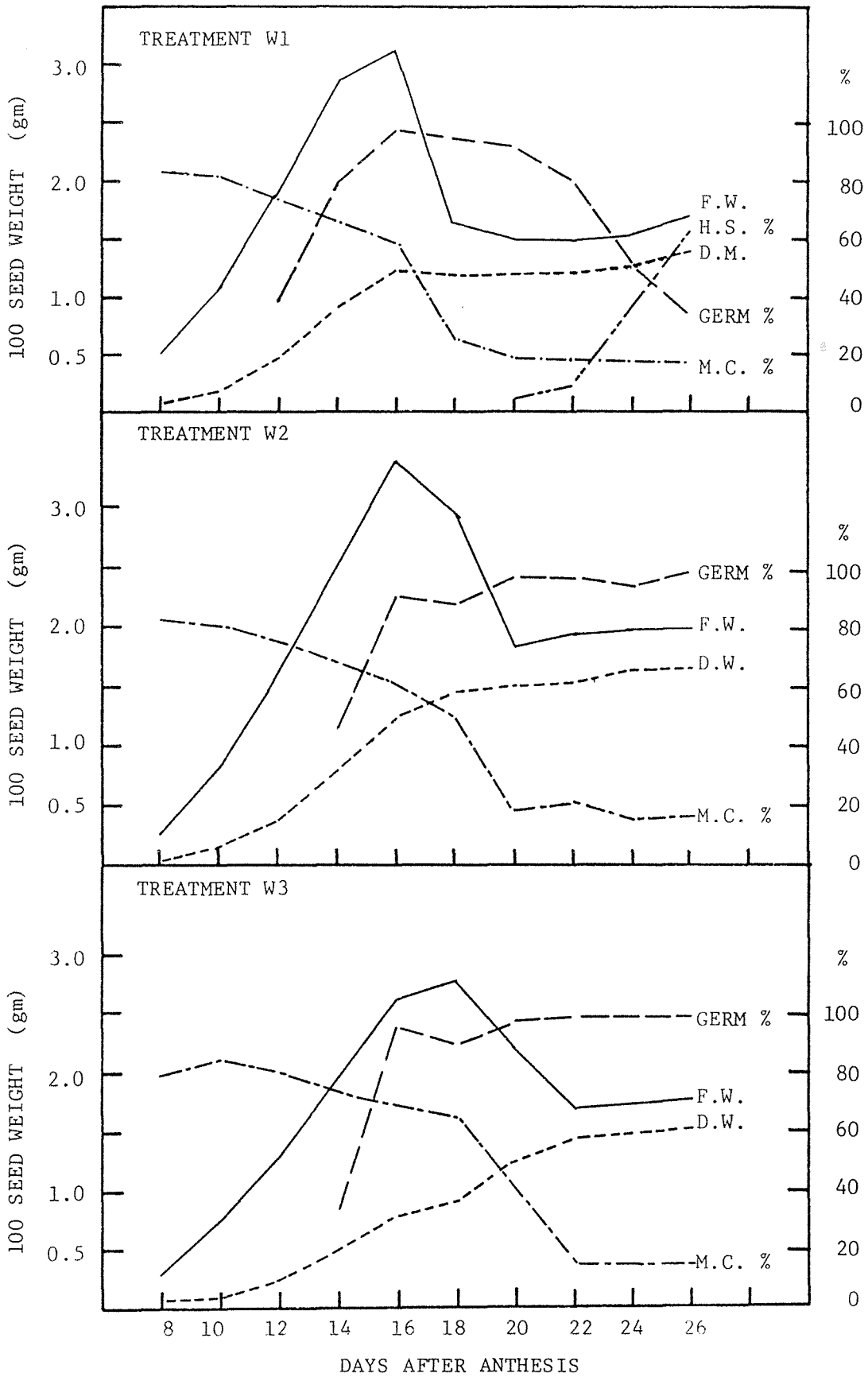


FIGURE C.3.1 EFFECT OF WATER TREATMENTS ON CHANGES IN PHYSIOLOGICAL COMPONENTS DURING SEED DEVELOPMENT OF SIRATRO

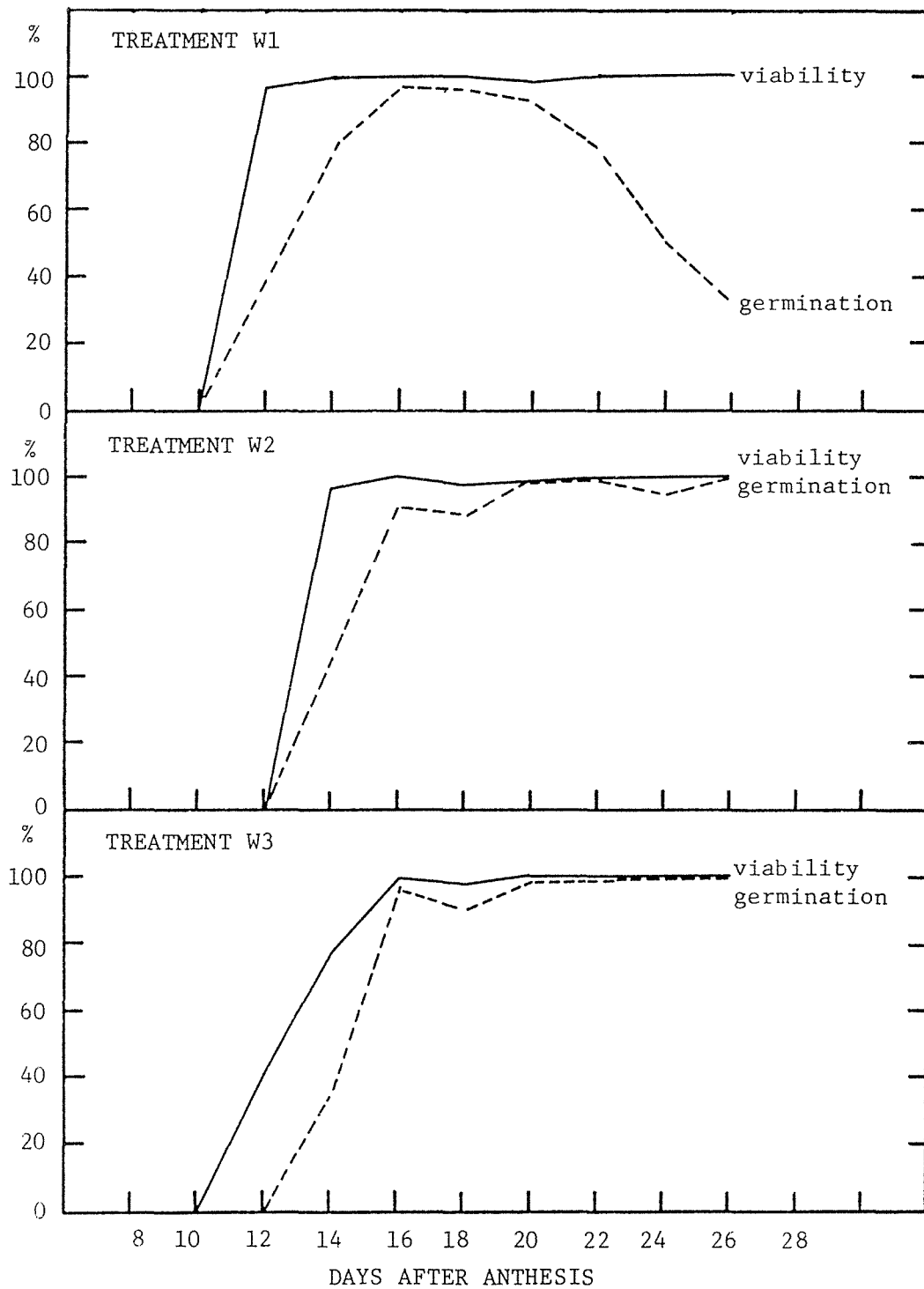


FIGURE C.3.2

EFFECT OF WATER TREATMENTS ON PERCENTAGE OF GERMINATION (NORMAL SEEDLINGS) AND SEED VIABILITY.

treatment W1 than in the better-watered treatments W2 and W3.

The rate of pod elongation was also impressive during this stage, as illustrated in Plates C.3.1, C.3.2 and C.3.3. The size of pods at two days and at 10 days for example, showed an approximate 5-fold increase. The colour of the seed and pod during this stage was mainly green, only changing to a dark brown at approximately 18 days (± 2 days) after anthesis. This colour change appears to coincide with the end of the growth stage of seed development.

Maturation or Ripening Stage

The fresh weight of seed declined sharply during the early part of this stage due to the associated loss of moisture, as shown in Figure C.3.1. The length of this initial decline varied from approximately two to four days and appeared to reflect the soil moisture regime of each treatment. Thereafter, fresh weight and moisture content remained relatively constant to the final harvest in all treatments.

Seed dry weight, on the other hand, showed little change over the ripening period once the initial and sharp decline in fresh weight occurred, although there tended to be a small but gradual increase to the final harvest.

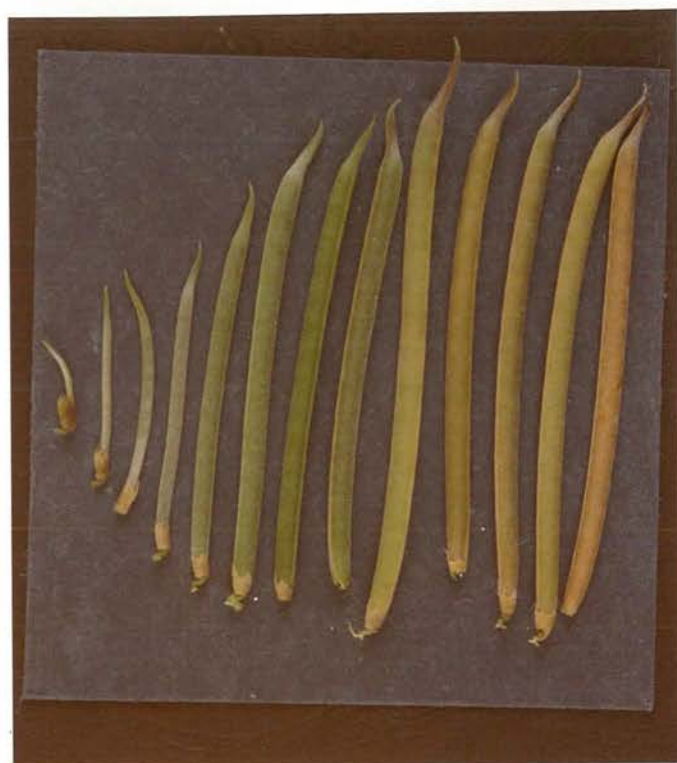
Seed germination remained relatively high and constant in the better-watered treatments W3 and W2 but showed a significant decline in seeds from plants grown under a long period of water stress (W1). This was due to a significant increase in the percentage of hard seeds in the latter treatment, reaching as high as 63% by the final harvest (Appendix Table 9). Along with germination, seed viability increased to a maximum 14 - 16 days after anthesis in late stressed and continuously watered plants (W2 and W3). However, early stressed plants (W1) reached maximum seed viability two days earlier. No significant increase in pod length occurred during this stage. At the final harvest most pods had already turned brown in colour, and seed coats were mainly dark brown or black (Plates C.3.1 - C.3.6).



DAYS AFTER ANTHESIS AT 2 DAY INTERVALS

2 DAYS —————> 26 DAYS

PLATE C.3.1 CHANGES IN POD SIZE AND COLOUR DURING
DIFFERENT STAGES OF SEED DEVELOPMENT
IN TREATMENT W1.



DAYS AFTER ANTHESIS AT 2 DAY INTERVALS

2 DAYS —————> 26 DAYS

PLATE C.3.2 CHANGES IN POD SIZE AND COLOUR
DURING DIFFERENT STAGES OF
SEED DEVELOPMENT IN TREATMENT
W2.



DAYS AFTER ANTHESIS AT 2 DAY INTERVALS

2 DAYS —————> 22 DAYS

PLATE C.3.3 CHANGES IN POD SIZE AND COLOUR
DURING DIFFERENT STAGES OF
SEED DEVELOPMENT IN TREATMENT
W3 (CONTROL).



8 DAYS	10 DAYS	12 DAYS	
14 DAYS	16 DAYS	18 DAYS	
20 DAYS	22 DAYS	24 DAYS	26 DAYS

AFTER ANTHESIS

PLATE C.3.4 CHANGES IN SEED SIZE AND COLOUR
DURING DIFFERENT STAGES OF SEED
DEVELOPMENT IN TREATMENT W1.



4 DAYS 6 DAYS 8 DAYS 10 DAYS
 12 DAYS 14 DAYS 16 DAYS
 18 DAYS 20 DAYS 22 DAYS 24 DAYS 26 DAYS
 AFTER ANTHESIS

PLATE C.3.5

CHANGES IN SEED SIZE AND COLOUR
 DURING DIFFERENT STAGES OF SEED
 DEVELOPMENT IN TREATMENT W2.



8 DAYS 10 DAYS 12 DAYS 14 DAYS
 16 DAYS 18 DAYS 20 DAYS 22 DAYS
 24 DAYS 26 DAYS
 AFTER ANTHESIS

PLATE C.3.6 CHANGES IN SEED SIZE AND COLOUR
 DURING DIFFERENT STAGES OF SEED
 DEVELOPMENT IN TREATMENT W3
 (CONTROL).

No seed shattering occurred in this experiment, presumably because of the high relative humidity levels in the experimental room (70/90% day/night).

C.3.3 DISCUSSION

Seed development occurred in two relatively distinct phases. During the first phase, the transport and accumulation of food reserves from the parent plant into the seed was most evident particularly over the last four to five days, as reflected in seed dry weight increases. This build-up, however, was slower in seeds from the well-watered plants (W3) suggesting that intra-plant competition for assimilates between plant growth and seed development continued to occur over this phase. This suggestion is supported by the increase in plant dry weight recorded in treatment W3 which continued right through both seed development phases to final harvest. By comparison, plant dry weight increase in treatments W1 and W2 virtually ceased 10 to 15 days after peak flowering, thereby possibly reducing competition and allowing more rapid accumulation of food reserves into the seed. In other words, water stress, by restricting plant growth, appeared to hasten the transfer and accumulation of food reserves from parent plant to seed, as also reported by Robins and Domingo (1956) and Sinha (1977). However, this water restriction, when applied early (W1) did result in lighter 'pinched' seed (Appendix Table 6) at later harvests, whereas later water stress (W2) favoured seed development and resulted in heavier seed weight. Seed fresh weight increased even more rapidly and reached a maximum two to four days before maximum dry weight. In contrast, the initially high moisture content declined steadily during this phase from approximately 80 to 60%. Seed germination, which commenced early in the first stage increased sharply and reached a maximum at physiological maturity, as stated by Shaw and Loomis (1950). As found by other workers (Anon, 1976a), germination percentage subsequently declined in plants subjected to extended water stress (W1) due to the onset of hard-seededness. Seed viability also increased with great rapidity in all treatments, a period of only two to four days being required between the detection

of the first viable seeds and maximum viability (Figure C.3.2). The level of seed viability seemed to be associated with the level of food reserves in the seed as reported by Hyde (1950).

The rate of pod elongation was most striking during this stage and similar to that reported in beans (*Phaseolus vulgaris* L.) by Loewenberg (1955). However, pod elongation ceased about 12 days after anthesis, but the enlargement of the pods due mainly to the increase in seed size continued until the seeds reached physiological maturity. Pod colour changes, which are an indication of approaching maturity, (Gbikpi *et al*, 1981) occurred more slowly under wet conditions (treatment W3) as also reported by Goodwin and Siddique (1977). However, this change in pod colour, from green to brown, occurred at about physiological maturity in all treatments.

The second phase of seed maturation and ripening was characterised by a rapid loss of fresh weight due to drying of the seed. In this experiment the commencement of this phase varied by only two days between the well-watered plants and the stressed plants viz 18 and 16 days, and appeared to reflect the watering regime of each treatment. Following this sharp drop in fresh weight (over 2 - 4 days) there was only a slight increase in fresh and dry weight recorded subsequently due to the continuing deposition of food reserves beyond the time of seed enlargement as reported by Harrington (1972) and Pollock and Roos (1972).

It is also apparent from the experiment that when Siratro plants are subjected to water stress over an extended period and under relatively high temperatures, there is a marked increase in the level of hard seededness produced. The critical question is why this was so striking in seeds from early stressed plants and totally absent in seeds from non-stressed or late stressed plants. Apparently, the conditions inducing such a reaction in seeds of the tropical forage legume Siratro are quite different from those for seeds of the temperate legumes (Aitken, 1939; Quinlivan, 1971; Hyde, 1954). In this experiment even though there was only a difference between treatments

of two to four days in the time taken for seed to reach physiological maturity, such a short time difference may have had a critical effect on the development of an impermeable seed coat. This earlier maturity (W1) was followed immediately by a very rapid loss of moisture in the seed over two days, compared with a more gradual decline in the other treatments (W2 and W3) and resulted in an impermeability of the seed coat. This impermeability may have been induced by the formation of cutin and suberin in the walls of the malpighian cells (Win Pe, 1978), thereby causing a marked increase in hard seededness. On the other hand, the degree of seed dehydration seemed to play a role in hard seed formation in this treatment (W1) as also reported by Bewley and Black (1982). After the sharp initial drop in seed moisture content during seed ripening, the moisture level then remained relatively high, at 17 - 18%, during the period when the rapid increase in hard seededness occurred. This was certainly above the figure of 14% referred to by Hyde (1954) as being critical for the onset of hard seed formation in white clover. Hard seed development in *Siratro* appears, therefore, to occur at higher seed moisture levels and does not appear to be as closely related to seed moisture content as suggested by the finding of Hyde (1954) for the temperate legume white clover.

It was noticed that only 5% hard seed occurred in seed samples harvested from early stressed plants (W1) in the previous experiment (Table C.2.14). However, in this subsequent seed development study seeds of the same age, when harvested from early stressed plants, showed a much higher (63%) hard seed content (Appendix Table 9). It is likely that these differences reflected the wide range of seed development categories harvested in samples taken from plants in 'per plant' harvests containing immature, mature and ripe seeds - and hence a low mean hard seed content. By comparison, seeds removed from plants in the seed development study were of the same known age. As a result only ripe seeds were obtained in seed samples taken during the later stages of seed development - with a consequently higher mean hard seed content.

* * * * *

SECTION D : GENERAL DISCUSSION AND CONCLUSION

"Siratro" is a relatively new and promising tropical forage legume in Thailand and the information obtained in the present studies is intended to be of agronomic and hopefully even of economic value since detailed work on seed production, particularly in relation to plant spacing and soil moisture stress, has previously been limited.

In the field experiment conducted during the dry season in Thailand, the response to irrigation was disappointing. However, it must be remembered that the actual irrigation treatment only 'spanned' a period of 30 days (i.e. between the period 30 days after sowing to peak flowering when the treatment ceased). Such a limited period of time was apparently insufficient to enable the plant to benefit fully or show any major vegetative and size advantage from such additional water until the final harvest. An inadequacy in the theoretical basis for irrigation, as mentioned earlier, cannot be discounted. Nevertheless, the significant and beneficial effect of irrigation on plants when sown at high population densities was clearly apparent in terms of both dry weight and seed yield.

In contrast, the effect of plant population density on plant structure and seed yield was striking. In both field experiments dry weight and leaf area per plant were consistently reduced as density increased. However, when converted to a unit area basis these parameters showed a positive response to increasing plant density particularly at the high populations. The exception to this generalisation is seen in the data on LAI in the wet season experiment. At and beyond the floral initiation stage the continuing growth and development of the wider spaced plants over an extended period of time and the substantial pressure of plant competition causing a noticeable drop in LAI in the closely spaced stands, resulted in a significant narrowing of the differences between low and high plant densities. By the final harvest, 40 days after peak flowering both plant weight and LAI had generally declined and differences between plant densities remained relatively small.

It is interesting to note that maximum LAI tended to be reached earlier at the higher plant densities and later at the lower plant densities indicating earlier competitive stress occurring at the higher plant densities. This effect can also be seen in the dry weight and leaf area per plant data, and has been reported by Herbert and Hill (1978a) in lupin, Ishag (1973b) in *Vicia faba* L. and Sinha (1977) in *Phaseolus vulgaris*. These researchers also mentioned that the addition of dry matter after flowering is often insignificant and that most of the 'growth' (photosynthate) produced after this stage is directed mainly towards the developing pods and seeds.

Although seed yield per plant declined significantly with increasing plant density, the dominating effect of sheer weight of numbers at the high densities meant that seed yield per hectare was positively related to plant density. While the typical parabolic relationship between seed production and plant density as established by Holliday (1960) was not clearly evident, it was nevertheless suggested at the point of maximum seed yield 30 days after peak flowering in the wet season experiment. At that stage maximum seed production was achieved at the 15 x 15 cm spacing - although it is recognised that production from the 10 x 10 cm spacing was not significantly lower.

When total seed yield was examined in terms of its components, it was found that 98% of total seed yield was contributed by pod numbers and only 2% by numbers of seeds per pod and seed weight. These results support those previously reported by Duarte and Adams (1972) who showed that changes in plant population density had their main effect on numbers of pods by changing the structure of the plant. Such structural changes, however, had relatively minor effects on seed weight or seed numbers per pod. Similar effects have also been reported by a number of researchers (Hodgson and Blackman, 1956; Leakey, 1972; Crothers and Westermann, 1976). Although the counting of branch numbers was not carried out in the field study, observations indicated that plants from wide spacings had more branches and more leaves than close-spaced plants. Such differences in plant structure presumably reflected differences in the number of potential sites for

reproductive development in terms of numbers of inflorescences and pods per plant.

It was found that seed quality depended on the level of seed maturity, as also reported by Hyde (1950), rather than on changes in plant population density. It is interesting to note that hard seed content from plants grown at close spacings was lower than the hard seed content from plants grown at wider spacings. Aitken (1939) reported similar results in the temperate forage legume (*Trifolium subterraneum*) and hypothesised that the more favourable environment for the plants resulted in a longer maturity period and caused thickening of the suberin layer of the seedcoat - hence an increase in the percentage of hard seed.

CONTROLLED ENVIRONMENT

The results from the controlled environment study clearly showed the response of Siratro plants to water stress. Both vegetative and reproductive yield were affected when plants were subjected to a water deficit at different stages of growth.

Adequate water throughout the plant's life cycle (W3) stimulated vigorous vegetative growth in terms of dry matter, number of green leaves and number of branches. These structures, however, were all severely depressed in plants subjected to early water stress (W1). It was noticed that in plants in the control treatment (W3) and in treatment (W2), where plants were subjected to water stress only following peak flowering, branch numbers increased rapidly after peak flowering. Hopkinson and Loch (1973) and Hopkinson (1977) explained that at the base of each primary axillary shoot, which may be vegetative or reproductive, there are two secondary vegetative buds which provide a reservoir of new vegetative shoots. In the event of primary shoot failure one of these shoots becomes floral.

The early restriction of soil moisture (W1) led to a severe reduction in plant growth. This emphasises the fact that Siratro is very

sensitive to water stress as also claimed by Ludlow (1980) and Ludlow *et al* (1983). The more susceptible parts of the plant to stress were not only the number of branches but also the number of leaves and leaf area as shown by Peake *et al* (1975). According to Withers (1979), the reduction in leaf number as a result of leaf-shedding is a morphological mechanism used by the plant to reduce evapotranspiration and thereby reduce water use by the plant.

The most striking effect of water deficit was on reproductive development. The massive vegetative growth accumulated through the life cycle of plants receiving ample moisture does not necessarily give a correspondingly high seed yield when compared with plants receiving a water stress from peak flowering (W2). It was also reported by some researchers that maximum seed yield cannot be achieved from plants which receive adequate water throughout their life cycle (Kattan and Fleming, 1956; Salter, 1962, 1963). Seed yield from the well-watered treatment (W3) was only 23% higher than from early stressed plants (W1) and was 72% less than that obtained in late-stressed plants (W2) at the final harvest. This evidence suggests that some stress during the early stages of reproductive growth, despite the fact that it reduces plant size, may in fact increase seed yield probably because of less competition from the vegetative parts (Salter, 1962; Salter and Goode, 1967). The highest seed yield obtained from plants in treatment W2 suggested that water stress tended to control the balance between vegetative and reproductive growth. Relatively mild stress levels appear to reduce vegetative growth and promote reproductive growth as also reported in lupin by Farrington (1976). Withers (1979) commented that when vegetative growth was restricted by water stress there was, apparently, a release of assimilates for increased reproductive growth. Nevertheless, it is important that the plant has the opportunity to develop an adequate vegetative framework before its growth is checked. This suggestion is based on the belief that such a vegetative framework is essential in order to provide numerous reproductive sites which can result in a higher number of inflorescences and in turn higher pod numbers. In this respect the importance of enabling the plant

to develop an adequate complement of primary and secondary branches and thereby providing a maximum number of inflorescences and pods is clearly evident from the data if maximum seed yield is to be achieved. It also contrasts sharply with the relatively minor contribution to seed yield that appears to come from the main stem and tertiary branches. As found earlier in the field experiment, the other two major seed components (number of seeds per pod and seed weight) were unaffected by water stress.

Increases in the number of inflorescences in Siratro plants subjected to some degree of water stress, or when growth is checked, have also been reported by Hopkinson (1977), Edey and Byth (1970) and Hutton (1970). Although the precise point at which this stress operates is not fully known, Hopkinson (1977) mentioned that both water stress and growth retardants may stimulate the development of already existing inflorescence buds which were presumably otherwise suppressed until they aborted. Humphreys (1981) also commented that an antagonism exists between vegetative and reproductive development. Apparently the suppression of vegetative growth by water stress may favour the subsequent expansion of floral buds and the distribution of assimilates to developing inflorescences. On the other hand, because floral induction in plants is also governed by plant hormones, it is possible that changes in the level of plant hormones occurring in plants subjected to water stress could affect the promotion of inflorescence buds. Hsiao (1973), for example, has reported that abscisic acid levels dramatically accumulate in plants during stress. This growth regulator, in high concentrations, can induce flowering in some short day plants (Evans, 1969) or promote the level of flowering if plants have already been slightly induced (Salisbury and Ross, 1978). Since Siratro is claimed to be a quantitative short day plant (Hutton, 1962), it is possible that water stress may induce higher levels of plant hormones which in turn may promote the level of flowering and finally the seed yield.

Again, the results from the controlled environment study showed the unresponsiveness of seed quality to water stress. Hard seed levels,

however, were found to be significantly higher in early stressed plants (W1) than in plants which were well watered (W3) or received late water stress (W2). The variable levels of seedling abnormality occurring in this study may have been due, in part, to physical damage occurring during the depodding of young seeds for germination tests.

EFFECT ON SEED DEVELOPMENT

The development of Siratro seeds followed a similar pattern to that reported by Mullett (1981) which appears to be more appropriate for this tropical legume than Hyde's (1950) description for the temperate legumes white and red clovers. Water stress, particularly severe stress, reduced the time between anthesis and maturity. This effect was clearly seen in treatment W1 and is also supported by work by Clarkson and Russell (1976). According to Mullett (1981), the first phase of seed development, which involves a rapid increase in dry weight, seems to be prolonged by adequate water as shown in treatment (W3). Moisture stress situations, however, have an opposite effect which was clearly demonstrated in treatments W1 and W2. The most striking effect of water stress on seed development was on hard seed formation which was recorded only in treatment W1. The development of hard seed has been reported to depend on various factors, including the function of the hilum (Hyde, 1954), seed maturity (Hyde, 1950; Quinlivan, 1971), genetic factors (Barton, 1965) or environmental conditions, particularly during seed maturation and ripening (Barton, 1965). The work of Aitken (1939) and Quinlivan (1965, 1966) on subterranean clover, has indicated that the degree of hard-seededness is influenced by genotype, by conditions during the growing season and by the temperature conditions to which the ripening seed is subjected. However, Taylor and Palmer (1979) could not demonstrate any effect of water stress on the level of hard seed in subterranean clover. Also, the work of Argel and Humphreys (1983a, b) on the tropical legume, *Stylosanthes hamata* has shown that hard-seededness develops most strongly at high temperatures while water stress had only a transitory and inconsistent effect on hard-seededness.

Although a significant percentage of hard seed was found in the early stress treatment (W1) in the controlled environment study no hard seed was recorded in the other treatments. It is possible that the high temperature prevailing in the growth room, combined with water stress applied early in the plant's development and low relative humidity, increased the rate of seed dehydration during the ripening phase. These factors, along with the period during which seeds were allowed to dry on the plant, resulted in an increase in seedcoat impermeability as also explained by Aitken (1939) and reported by Bewley and Black (1982).

Hopkinson and Loch (1973) stated that annual seed production of Siratro in Australia seldom exceeds 500 kg/ha although seed yields of up to 3,000 kg/ha can occasionally occur under optimum conditions. The seed yield obtained from plants grown in the controlled environment experiment indicated that Siratro has the potential to produce up to 5,300 kg/ha of seed under ideal conditions. The differences in maximum seed yield between the controlled environment trial and the field trial in each water treatment were large and were probably due to three main factors. Firstly, environmental variations in the field, such as the changing microclimate and availability of plant nutrients and soil moisture, results in plants in the field being grown under conditions which are changing continually. By comparison, in the controlled environment of the growth room, these factors are relatively stable and uniform. Secondly, the large differences in competition and its effects - between the community of plants in the field and the single plant in the growth room. And thirdly, the potential and often real problems of pests and diseases in the field compared with the virtually complete control of these factors in a controlled environment. Certainly in the field experiments, in both dry and wet seasons, insect infestation was a problem affecting Siratro seed production. Starting from seedling establishment, Siratro was attacked by bean fly. During floral initiation, flowering and pod setting, insects, particularly *Lampides boetricus* Linn, caused damage to buds, flowers, young pods and even mature pods. And although leaf blight disease (*Rhizoctonia solani*) did not occur in

the field experiments, it has been reported to cause severe damage to Siratro, particularly under high rainfall. Therefore in order to achieve high seed yield in the field, an effective insect and disease control programme is essential.

Since Siratro is an indeterminate plant it is common to find flowers, buds, pods and even shattered seed pods all on the same peduncle. This uneven flowering causes difficulty in harvesting. It was clearly shown from the present experiment that harvesting either too early or too late can reduce the opportunity to recover those high seed yields. Low seed quality (particularly low seed weight) was the main problem when seeds were harvested too early, while loss of seed number due to shattering occurred when the harvest was too late. Hopkinson and Loch (1973) have reported 500 to 1,000 kg/ha of good quality seed being lost through shattering in commercial Siratro seed crops in Australia. To minimise these losses Siratro, if planted in the dry season, should be harvested approximately 20 days after peak flowering. However, if the crop is sown in the wet season, harvesting can be delayed until 30 days after peak flowering without loss of seed due to shattering.

CONCLUSIONS AND RECOMMENDATIONS

The findings from this study suggest that Siratro seed production could well be a viable commercial proposition in areas where an appropriate change from adequate moisture availability to moisture stress conditions can be achieved by controlled irrigation or by natural changes in the rainfall pattern. Certainly many tropical areas meet this latter requirement, the North-east region of Thailand being one example. According to climatic records (Appendix Figure 2), this area has a normal wet season from May to October, ensuring excellent early growth and development, followed by a reliable dry period from November to March, with cool nights and sunny days, providing an opportunity for timely water stress and good subsequent harvesting conditions. Such a climate appears well suited to high seed production of Siratro and possibly other pasture legumes. The results in the present study also suggest some general recommendations

for maximising Siratro seed production in the North-east region of Thailand.

In order to achieve reliable high seed yields, good management in such areas as seedbed preparation, appropriate fertilizer application, weed control, correct inoculant and an effective plant protection programme needs to be considered. Also, since Siratro can have a relatively high percentage of hard seed (40 - 70%), seed scarification is generally necessary to ensure good establishment. Seed scarification treatments using sand paper or soaking in hot water at 80°C for 10 minutes are effective, safe and inexpensive.

Time of planting can be manipulated using the results from this study and also local climatic records. Two general options seem most promising, these options being ranked as follows to fit the necessary agronomic and economic situation in Thailand.

Option 1: Siratro can be planted towards the end of the wet season (say early October). This sowing time can be used whether irrigation is available or not. In the former case, irrigation can be applied, if necessary, from the beginning of the natural dry season but should be stopped at peak flowering. By this method maximum seed yields can be achieved. In areas where irrigation is not possible, it is likely that there will still be sufficient moisture (from rainfall and soil storage) for plant growth during at least the first month after sowing before the season becomes completely dry. Such an option fits well from an agronomic point of view and also possibly from an economic point of view as it does not conflict for time or labour with the production of main season crops (e.g. rice), planted at the beginning of the wet season. Therefore planting Siratro towards the end of the wet season, as mentioned, would not only contribute jobs for local labour but might also help to check the local labour drift to the cities, in the 'off'

season. In addition, it would assist farmers by increasing their income relative to that normally derived from less profitable alternatives such as cassava and corn.

Option 2: Siratro could be planted at the beginning of the wet season (May). However, very intensive crop husbandry will be required because under this planting system Siratro plants will be subjected to a long vegetative growth period which, coupled with a high temperature and high humidity environment, can stimulate the spread of diseases, insects and weeds. In the field experiment described in the present study, seed yield was 11% less than in Option 1 with irrigation. However, because of the massive size of the vegetative plants, farmers can cut Siratro during the vegetative stage and use the herbage for animal feeding, particularly at the end of the wet season when critical feed shortages commonly arise.

This option does not quite fit from an economic point of view since there is a labour conflict with main season crops such as rice.

It has been shown from the controlled environment experiment that the production of a large vegetative plant, before growth is checked due to water stress, can allow the formation of numerous reproductive sites and lead to high seed yields. It is therefore likely that if Siratro could be planted later in the wet season, for example in July, sufficient water would be available during the remaining rainy season to allow Siratro plants to produce a vigorous, strong, branching framework to support a potentially high seed yield. Certainly, this suggestion better fits the agronomic and economic conditions prevailing in Thailand and could also be used as an insurance against

main crop (rice) failure.

Hand harvesting is the best way to harvest Siratro, particularly in areas where local labour is not expensive and freely available. The advantage of this method is in the high seed quality which is usually obtained since only matured or ripened seed pods will be harvested. The disadvantage of this method is that it is very time consuming.

It is not easy to convince Thai farmers, who are familiar with the planting of rice or other field crops, to change their attitudes towards the growing of forage legume crops. This situation occurs simply because rice is the staple diet for Thai people and also because the marketing of traditional field crops such as corn, soybean, mungbean and cassava is a more familiar practice and relatively stable. These two factors give farmers confidence to grow field crops rather than forage crops. In addition, forage crop seed production is quite new to most Thai farmers in terms of both crop agronomy and marketing. However, it has been reported that Siratro seed can be sold at up to 350* baht/kg (approximately US\$15) while the export price for rice is only 5 baht/kg (US\$0.22). This suggests that Siratro seed crops provide a good opportunity for farmers to increase their incomes by setting aside some areas of their farms which might be unsuitable for growing rice to grow Siratro for seed as an alternative to cassava or kenaf. Siratro could also be grown as a 'catch' crop as an insurance against main crop (rice) failure.

The future attitude of Thai farmers to the growing of legume seed crops generally, and Siratro in particular, may depend strongly on the technical support they receive from researchers and marketing experts. Such support would go a long way towards developing farmers confidence and to counteract the increasing problem of rural poverty, particularly in less developed rural areas such as the North-east region of Thailand.

* *Export price March 1980 (Arthur Yates & Co., Ltd) 23 baht = US\$1.*

BIBLIOGRAPHY

- ADAMS, M.W. 1967: Basis of yield component compensation in crop plants with special reference to the field bean, *Phaseolus vulgaris*.
Crop Sci. 7 : 505 - 510.
- ADAMS, M.W. 1975: Plant architecture and yield in the grain legumes. Report of the T.A.C. Working Group on the Biology of Yield of Grain Legume.
F.A.O. Rome : 16.
- AHLAWAT, I. AND C. SARAF 1981: Response of pigeon pea (*Cajanus cajan* L.) to plant density and phosphorous fertiliser under dryland conditions.
J. Agric. Sci. Camb. 97 : 119 - 124.
- AHMED, B. AND P. QUILT 1980: Effect of soil moisture stress on yield, nodulation and nitrogenase activity of *Macroptilium atropurpureum* cv Siratro and *Desmodium intortum* cv Greenleaf.
Plant and Soil 57 : 187 - 194.
- AITKEN, Y. 1939: The problem of hard seeds in subterranean clover.
Proc. Roy. Soc. Victoria. 41 (NS) : 187 - 210.
- ALDRICH, S.R. 1943: Maturity measurement in corn and an indication that grain development continues after premature cutting.
J. Amer. Soc. Agron. 35 : 667 - 680.
- ALVEY, N.G. *et al.* 1977: Genstat a general statistical program.
Rothsted Experimental Station.
- ALVIM, P.T. 1960: Moisture stress as a requirement for flowering of coffee.
Science. 132 : 354.
- ANDERSON, S. 1954: A method for determining stages of development in wheat.
Physiol. Plant. 7 : 513 - 516.
- ANDREWS, C.H. 1966: Some aspects of pod and seed development in Lee soybean.
Ph.D. Thesis. Mississippi State Univ.
(Diss. Abstr. 27 : 1347 B).

- ANDREW, C.S. AND W.W. BRYAN 1955: Pasture studies on the coastal lowlands of sub-tropical Queensland. I. Introduction and initial plant nutrient studies.
Aust. J. Agric. Res. 6 : 265 - 290.
- ANDREW, C.S. AND W.W. BRYAN 1958: Pasture studies on the coastal lowlands of sub-tropical Queensland. III. The nutrient requirements and potentialities of *Desmodium uncinatum* and white clover on a latertic podzolic soil.
Aust. J. Agric. Res. 9 : 267 - 285.
- ANON 1976a: International Rules for Seed Testing.
Seed Sci. and Technol. 4 : 1 - 177.
- APPADURAI, R.R.; S.B. RAJAKARUNA AND H. GUNASENA 1966: Effect of spacing and leaf area on pod yields of kidney-bean (*Phaseolus vulgaris* L.).
Indian J. Agric. Sci. 37 : 22 - 26.
- ARGEL, P.J. AND L.R. HUMPHREYS 1983a: Environmental effects on seed development and hardseededness in *Stylosanthes hamata* cv Verano. I. Temperature.
Aust. J. Agric. Res. 34 : 261 - 270.
- ARGEL, P.J. AND L.R. HUMPHREYS 1983b: Environmental effects on seed development and hardseededness in *Stylosanthes hamata* cv Verano. II. Moisture Supply and Illuminance.
Aust. J. Agric. Res. 34 : 271 - 277.
- ASPINALL, D. AND F.L. MILTHORPE 1959: An analysis of competition between barley and white pericaria.
Ann. Appl. Biol. 47 : 156 - 172.
- AUSTIN, R.B. 1972: Effect of environment before harvesting on viability. In "Viability of Seeds" : 114 - 149.
Ed. E.H. Roberts, Chapman and Hall, London.
- BARTON, L.V. 1965: Dormancy in seeds imposed by the seed coat. Encyclopaedia of Plant Physiology, Ruhland, Berlin, Springer. Vol. XV/2 : 727 - 745.
- BASNET, B.; E.L. MADER AND C.D. NICKELL 1974: Influence of between and within row spacing on agronomic characteristics of irrigated soybean.
Agron. J. 66 : 657 - 659.

- BEGG, J.E. AND N.C. TURNER 1976: Crop water deficits.
Adv. Agron. 28 : 161 - 217.
- BENNETT, J.P.; M.W. ADAMS AND C. BURGA 1977: Pod yield component variation an intercorrelation in *Phaseolus vulgaris* L. as affected by planting density.
Crop. Sci. 17 : 73 - 75.
- BEWLEY, J.D. AND M. BLACK 1982: Physiology and Biochemistry of seeds in relation to germination. Vol. II. Viability, Dormancy, and Environmental Control.
New York : 375.
- BIDDISCOMBE, E.F. 1975: Effect of moisture stress on flower drop and seed yield of narrow-leafed lupin (*Lupinus angustifolius* L. cv Unicrop).
J. Aust. Inst. Agric. Sci. 41 : 70 - 72.
- BILS, R.F. AND R.W. HOWELL 1963: Biochemical and cytological changes in developing soybean cotyledons.
Crop. Sci. 3 : 304 - 308.
- BLUNT, C.G. AND L.R. HUMPHREYS 1970: Phosphate response of mixed swards at Mt Cotton, South-eastern Queensland.
Aust. J. Exp. Agric. Anim. Husband. 10 : 431 - 441.
- BOGDAN, A.V. 1966: *Glycine javanica* under experimental cultivation in Kenya.
Trop. Agric. (Trinidad) 43 : 99 - 105.
- BOYER, J.S. 1970a: Leaf enlargement and metabolic rates in corn, soybeans and sunflowers at various leaf water potentials.
Plant Physiol. 46 : 233 - 235.
- BOYER, J.S. 1970b: Differing sensitivity of photosynthesis to low leaf water potential in corn and soybeans.
Plant Physiol. 46 : 236 - 239.
- BOYER, J.S. AND H.G. MCPHERSON 1975: Physiology of water deficits in cereal crops.
Adv. Agron. 27 : 1 - 23.
- BRAITHWAITE, B.M. AND J.R. RAND 1970: The pest status of *Amemus* spp. in tropical legume pasture in North Coastal N.S.W.
Proc. XIth Int. Grassld Congr., Surfers Paradise, Australia : 676 - 681.

- CAMERON, D.F. 1967: Hardseededness and seed dormancy of Townsville lucerne (*Stylosanthes himilis*) selection.
Aust. J. Exp. Agric. Anim. Husb. 7 : 237 - 240.
- CARLOS D. AND D.J. HUME 1978: Flowering abortion and yield of early-maturing soybean at three densities.
Agron. J. 70 : 801 - 805.
- CARR, D.J. AND K.G.M. SKENE 1961: Diauxic growth curves of seed with special reference to French Beans (*Phaseolus vulgaris* L.).
Aust. J. Biol. Sci. 14 : 1 - 12.
- CARTTER, J.L. AND E.E. HARTWIG 1962: The management of soybeans.
Adv. Agron. 14 : 359 - 412.
- CHOW, K.H. AND L.V. CROWDER 1974: Flowering behaviour and seed development in four *Desmodium* spp.
Agron. J. 66 : 236 - 238.
- CLARKSON, N.M. AND J.S. RUSSELL 1976: Effect of water stress on the phasic development of Annual *Medicago* Species.
Aust. J. Agric. Res. 27 : 227 - 234.
- COLBRAN, R.C. 1964: Cover crops for nematode control in old banana land.
Qld J. Agric. Sci. 21 : 233 - 236.
- COOPER, R.L. 1971: Influence of soybean production practices on lodging and seed yield in highly productive environments.
Agron. J. 63 : 490 - 493.
- CROTHERS, S.E. AND D.T. WESTERMANN 1976: Plant population effects on the seed yields of *Phaseolus vulgaris* L.
Agron. J. 68 : 958 - 960.
- DATE, R.A. 1969: A decade of legume inoculant quality control in Australia.
J. Aust. Inst. Agric. Sci. 35 : 27 - 37.
- DATE, R.A. 1977: Inoculation of tropical pasture legumes. In 'Exploiting the legume Rhizobium symbiosis in Tropical Agriculture' : 293 - 312.
Proceedings of a Workshop August 1976.
College of Tropical Agriculture miscellaneous publication 145.

- DAY, W. 1981: Water stress and crop growth. In "Physiological processes limiting plant productivity" : 199 - 215.
Ed. C.B. Johnson, Butterworths, London.
- DELOUCHE, J.C. 1980: Environmental effects on seed development and seed quality.
Hort. Sci. 15 : 775 - 780.
- DONALD, C.M. 1951: Competition among pasture plants. I. Intra-specific competition among annual pasture plant.
Aust. J. Agric. Res. 2 : 355 - 376.
- DONALD, C.M. 1963: Competition among crop and pasture plants.
Adv. Agron. 15 : 1 - 119.
- DUARTE, R.A. AND M.W. ADAMS 1972: A path coefficient analysis of some yield component interrelations in field beans (*Phaseolus vulgaris* L.)
Crop. Sci. 12 : 579 - 582.
- DUBETZ, S. AND P.S. MAHALLE 1969: Effect of soil water stress on bush beans *Phaseolus vulgaris* L. at three stages of growth.
J. Amer. Soc. Hort. Sci. 94 : 479 - 481.
- DUNSMORE, J.R. AND C.B. ONG 1969: Preliminary work on pasture species and beef production in Sarawak, Malaysia.
Trop. Grasslds 3 : 117 - 121.
- DURE, L.S. 1975: Seed formation.
Ann. Rev. Plant Physiol. 26 : 259 - 278.
- EDEY, J.M. AND D.E. BYTH 1970: The influence of 2,3,5 - triiodobenzoic acid (TIBA) on vegetative and reproductive growth of legumes.
Aust. J. Exp. Agric. Anim. Husb. 10 : 732 - 738.
- EVANS, L.T. 1969: A short case history of the physiology of flowering. In The induction of flowering. Some case histories : 1 - 13.
Ed. L.T. Evans.
Division of Plant Industry, CSIRO, Canberra.
- FARRINGTON, P. 1976: Fruit development and associated changes in the distribution of dry weight and nitrogen in *Lupinus angustifolius* cv Uniharvest and *L. cosentinii* selection CB 12.
Aust. J. Expt. Agric. Anim. Husb. 16 : 387 - 393.

- FISHER, M.J. AND N.A. CAMPBELL 1977: The influence of water stress on the growth and development of Townsville stylo (*stylosanthes humilis*) in pure ungrazed swards at Katherine, Northern Territory.
Aust. J. Expt. Agric. Anim. Husb. 17 : 598 - 606.
- FISHER, M.J.; D.A. CHARLES-EDWARDS AND M.M. LUDLOW 1981: An analysis of the effects of repeated short term soil water deficits on stomatal conductance to carbon dioxide and leaf photosynthesis by the legume *Macroptilium atropurpureum* cv Siratro.
Aust. J. Plant Physiol. 8 : 347 - 357.
- FISHER, M.J. AND M.M. LUDLOW 1982: Response of Siratro (*Macrotilium atropurpurium*) to water stress.
Proc. 14th Int. Grassld Congr.
Kentucky, U.S.A. : 396 - 398.
- FLINN, A.M. AND J.S. PATE 1968: Biochemical and Physiological changes during maturation of fruit of field pea (*Pisum arvense* L.).
Ann. Bot. N.S. 32 : 479 - 495.
- FONTES, L.A.N. AND A.J. OHLROGGE 1972: Influence of seed size and population on yield and other characteristics of soybeans.
Agron. J. 64 : 833 - 836.
- GATES, C.T. 1955a: The response of the young tomato plant to a brief period of water shortage.
I. The whole plant and its principal part.
Aust. J. Biol. Sci. 8 : 196 - 214.
- GATES, C.T. 1955b: The response of the young tomato plant to a brief period of water shortage.
II. The individual leaves.
Aust. J. Biol. Sci. 8 : 215 - 230.
- GATES, C.T. 1964: The effect of water stress on plant growth.
J. Aust. Inst. Agric. Sci. 30 : 3 - 22.
- GBIKPI, P.J. AND R.K. CROOKSTON 1981: A whole plant indicator of soybean physiological maturity.
Crop. Sci. 21 : 469 - 472.
- GOODWIN, P.B. AND MD. A. SIDDIQUE 1977: Maturation of beans (*Phaseolus vulgaris* cv Apollo) seeds as influenced by temperature and moisture.
Australian Seeds Research Conference.
Working paper 1 (a)4 - 1 (a)6.

- GRAY, S.G. 1962: Hot water treatment for *Leucaena glauca* (L.) Benth.
Aust. J. Exp. Agric. Anim. Husb. 2 : 178 - 180.
- GRIERSON, W.; J. SOULE AND K. KAWADA 1982: Beneficial Aspects of
Physiological Stress.
Hort. Rev. 4 : 247 - 271.
- GRIFFITHS, D.J.; H.M. ROBERTS; J. LEWIS; J.L. STODDART AND E.W. BEAN
1967: Principles of herbage seed production.
Tech. Bull. No.1. Welsh Pl.
Breed. Stn, Aberystwyth : 135.
- GRITTON, E.T. AND J.A. EASTIN 1968: Response of pea (*Pisum sativum*
L.) to plant population and spacing.
Agron. J. 60 : 482 - 485.
- HARE, M.D. AND A. WARANYUWAT 1980: A manual for tropical pasture
seed production in northeast Thailand.
Northeast Livestock Development Project,
Department of Livestock Development, Tha
Phra, Khon Kaen, Thailand : 60.
- HARRINGTON, J.F. 1972: Seed storage and longevity. In "Seed
Biology" Vol. III : 145 - 245.
Ed. T.T. Kozlowski, Academic Press, New York.
- HAYNES, J.L. AND J.D. SAYRE 1956: Response of corn to within row
competition.
Agron. J. 48 : 362 - 364.
- HERBERT, S.J. AND G.D. HILL 1978a: Plant density and irrigation
studies on lupins. I. Growth analysis of *Lupinus*
angustifolius cv 'WAU IIB'.
N.Z. J. Agric. Res. 21 : 467 - 474.
- HERBERT, S.J. AND G.D. HILL 1978b: Plant density and irrigation
studies on lupins. II. Components of seed yield of
Lupinus angustifolius cv 'WAU IIB'.
N.Z. J. Agric. Res. 21 : 475 - 481.
- HICKS, D.R.; J.W. PENDLETON; R.L. BERNARD AND T.J. JOHNSTON 1969:
Response of soybean plant type to planting patterns.
Agron. J. 61 : 290 - 293.

- HILER, E.A.; C.H.M. VAN BAVEL; M.M. HOSSAIN AND W.R. JORDAN 1972:
Sensitivity of Southern Peas to plant water deficit at
three growth stages.
Agron. J. 64 : 60 - 64.
- HILL, M.J. 1971: A study of seed production in "grasslands ruanui"
perennial ryegrass (*Lolium perenne* L.) "grassland kahu"
timothy (*Phleum pratense* L.) and prairie grass (*Bromus
unioloides* H.B.K.).
A Ph.D. Thesis, Massey University, New Zealand.
- HILL, M.J. AND B.R. WATKIN 1975: Seed production studies on perennial
ryegrass, timothy and prairie grass. 2. Changes in
physiological components during seed development and time
and method of harvesting for maximum seed yield.
J. Br. Grassld Soc. 30 : 131 - 140.
- HODGSON, G.L. AND G.E. BLACKMAN 1956: An analysis of the influence
of plant density on the growth of *Vicia faba*. I. The
influence of density on the pattern of development.
J. Expt. Bot. 7 : 147 - 165.
- HOLLIDAY, R. 1960: Plant population and crop yield.
Nature. 186 : 22 - 24.
- HOLLIDAY, R. 1960a: Plant population and crop yield. Part I.
Field Crop Abstr. 13(3) : 159 - 167.
- HOPKINSON, J.M. 1977: Formative factors - Tropical pasture legume
seed crops.
Australian Seed Research Conference
Working paper 1 (a)14 - 1 (a)22.
- HOPKINSON, J.M. 1977: Siratro seed production.
Trop. Grasslds. 11 : 33 - 39.
- HOPKINSON, J.M. AND D.S. LOCH 1973: Improvement of seed yield of
Siratro (*Macroptilium atropurpureum*). I. Production and
loss of seed in the crop.
Trop. Grasslds. 7 : 255 - 268.
- HSIAO, T.C. 1973: Plant responses to water stress.
Ann. Rev. Plant Physiol. 24 : 519 - 570.

- HSIAO, T.C. AND E. ACEVEDO 1974: Plant responses to water deficits, water use efficiency, and drought resistance.
Agric. Meteo. 14 : 59 - 84.
- HUMPHREYS, L.R. 1978: Tropical pasture and fodder crops.
Longman, London, U.K. : 135.
- HUMPHREYS, L.R. 1979: Tropical pasture seed production.
FAO plant production and protection paper : 143.
- HUMPHREYS, L.R. 1981: Environmental adaptation of tropical pasture plants.
MacMillan, London. : 261.
- HUTTON, E.M. 1962: Siratro - a tropical pasture legume bred from *Phaseolus atropurpureus*.
Aust. J. Exp. Agric. Anim. Husb. 2 : 117 - 125.
- HUTTON, E.M. 1970: Tropical pastures.
Adv. Agron. 22 : 1 - 73.
- HUTTON, E.M. AND N.E. GRYLIS 1956: Legume "little leaf", a virus disease of sub-tropical pasture species.
Aust. J. Agric. Res. 7 : 85 - 97.
- HUTTON, E.M. AND L.B. BEALL 1977: Breeding of *Macroptilium atropurpureum*.
Trop. Grasslds. 2 : 15 - 31.
- HYDE, E.O.C. 1950: Studies on the development of white clover seed.
N.Z. Grassld Assoc. Proc.
twelfth conf. : 101 - 107.
- HYDE, E.O.C. 1954: The function of the hilum in some Papilionaciae in relation to the ripening of the seed and the permeability of the testa.
Ann. Bot. 18 : 241 - 256.
- HYDE, E.O.C.; M.A. MCLEAVEY AND G.S. HARRIS 1959: Seed development in ryegrass, and in red and white clover.
N.Z. Agric. Res. 2 : 947 - 952.

- IMRIE, B.C. 1973: Flowering response of *Macroptilium atropurpureum* to day length, temperature and nitrogen levels.
Sabrao Newsl. 5 : 95 - 100.
- INGRAM, J. 1976: The effects of plant density on varieties of winter beans (*Vicia faba*).
J. Natn. Inst. Agric. Bot. 14 : 29 - 38.
- ISHAG, H.M. 1973a: Physiology of seed yield in field beans (*Vicia faba* L.). I. Yield and yield components.
J. Agric. Sci. Camb. 80 : 181 - 189.
- ISHAG, H.M. 1973b: Physiology of seed yield in field beans (*Vicia faba* L.). II. Dry matter production.
J. Agric. Sci. Camb. 80 : 191 - 199.
- JAVIER, E.O.; G.T. SARIS AND R.C. MENDOZA 1978: Seed production of tropical forage legume. II. *Phaseolus atropurpureus* cv Siratro.
Philippine. J. Crop Sci. 1 : 78 - 80.
- JONES, R.J. 1965: The use of cyclodiene insecticides as liquid seed dressing to control bean fly, (*Melanagromyza phaseoli*) in species of *Phaseolus* and *Vigna marina* in South-eastern Queensland.
Aust. J. Expt. Agric. Anim. Husb. 5 : 458 - 465.
- JONES, R.J. 1982: The effect of rust (*Uromyces appendiculatus*) on the yield and digestibility of *Macroptilium atropurpureum* cv. Siratro.
Trop. Grasslds. 16 : 130 - 135.
- JONES, R.J. AND C.S. ANDREW 1967: Effect of seed and phosphate rate on growth of Siratro.
CSIRO. Aust. Divn. Trop. Past. Ann. Rept. 1966 - 67 : 46.
- JONES, R.J.; J.G. DAVIES AND R.B. WAITE 1967: The contribution of some tropical legumes to pasture yields of dry matter and nitrogen at Samford, Southeastern Queensland.
Aust. J. Expt. Agric. Anim. Husb. 7 : 56 - 65.
- JONES, R.J. AND R.M. JONES 1978: The ecology of Siratro-based pastures. In "Plant relations in pastures" : 353 - 367.
Ed. J.R. Wilson, Melbourne : CSIRO.

- JONES, R.M. 1969: Mortality of some tropical grasses following frosting in the first winter after sowing.
Trop. Grasslds. 3 : 57 - 63.
- JONES, R.M.; J.L. ALCORN AND M.C. REES 1969: Death of Siratro to violet root rot.
Trop. Grasslds. 3 : 137 - 139.
- KATTAN, A.A. AND J.W. FLEMING 1956: Effect of irrigation at specific stages of development on yield quality, growth and composition of snap beans.
Proc. Amer. Soc. Hort. Sci. 68 : 329 - 342.
- KIRBY, E. 1977: Population and competition.
J. Nat. Inst. Agric. Bot. 14 : 187 - 190.
- KLEIN, L.M. AND J.E. HARMOND 1971: Seed moisture - A harvest timing index for maximum yields.
Transaction of the ASAE. 14 : 124 - 126.
- KOWITHAYAKORN, L. 1978: A study of herbage and seed production of lucerne (*Medicago sativa* L.) under different plant spacings and cutting treatments.
Masterate Thesis, Massey University, New Zealand.
- KRAMER, P.J. 1963: Water stress and plant growth.
Agron. J. 55 : 31 - 35.
- KRAMER, P.J. 1980: Drought, Stress and the Origin of Adaptation. In "Adaptation of Plants to Water and High Temperature Stress" : 7 - 20.
Ed. N.C. Turner and P.J. Kramer. A. Wiley - interscience publication. New York.
- KRETSCHMER, A.E. JR 1972: Siratro (*Phaseolus atropurpureus* D.C.) A summer-growing perennial pasture legume for Central and South Florida.
Florida Agric. Exp. Sta. Circ. S - 214.
- LAND DEVELOPMENT REPORT 1979:
Land Development Department, Soil Survey Division,
Bangkok, Thailand. No.245 : 56 (in Thai).
- LAOHASIRIWONG, S. 1982: Effects of duration of water stress at different growth stages on growth and yield of Soybeans (*Glycine max* L.) Merrill).
Masterate Thesis, Massey University, New Zealand.

- LEACH, G.J.; R.M. JONES AND R.J. JONES 1976: The agronomy and ecology of improved pastures. In "Tropical Pasture Research" : 227 - 307.
Ed. N.H. Shaw and W.W. Bryan, Comm. Bur. Past. Field Crops. Bull. 51. Hurley, Berkshire, England.
- LEAKEY, C.L.A. 1972: The effect of plant population and fertility level on yield and its components in two determinate cultivars of *Phaseolus vulgaris* L. Savi.
J. Agric. Sci. Camb. 79 : 259 - 267.
- LEHMAN, W.F. AND J.W. LAMBERT 1960: Effects of spacing of soybean plants between and within rows on yield and its components.
Agron. J. 52 : 84 - 86.
- LITTLE, T.M. AND F.J. HILLS 1975: Statistical Methods in Agricultural Research.
University of California, Davis : 242.
- LOEWENBERG, J.B. 1955: The development of bean seeds (*Phaseolus vulgaris* L.)
Plant Physiol. Lancaster. 30 : 244 - 249.
- LÖSCH, R. AND J.D. TENHUNEN 1981: Stomatal responses to humidity - phenomenon and mechanism. In "Stomatal physiology : 137 - 161.
Ed. P.G. Jarvis and T.A. Mansfield.
Society for Experimental Biology Seminar Series 8.
- LUCK, P.E. AND N.J. DOUGLAS 1966: Dairy pasture research and development in the near north coast centred on Cooroy, Queensland.
Proceedings No.6, Tropical Grassland Society of Australia : 35 - 49.
- LUDLOW, M.M. 1975: Effect of water stress on the decline of leaf net photosynthesis with age : 123 - 134. In "Environmental and Biological control of photosynthesis.
Ed. R. Marcelle. Junk, The Hague.
- LUDLOW, M.M. 1980: Stress physiology of tropical pasture plants.
Trop. Grasslds. 14 : 136 - 145.
- LUDLOW, M.M. AND T.T. NG 1976: Effect of water deficit on carbon dioxide exchange and leaf elongation rate of *Panicum maximum* var. *trichoglume*.
Aust. J. Plant Physiol. 3 : 401 - 413.

- LUDLOW, M.M. AND K. IBARAKI 1979: Stomatal control of water loss in Siratro (*Macroptilium atropurpureum* (DC) Urb.), a tropical pasture legume.
Ann. Bot. 43 : 639 - 647.
- LUESCHEN, W.E. AND D.R. HICKS 1977: Influence of plant population on field performance of three soybean cultivars.
Agron. J. 69 : 390 - 393.
- LUDLOW, M.M.; A.C.P. CHU; R.J. CLEMENTS AND R.G. KERSLAKE 1983: Adaptation of species of *Centrosema* to water stress.
Aust. J. Plant Physiol. 10 : 119 - 130.
- MACK, H.J. AND D.L. HATCH 1968: Effects of plant arrangement and population density on yield of bush snap bean.
Proc. Amer. Soc. Hort. Sci. 92 : 418 - 425.
- MACK, H.J. AND G.W. VARSEVELD 1982: Response of bush snap beans (*Phaseolus vulgaris* L.) to irrigation and plant density.
J. Amer. Soc. Hort. Sci. 107 : 286 - 290.
- MACSWAN, I.C. AND P.A. KOEPESELL 1975: Oregon plant disease control handbook.
Oregon, U.S.A. : 193.
- MATSON, A.J. 1964: Some factors affecting the yield response of soybeans to irrigation.
Agron. J. 56 : 552 - 555.
- MEADLEY, J.T. AND G.M. MILBOURN 1970: The growth of vining peas. II. The effect of density of planting.
J. Agric. Sci. Camb. 74 : 273 - 278.
- MEARS, P.T. 1967: Tropical pasture in the Richmond Tweed region of N.S.W. recent experiences and future development.
Trop. Grasslds. 1 : 98 - 105.
- MIDDLETON, C.H. 1973: Effect of sowing rate on yield and composition of Siratro - Nandi *Setaria* pasture.
Qld J. Agric. Anim. Sci. : 45 - 52.
- MIDDLETON, C.H. AND P. HICKMOTT 1972: Late Siratro planting risky.
Qld. Agric. J. 98 : 465 - 466.

- MINSON, D.J. AND R. MILFORD 1966: The energy values and nutritive value indices of *Digitaria decumbens*, *Sorghum almum* and *Phaseolus atropurpureus*.
Aust. J. Agric. Res. 17 : 411 - 424
- MOFFETT, M.L. 1973: Seed transmission of *Pseudomonas phaseolicola* (Halo-blight) in *Macroptilium atropurpureum* cv. Siratro.
Trop. Grasslds. 7 : 195 - 199.
- MOMEN, N.N.; R.E. CARLSON; R.H. SHAW AND D. ARJMAND 1979: Moisture-stress effects on the yield components of two soybean cultivars.
Agron. J. 71 : 86 - 90.
- MULLETT, J.H. 1981: Seed development and seed production.
Aust. Hort. 79 : 52 - 61.
- NELSON, W.E. 1962: The effects of soil moisture stress at critical stages of growth of some vegetable crops.
Thesis, Rutgers St. Univ. N.J.
(cited by Salter and Goode, 1967).
- NEWTON, S.D. AND G.D. HILL 1977: The effect of time of sowing and density on pod position and yield of two cultivars of field beans (*Vicia faba* L.)
Proc. Agron. Soc. N.Z. 7 : 57 - 63.
- NORMAN, M.J.T. 1970: Relationships between liveweight gain of grazing beef steer and availability of Townsville lucern.
Proc. XIth Int. Grassld Congr., Surfers Paradise, Australia : 829 - 832.
- NORMAN, M.J.T. AND L.J. PHILLIPS 1970: Wet season grazing of Townsville stylo pasture at Katherine, N.T.
Aust. J. Exp. Agric. Anim. Husb. 10 : 710 - 715.
- NORMAN, M.J.T. AND G.A. STEWART 1964: Investigations on the feeding of beef cattle in the Katherine region, N.T.
J. Aust. Inst. Agr. Sci. 30 : 39 - 46.
- NORRIS, D.O. 1967: The intelligent use of inoculants and lime pelleting for tropical legumes.
Trop. Grasslds. 1 : 107 - 121.

- OBENDORF, R.L.; E.N. ASHWORTH AND G.T. RYTKO 1980: Influence of seed maturation on germinability in soybean.
Crop. Sci. 20 : 483 - 486.
- OLIKER, M.; A. POLJAKOFF-MAYBER AND A.M. MAYER 1978: Changes in weight, nitrogen accumulation, respiration and photosynthesis during growth and development of seeds and pods of *Phaseolus vulgaris*.
Amer. J. Bot. 65 : 366 - 371.
- OSBORNE, D.J. 1981: Physiological and biochemical events in seed development.
Advance in Research and Technology of Seed, Part 6 : 43 - 62.
- OSTROWSKI, H. 1970: Molybdenized superphosphate requirement for pasture establishment on red forest soils in sub-tropical Queensland.
Proc. XIth Int. Grassld Congr., Surfers Paradise, Queensland, Australia : 124 - 126.
- PALMER, T.P. 1971: Plant density and herbage production in lucerne (*Medicago sativa*).
Proc. Agron. Soc. N.Z. 1 : 77 - 85.
- PASTURE IMPROVEMENT PROJECT 1976 - 1980:
Khon Kaen University. Annual Report.
Khon Kaen, Thailand.
- PEAKE, D.C.I.; G.D. STIRK AND E.F. HENZELL 1975: Leaf water potentials of pasture plants in a semi-arid sub-tropical environment.
Aust. J. Expt. Agric. Anim. Husb. 15 : 645 - 654.
- PETINOV, N.S. 1965: The physiology of irrigated agricultural plants.
Field Crop Abstr. 18 : 1 - 8.
- PHIPPS, R.H. 1973: Methods of increasing the germination percentage of some tropical legumes.
Trop. Agric. (Trinidad). 50 : 291 - 296.
- POLLOCK, B.M. AND E.E. ROOS 1972: Seed and seedling vigour. In "Seed Biology" Vol. I. : 313 - 387.
Ed. T.T. Kozlowski. Academic Press, London.

- QUINLIVAN, B.J. 1965: The influence of the growing season and the following dry season on the hardseededness of subterranean clover in different environment.
Aust. J. Agric. Res. 16 : 277 - 291.
- QUINLIVAN, B.J. 1966: The relationship between temperature fluctuations and the softening hard seeds of some legume species.
Aust. J. Agric. Res. 17 : 625 - 631.
- QUINLIVAN, B.J. 1968b: Seed coat impermeability in the common annual legume pasture species of Western Australia.
Aust. J. Exp. Agric. Anim. Husb. 8 : 695 - 701.
- QUINLIVAN, B.J. 1971: Seed coat impermeability in legumes.
J. Aust. Inst. Agric. Sci. 37 : 283 - 295.
- REES, M.C.; R.M. JONES AND R. ROE 1976: Evaluation of pasture grasses and legumes grown in mixtures in South-east Queensland.
Trop. Grasslds. 10 : 65 - 78.
- RICKERT, K.G. AND L.R. HUMPHREYS 1970: Effect of variation in density and phosphate application on growth and composition of Townsville stylo (*Stylosanthes humilis*).
Aust. J. Exp. Agric. Anim. Husb. 10 : 442 - 449.
- ROBINS, J.S. AND C.E. DOMINGO 1956: Moisture deficits in relation to the growth and development of dry beans.
Agron. J. 48 : 67 - 70.
- ROGERS, I.S. 1976: The effect of plant density on the yield of three varieties of French beans (*Phaseolus vulgaris* L.)
J. Hort. Sci. 51 : 481 - 488.
- RUBEL, A.; R.W. RINNE AND D.T. CANVIN 1972: Protein, oil and fatty acid in developing soybean seeds.
Crop. Sci. 12 : 739 - 741.
- SALISBURY, F.B. AND C.W. ROSS 1978: Plant physiology. Second Edition.
Wadsworth, U.S.A. : 422.
- SALTER, P.J. 1962: Some response of peas to irrigation at different growth stages.
J. Hort. Sci. 37 : 147 - 149.

- SALTER, P.J. 1963: The effect of wet or dry soil condition at different growth stages on the components of yield of pea crop.
J. Hort. Sci. 38 : 321 - 334.
- SALTER, P.J. AND J.E. GOODE 1967: "Crop responses to water at different stages of growth" : 49 - 60.
Research Review No.2. Commonwealth Bureau of Horticulture and Plantation Crops. Commonwealth Agricultural Bureaux, Bucks., England.
- SALTER, P.J. AND J.B. WILLIAMS 1967: The effect of irrigation on pea crops growth at different plant spacings.
J. Hort. Sci. 42 : 59 - 66.
- SAUNDERS, G.W. 1968: Pests of legume seed crops in North Queensland.
Qld.Agric. J. 94 : 725 - 730.
- SHAW, N.H. AND L.'T MANNETJE 1970: Studies on a spear grass pasture in central coastal Queensland - The effect of fertilizer, stocking rate, and over sowing with *Stylosanthes humilis* on beef production and botanical composition.
Trop. Grasslds. 4 : 43 - 56.
- SHAW, N.H. AND P.C. WHITEMAN 1977: Siratro - A success story in breeding a tropical pasture legume.
Trop. Grasslds. 11 : 7 - 14.
- SHAW, R.H. AND W.E. LOOMIS 1950: Bases for the prediction of corn yield.
Plant. Physiol. 25 : 225 - 244.
- SHELTON, H.M. AND L.R. HUMPHREYS 1971: Effect of variation in density and phosphate supply on seed production of *Stylosanthes humilis*.
J. Agric. Sci. Camb. 76 : 325 - 328.
- SHERIFF, D.W. AND P.E. KAYE 1977: Responses of diffusive conductance to humidity in a drought avoiding and drought resistant (in terms of stomatal response) legume.
Ann. Bot. 41 : 653 - 655.
- SINHA, S.K. 1977: Food legumes : Distribution, adaptability and biology of yield.
FAO Plant production and protection paper No.3 : 124.

- SIONIT, N. AND P.J. KRAMER 1977: Effect of water stress during different stages of growth of soybeans.
Agron. J. 69 : 274 - 278.
- SKERMAN, P.J. 1977: Tropical forage legumes.
FAO Plant production and Protection series. No.2. : 609.
- SLATYER, R.O. 1967: "Plant-water relationship".
Academic Press, London : 366.
- SONODA, R.M. 1976: Reaction of *Macroptilium atropurpureum* and related species to three diseases in Florida.
Trop. Grasslds. 10 : 61 - 63.
- SONODA, R.M.; A.E. KRETSCHMER JR AND J.B. BROLMANN 1971: Web-blight of introduced forage legumes in Florida.
Trop. Grasslds. 5 : 105 - 107.
- STOBBS, T.H. 1965: Beef production from Uganda pasture containing *Stylosanthes gracilis* and *Centrosema pubescens*.
Proc. IXth. Int. Grassld Congr., Sao Paulo, Brazil. Vol. II. - 939 - 942.
- STODDART, J.L. 1964b: Seed ripening in grasses. II. Changes in free amino acid content.
J. Agric. Sci. 62 : 321 - 325.
- TAMAKI, K; K. ASANUMA AND J. NAKA 1973: Physiological studies of the growing process of broad bean plants. VII. Effects of plant density on the growth and seed production.
Technical Bulletin of the Faculty of Agriculture, Kagawa University. 25 : 1 - 11.
- TAYLOR, G.B. AND M.J. PALMER 1979: The effect of some environmental conditions on seed development and hard-seededness in subterranean clover (*Trifolium subterraneum* L.).
Aust. J. Agric. Res. 30 : 65 - 76.
- TEKRONY, D.M.; D.B. EGLI; J. BALLE; T. PFEIFFER AND R.J. FELLOWS 1979: Physiological maturity in soybean.
Agron. J. 71 : 771 - 775.
- TOPARK-NGARM, A. 1976: Effect of seeding rate and cutting frequency of forage yields of four *Stylosanthes* spp.
Ann. Rept. Khon Kaen University, Pasture Improvement Project, Khon Kaen, Thailand : 27 - 29.

- TOTHILL, J.C. AND R.M. JONES 1977: Stability in sown and oversown Siratro pastures.
Trop. Grasslds. 11 : 55 - 64.
- TURNER, N.C. AND J.E. BEGG 1981: Plant-water relations and adaptation to stress.
Plant and soil. 58 : 97 - 131.
- UEHARA, G. 1977: An overview of the soils of the arable tropics. In "Exploiting the legume - Rhizobium symbiosis in tropical agriculture" : 67 - 80.
Proceeding of a Workshop, August 1976.
College of Tropical Agriculture.
Miscellaneous Publication 145.
- VAADIA, Y.; F.C. RANEY AND R.M. HAGAN 196L: Plant water deficit and physiological processes.
Ann. Rev. Plant Physiol. 12 : 265 - 292.
- WARDLAW, I.F. 1969: The effect of water stress on translocation in relation to photosynthesis and growth. II. Effect during leaf development in *Lolium temulentum* L.
Aust. J. Biol. Sci. 22 : 1 - 16.
- WHIGHAM, D.K. AND H.C. MINOR 1978: Agronomic characteristics and environmental stress. In "Soybean physiology, agronomy and utilization" : 78 - 118.
Ed. A.G. Norman. Academic Press,
New York.
- WHITEMAN, P.C. 1968: Effect of temperature on the vegetative growth of six tropical legume species.
Aust. J. Exp. Agric. Anim. Husb. 8 : 528 - 532.
- WICKHAM, B. 1976: Siratro seed production.
Ann. Rept. Khon Kaen University,
Pasture Improvement Project, Khon
Kaen, Thailand : 112 - 126.
- WICKHAM, B.; A. MOOLSIRI AND P. LORWILAI 1980: Effect of planting method and dry season irrigation on Siratro seed production.
Ann. Rept. Khon Kaen University,
Pasture Improvement Project, Khon
Kaen, Thailand : 70 - 72.

- WICKHAM, B.; B. WILAIPON AND H.M. SHELTON 1977: Seed production of *Macroptilium atropurpureum* (Siratro).
Ann. Rept. Khon Kaen University,
Pasture Improvement Project, Khon
Kaen, Thailand : 78 - 80.
- WILAIPON, N. 1980: Response of Siratro, Centrosema and *Stylosanthes humilis* to phosphorous fertilizer.
Ann. Rept. Khon Kaen University,
Pasture Improvement Project, Khon
Kaen, Thailand : 48 - 49.
- WILAIPON, P. 1976: Seeding rate effects on growth and seed production of *Stylosanthes humilis* cv. Lawson.
Ann. Rept. Khon Kaen University,
Pasture Improvement Project, Khon
Kaen, Thailand : 107 - 110.
- WILLEY, R. AND S. HEATH 1969: The quantitative relationships between plant population and crop yield.
Adv. Agron. 21 : 280 - 321.
- WILSON, J.R.; M.M. LUDLOW; M.J. FISHER AND E.D. SCHULZE 1980: Adaptation to water stress of the leaf water relation of four tropical forage species.
Aust. J. Plant Physiol. 7 : 207 - 220.
- WIN PE 1978: A study of seed development, seed coat, structure and seed longevity in "Grasslands pawera" red clover (*Trifolium pratense* L.).
Ph.D. Thesis, Massey University, New Zealand.
- WITHERS, N.J. 1975: A spacing and defoliation study with unicroop lupins.
Proc. Agron. Soc. N.Z. 15 : 13 - 16.
- WITHERS, N.J. 1979: An evaluation of lupins (*Lupinus* spp.) for seed protein production.
Ph.D. Thesis, Massey University, New Zealand.
- WYNN-WILLIAM, R.B. AND T.P. PALMER 1974: Seeding rate, row spacing and lucern (*Medicago sativa* cv. Saranac) seed production.
Proc. Agron. Soc. N.Z. 4 : 63 - 65.

- YAZDI-SAMADI, B.; R.W. RINNE AND R.D. SEIF 1977: Components of developing soybean seeds: oil, protein, sugars, starch, organic acids, and amino acids.
Agron. J. 69 : 481 - 486.
- ZALESKI, A. 1964: Effect of density on plant population, photoperiod, temperature and light intensity on inflorescence formation in white clover.
J. Br. Grassld Soc. 19 : 237 - 247.

* * * * *

APPENDIX TABLE 1

RESULTS OF SOIL ANALYSIS
(OVEN DRY BASIS)

SOIL SURVEY LABORATORY, SOIL SURVEY DIVISION, DEPARTMENT OF LAND DEVELOPMENT

SOIL NAME AND LABORATORY NUMBER	HOR- IZON	DEPTH (cm)	PARTICLE SIZE ANALYSIS			pH		CaCO ₃ %	CONDUCT- IVITY 1:5 EC x 10 ⁶	CAR- BON %	EXCHANGE CAPACITY AND CATIONS (Milli-equiv/100 g)								BASE SATUR- ATION % $\frac{B \times 100}{B + A}$	P p.p.m. BRAY No.2	K p.p.m. AMMON ACETATE	
			USDA GRADING %			1:1	1:1				Ca	Mg	K	Na	SUM BASES (B)	EXTR ACIDITY (A)	SUM (B + A)	C E C SOIL				C E C CLAY
			SAND	SILT	CLAY	H ₂ O	KCl															
Wang Saphung series	Ap	0-12	39.5	36.0	24.5	5.85	5.1	1.5	508.0	3.49	11.6	4.1	0.4	0.2	16.3	6.4	22.7	19.3	78.8	72	7.0	149
	B _{21t}	12-33	32.0	31.0	37.0	4.9	3.7	1.5	220.0	1.57	11.0	3.1	0.3	0.3	14.7	11.4	26.1	22.6	61.1	56	2.8	99
	B _{22t}	33-55	28.0	47.5	24.5	5.25	4.25	2.1	272.0	2.40	18.3	3.1	0.3	0.3	22.0	6.2	28.2	28.2	115.1	78	3.4	123
	C	55-80	29.5	18.0	52.5	6.3	5.35	2.1	224.0	2.36	19.0	2.7	0.3	0.3	22.3	4.5	26.8	26.9	51.2	83	4.4	129

APPENDIX TABLE 2

CONTROLLED ENVIRONMENT CONDITIONS

Temperature:	30/20 ± 0.5°C		
		day/night	
Humidity:	70/90 ± 5% RH		
	13/2 mb VPD		
Lighting:	12 hour photoperiod		
	W m ⁻² PAR* pre 159	μE.m ⁻² .sec ⁻¹	742
	post 135		640
	mean 147		691

* 400 - 700 nm photosynthetically active radiation.

APPENDIX TABLE 3 CLIMATE LAB - N.C.S.U. PHYTOTRON NUTRIENT

2 ml A + 2 ml B/1 water					
<u>grams/litre</u>					
	Molecular Wt (g)	Conc.	Final Soln		PPM
<u>STOCK SOLUTION A:</u>					
Ammonium nitrate					
NH_4NO_3	80.02	80.05	.1601	N	56.05
Calcium nitrate				Ca	54.06
$\text{Ca}(\text{NO}_3)_2 \times 4\text{H}_2\text{O}$	236.15	159.25	.3185	N	37.79
Sequestrene 330				Fe	5.96
10% DTPA Na Fe	468.20	29.8	.0596	Na	2.93
<u>STOCK SOLUTION B:</u>					
Potassium phosphate				K	7.18
KH_2PO_4	136.08	12.5	.025	P	5.69
Potassium phosphate				K	4.94
K_2HPO_4	174.17	5.5	.011	P	1.96
Potassium nitrate				K	49.42
KNO_3	101.11	63.9	.1278	N	17.71
Magnesium sulphate				Mg	6.08
$\text{MgSO}_4 \times 7\text{H}_2\text{O}$	246.50	30.81	.06162	S	8.02
Sodium sulphate				Na	22.98
Na_2SO_4	142.05	35.5	.071	S	16.03
Zinc sulphate				Zn	0.011
$\text{ZnSO}_4 \times 7\text{H}_2\text{O}$	287.55	0.025	.00005	S	0.006
Manganese chloride				Mn	0.144
MnCl_2	197.92	0.26	.00052	Cl	0.186
Copper sulphate				Cu	0.005
$\text{CuSO}_4 \times 5\text{H}_2\text{O}$	249.68	0.01	.00002	S	0.003
Boric acid					
H_3BO_3	61.82	0.35	.0007	B	0.123
Sodium molybdate				Na	0.001
$\text{Na}_2\text{MoO}_4 \times 2\text{H}_2\text{O}$	241.93	0.0027	.0000054	Mo	0.002

<u>Nutrient</u>	<u>PPM</u>	<u>um</u>	<u>Nutrient</u>	<u>PPM</u>	<u>um</u>
N	111.55	NH_4 2200	B	0.123	BO_3 11.39
		NO_3 6130			
P	7.65	PO_4 6.8	Mn	0.144	2.55
K	61.54	80	Cu	0.005	0.08
S	24.06	SO_4 750	Zn	0.011	0.17
Ca	54.06	1280	Mo	0.002	0.02
Fe	5.96	125	Cl	0.186	5.36
Mg	6.08	250	Na	25.911	1125

pH of final solution = 6.5 - 7.5

APPENDIX TABLE 4

PERCENTAGE OF SEED MOISTURE CONTENT (DAYS AFTER ANTHESIS)

HARVESTING

Days after anthesis

<u>Water Treatment</u>	<u>8</u>	<u>10</u>	<u>12</u>	<u>14</u>	<u>16</u>	<u>18</u>	<u>20</u>	<u>22</u>	<u>24</u>	<u>26</u>
W1	84.60	82.40	75.40	67.15	60.35	27.80	19.50	18.55	18.25	17.70
W2	83.65	81.70	76.70	68.30	62.40	50.25	18.60	21.70	16.90	17.40
W3	80.75	85.45	80.65	74.35	69.15	66.15	41.85	14.85	15.35	15.60
Mean	83.00	83.18	77.58	69.93	63.97	48.07	26.65	18.37	16.83	16.90

APPENDIX TABLE 5

100 SEED FRESH WEIGHT (GM) (DAYS AFTER ANTHESIS)

HARVESTING

Days after anthesis

<u>Water Treatment</u>	<u>8</u>	<u>10</u>	<u>12</u>	<u>14</u>	<u>16</u>	<u>18</u>	<u>20</u>	<u>22</u>	<u>24</u>	<u>26</u>
W1	0.515	1.080	1.890	2.860	3.140	1.670	1.535	1.510	1.560	1.710
W2	0.275	0.820	1.630	2.540	3.395	2.965	1.880	1.980	2.010	2.035
W3	0.285	0.750	1.290	1.965	2.610	2.770	2.165	1.715	1.825	1.855
Mean	0.358	0.883	1.603	2.455	3.048	2.468	1.860	1.735	1.798	1.867

APPENDIX TABLE 6

100 SEED DRY WEIGHT (GM) (DAYS AFTER ANTHESIS)

HARVESTING

Days after anthesis

<u>Water Treatment</u>	<u>8</u>	<u>10</u>	<u>12</u>	<u>14</u>	<u>16</u>	<u>18</u>	<u>20</u>	<u>22</u>	<u>24</u>	<u>26</u>
W1	0.075	0.190	0.465	0.940	1.245	1.205	1.235	1.230	1.275	1.415
W2	0.045	0.150	0.380	0.805	1.275	1.475	1.530	1.550	1.670	1.680
W3	0.055	0.110	0.250	0.505	0.805	0.940	1.255	1.460	1.545	1.565
Mean	0.058	0.150	0.365	0.750	1.108	1.207	1.340	1.413	1.497	1.553

APPENDIX TABLE 7

GERMINATION PERCENTAGE (NORMAL SEEDLINGS) (DAYS AFTER ANTHESIS)

HARVESTING

Days after anthesis

<u>Water Treatment</u>	<u>8</u>	<u>10</u>	<u>12</u>	<u>14</u>	<u>16</u>	<u>18</u>	<u>20</u>	<u>22</u>	<u>24</u>	<u>26</u>
W1	0.00	0.00	39.00	79.00	98.00	96.00	93.00	81.00	52.00	35.00
W2	0.00	0.00	0.00	46.00	91.00	88.00	98.00	98.00	95.00	100.00
W3	0.00	0.00	0.00	84.00	96.00	90.00	98.00	99.00	100.00	100.00
Mean	0.00	0.00	13.00	53.00	95.00	91.33	96.33	92.67	82.33	78.33

APPENDIX TABLE 8

VIABILITY PERCENTAGE OF SEED (DAYS AFTER ANTHESIS)

HARVESTING

Days after anthesis

<u>Water Treatment</u>	<u>8</u>	<u>10</u>	<u>12</u>	<u>14</u>	<u>16</u>	<u>18</u>	<u>20</u>	<u>22</u>	<u>24</u>	<u>26</u>
W1	0.00	2.00	96.00	99.00	100.00	100.00	98.00	100.00	100.00	100.00
W2	0.00	0.00	0.00	96.00	100.00	97.00	99.00	100.00	100.00	100.00
W3	0.00	0.00	41.00	77.00	100.00	97.00	100.00	99.00	100.00	100.00
Mean	0.00	0.67	45.67	90.67	100.00	98.00	99.00	99.67	100.00	100.00

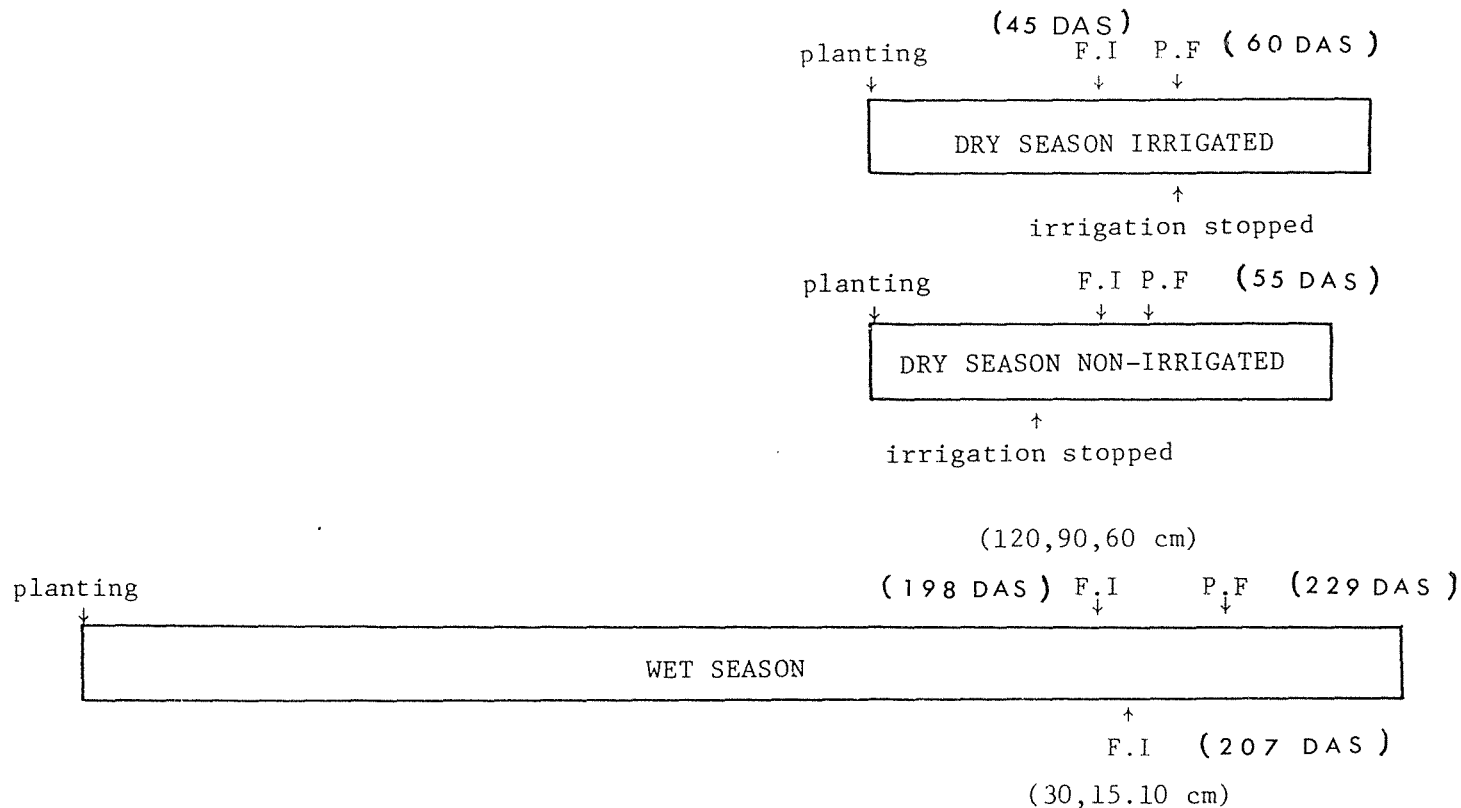
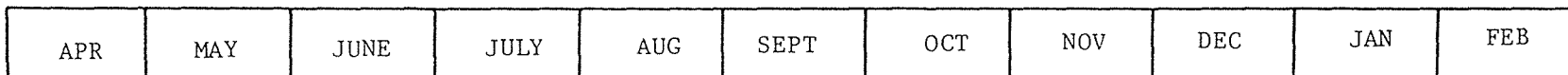
APPENDIX TABLE 9

HARD SEED PERCENTAGE (DAYS AFTER ANTHESIS)

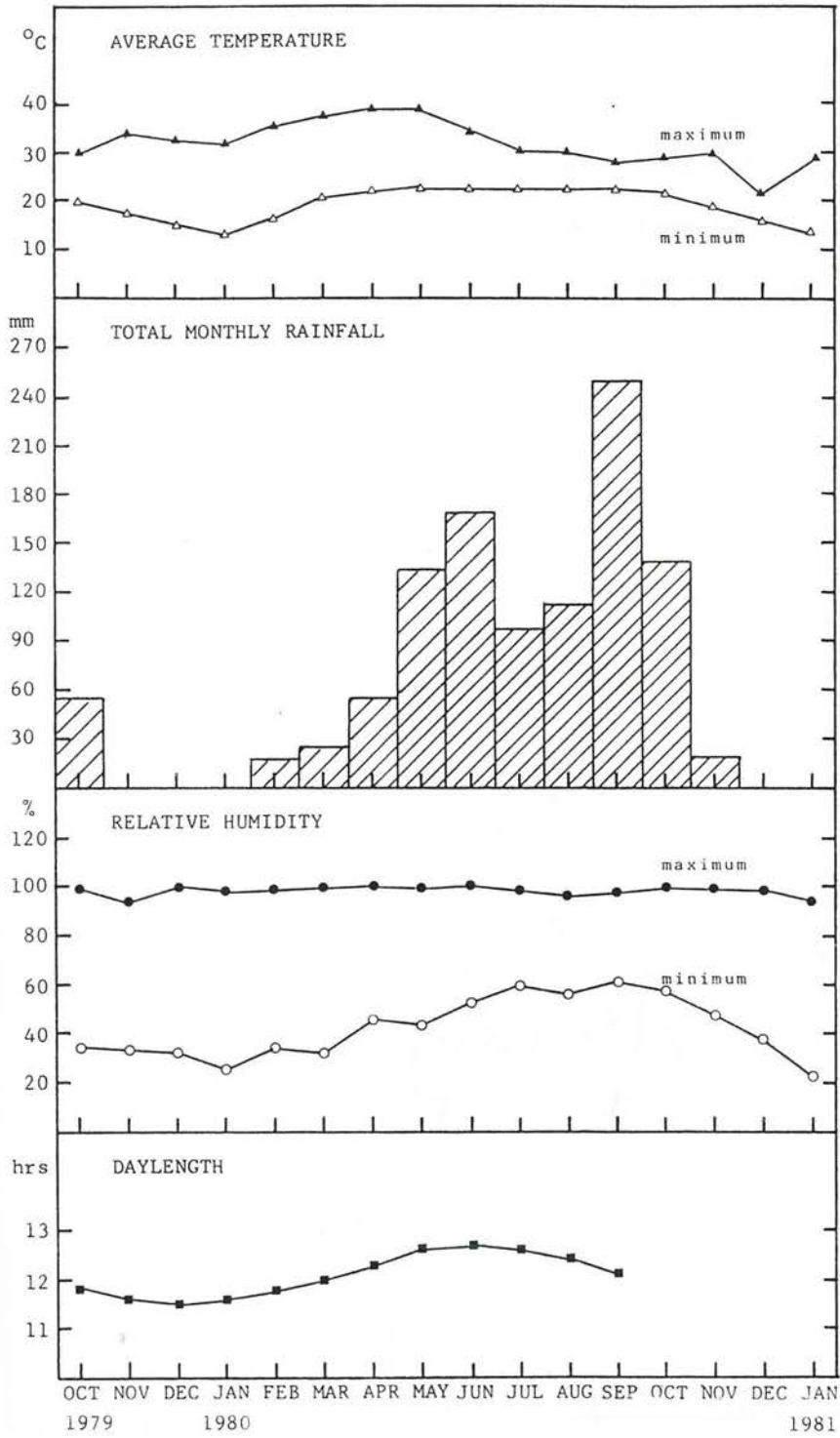
HARVESTING

Days after anthesis

<u>Water Treatment</u>	<u>8</u>	<u>10</u>	<u>12</u>	<u>14</u>	<u>16</u>	<u>18</u>	<u>20</u>	<u>22</u>	<u>24</u>	<u>26</u>
W1	0.00	0.00	0.00	0.00	0.00	0.00	5.00	10.00	38.00	63.00
W2	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
W3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00	0.00	0.00	2.00	3.33	12.67	21.00

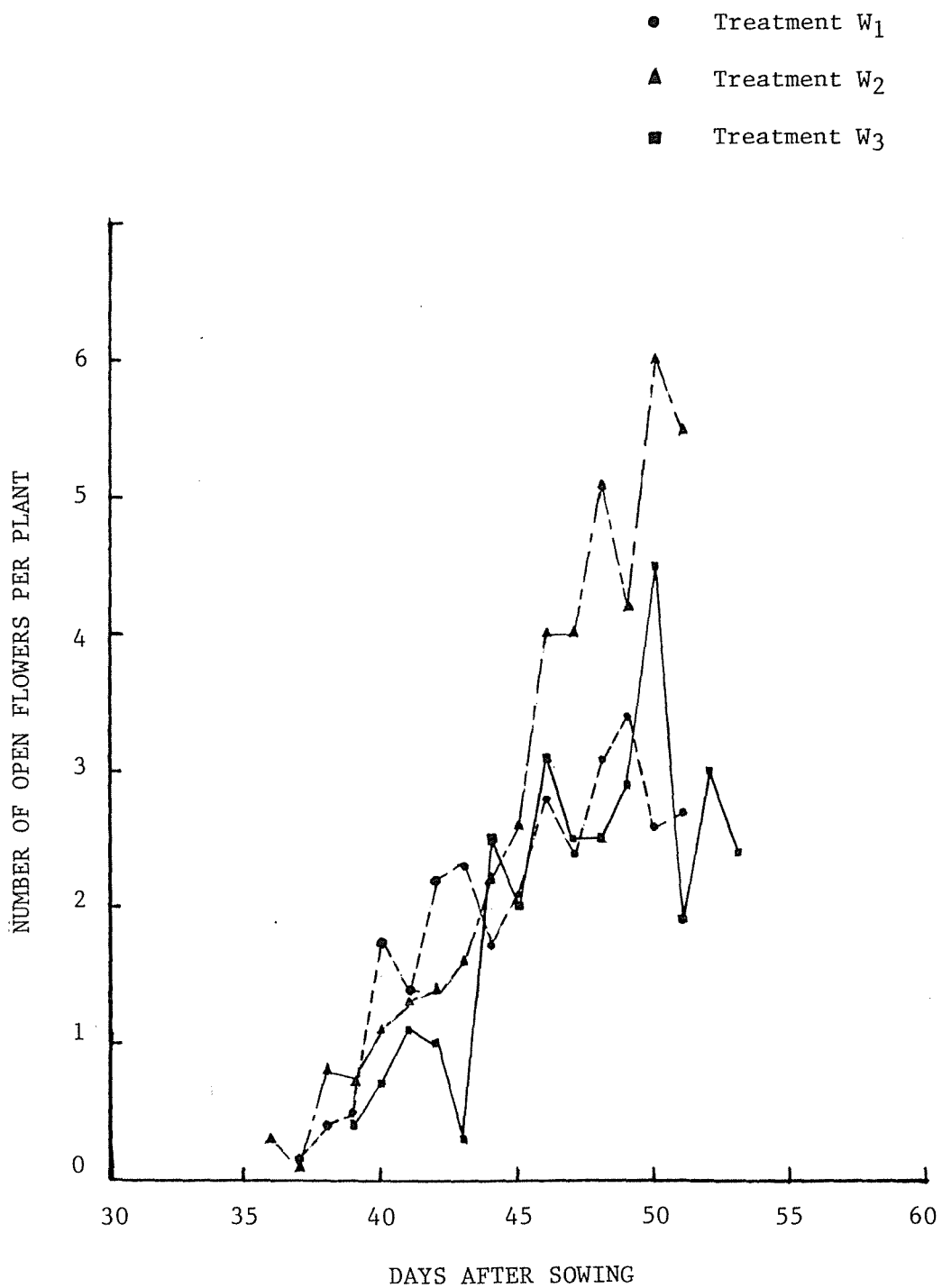


APPENDIX FIGURE 1 STAGES OF PLANT GROWTH DURING FIELD EXPERIMENTS.

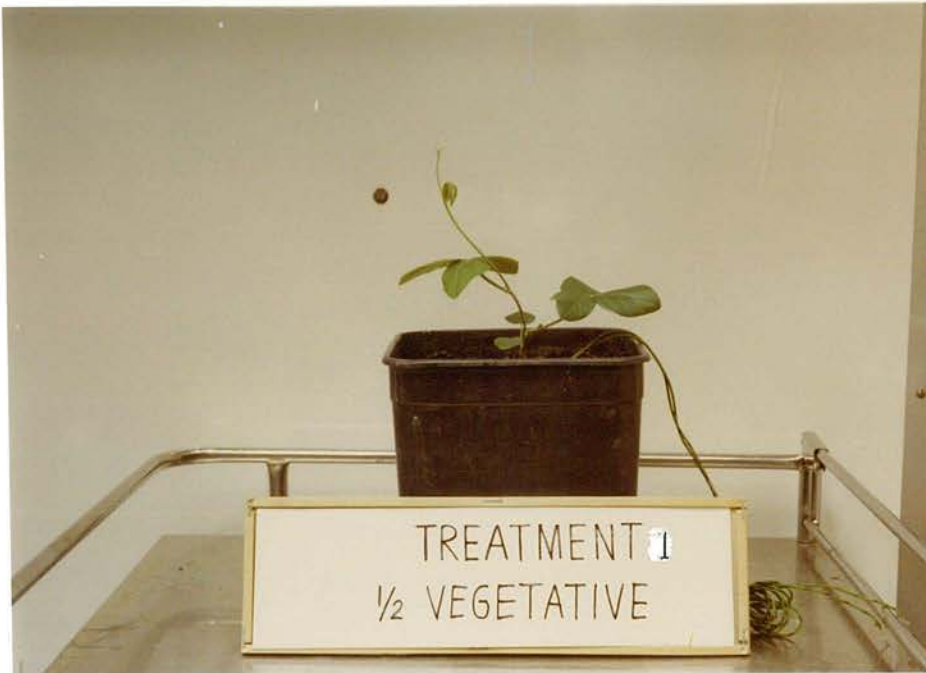


APPENDIX FIGURE 2

CLIMATIC RECORDS DURING FIELD EXPERIMENTS.



APPENDIX FIGURE 3 FLOWERING PATTERN IN EACH WATER TREATMENT.



APPENDIX PLATE 1 HALF VEGETATIVE GROWTH STAGE.



TREATMENT W1



TREATMENT W3

APPENDIX PLATE 2 FLORAL INITIATION STAGES
FOR TREATMENTS 1 AND 3.



APPENDIX PLATE 3 PEAK FLOWERING STAGE.



APPENDIX PLATE 4

PLANT AT 10 DAYS AFTER
PEAK FLOWERING.



APPENDIX PLATE 5

PLANT AT 15 DAYS AFTER
PEAK FLOWERING.



APPENDIX PLATE 6

PLANT AT 20 DAYS AFTER
PEAK FLOWERING.

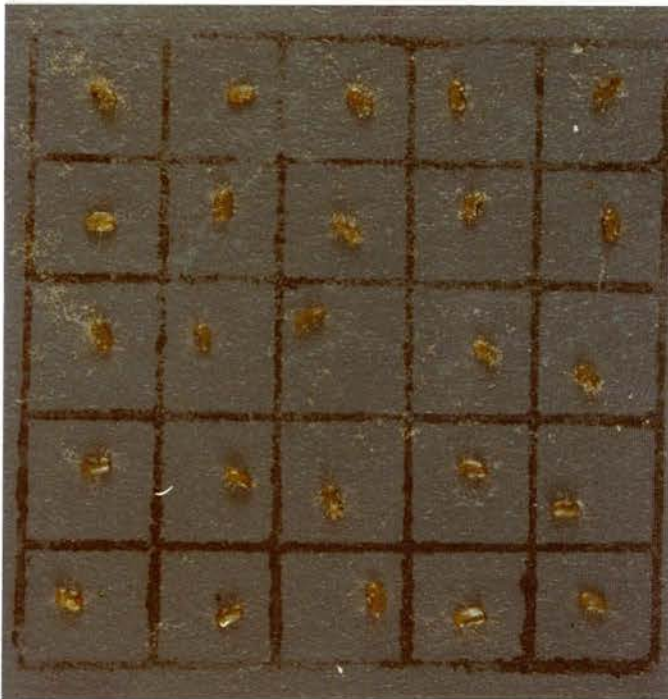


APPENDIX PLATE 7

PLANT AT 25 DAYS AFTER
PEAK FLOWERING.



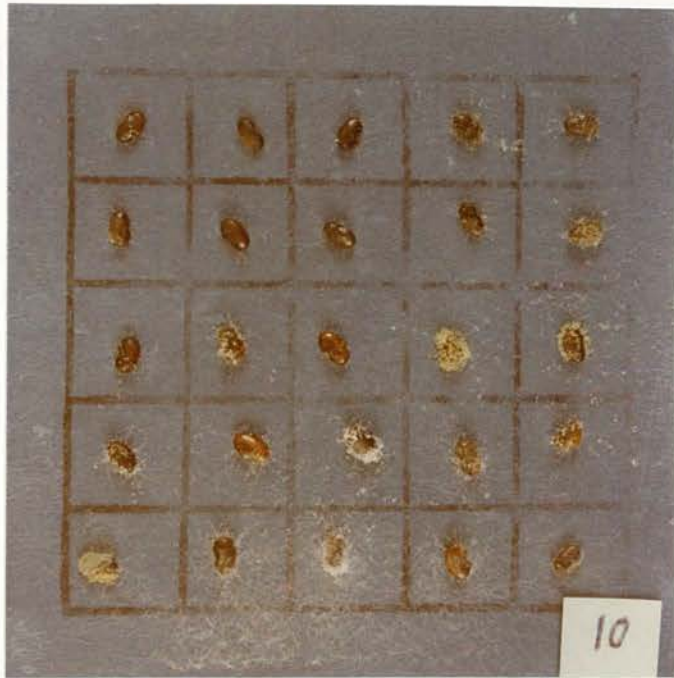
TREATMENT W1



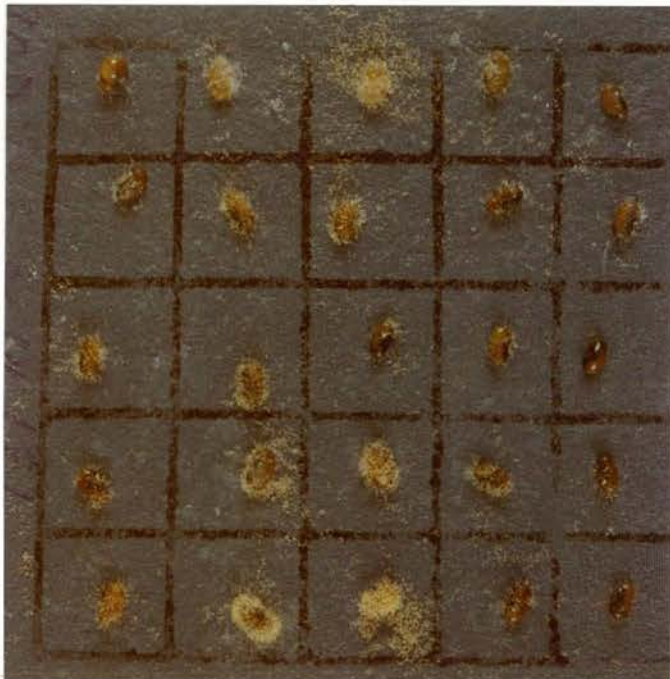
TREATMENT W3
(CONTROL)

APPENDIX PLATE 8

GERMINATION CAPACITY.
COMPARISON BETWEEN SEEDS
FROM TREATMENT W1 AND W3
(CONTROL) FROM PODS AT 8
DAYS AFTER ANTHESIS.



TREATMENT W1

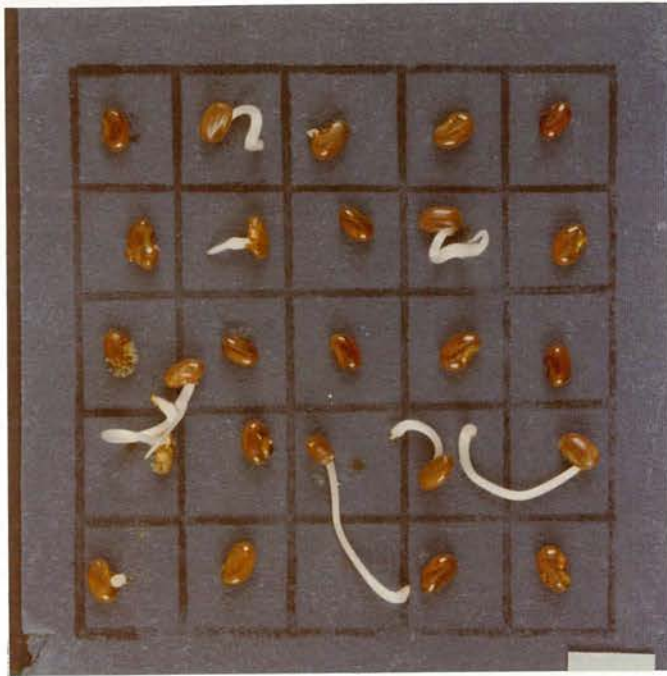


TREATMENT W3

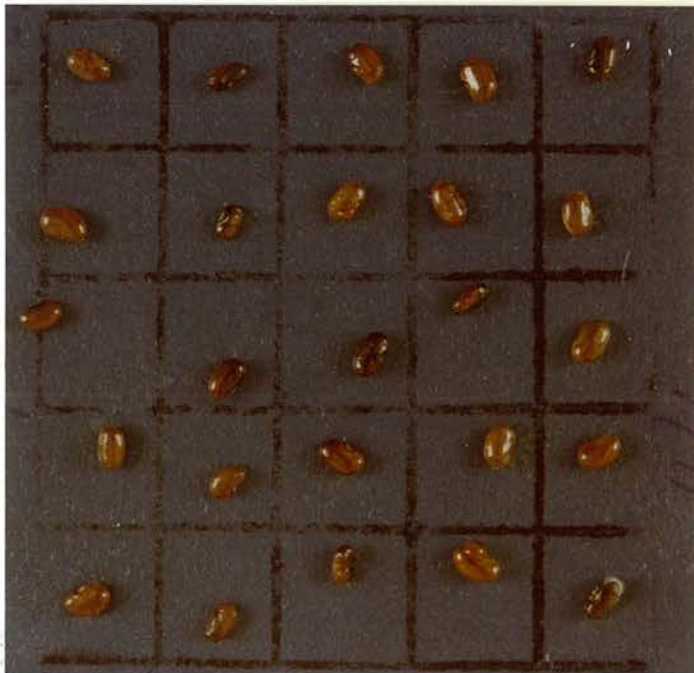
APPENDIX PLATE 9

GERMINATION CAPACITY.

COMPARISON BETWEEN SEEDS
FROM TREATMENT W1 AND W3
(CONTROL) FROM PODS AT
10 DAYS AFTER ANTHESIS.



TREATMENT W1

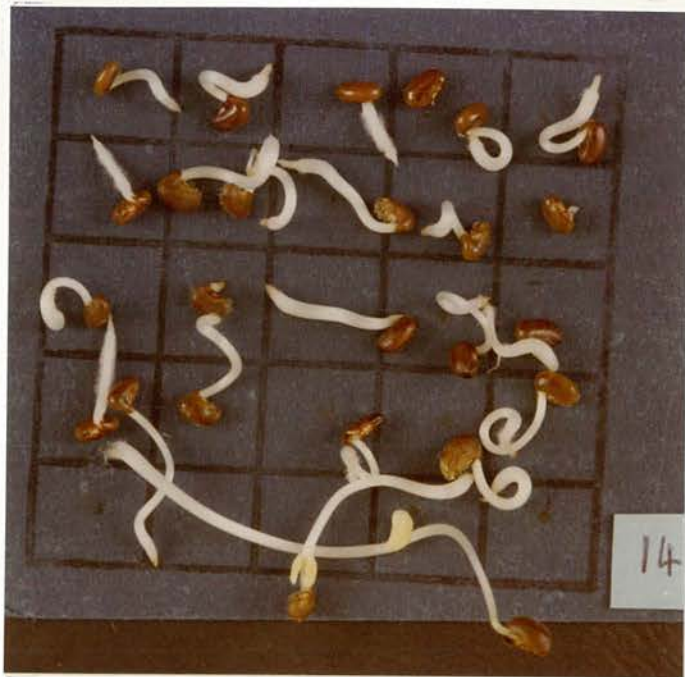


TREATMENT W3

APPENDIX PLATE 10

GERMINATION CAPACITY.

COMPARISON BETWEEN SEEDS
FROM TREATMENT W1 AND W3
(CONTROL) FROM PODS AT
12 DAYS AFTER ANTHESIS.



TREATMENT W1

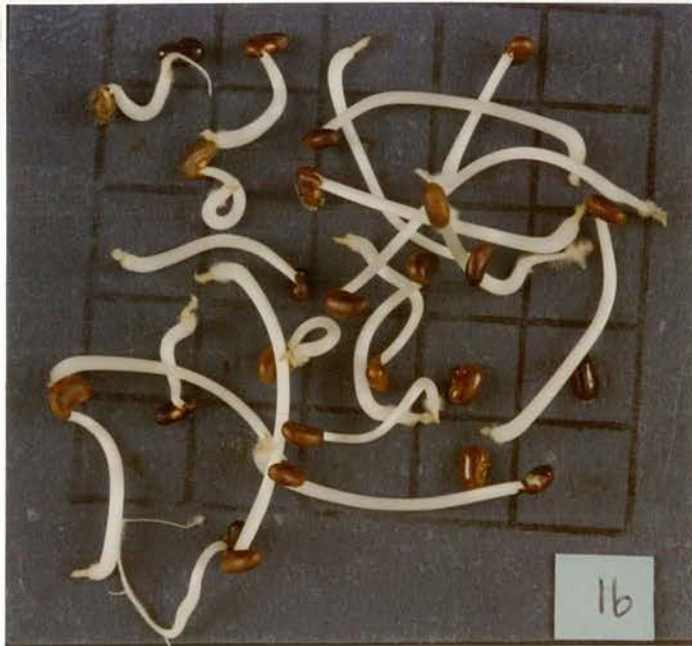


TREATMENT W3

APPENDIX PLATE 11

GERMINATION CAPACITY.

COMPARISON BETWEEN SEEDS
FROM TREATMENT W1 AND W3
(CONTROL) FROM PODS AT
14 DAYS AFTER ANTHESIS.



TREATMENT W1



TREATMENT W3

APPENDIX PLATE 12

GERMINATION CAPACITY.

COMPARISON BETWEEN SEEDS
FROM TREATMENT W1 AND W3
(CONTROL) FROM PODS AT
16 DAYS AFTER ANTHESIS.



TREATMENT W1

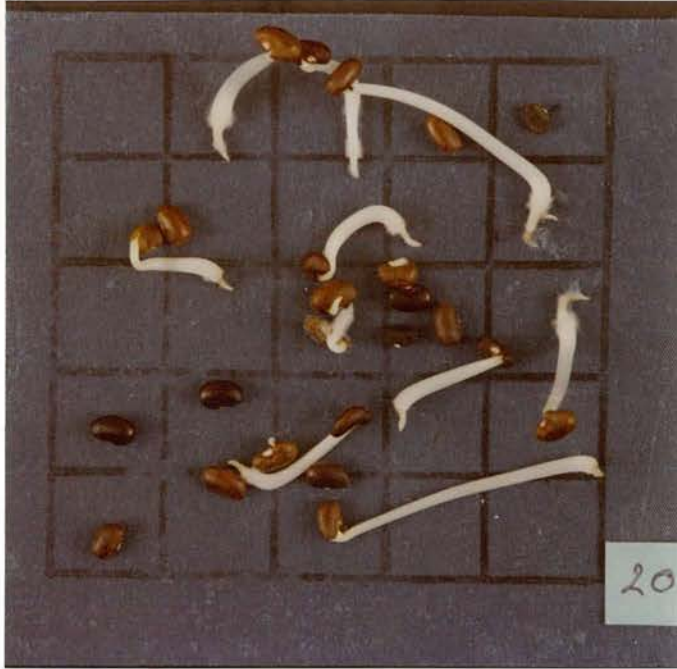


TREATMENT W3

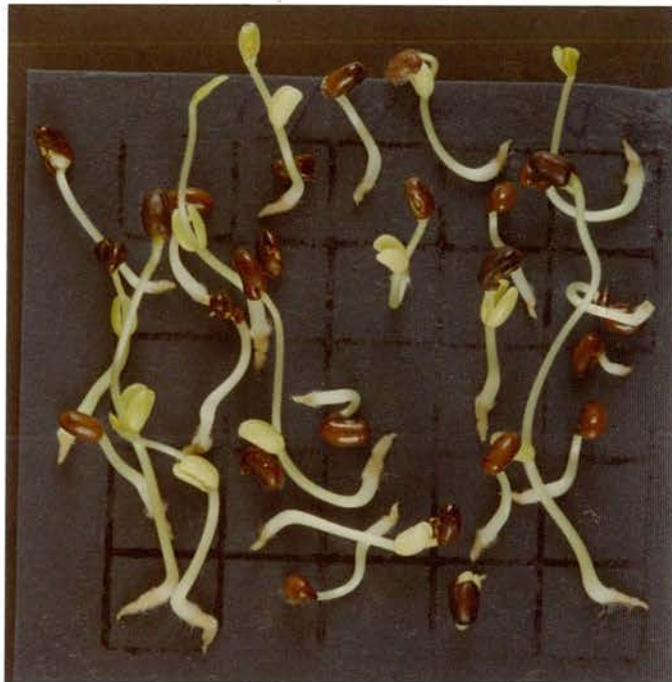
APPENDIX PLATE 13

GERMINATION CAPACITY.

COMPARISON BETWEEN SEEDS
FROM TREATMENT W1 AND W3
(CONTROL) FROM PODS AT
18 DAYS AFTER ANTHESIS.



TREATMENT W1

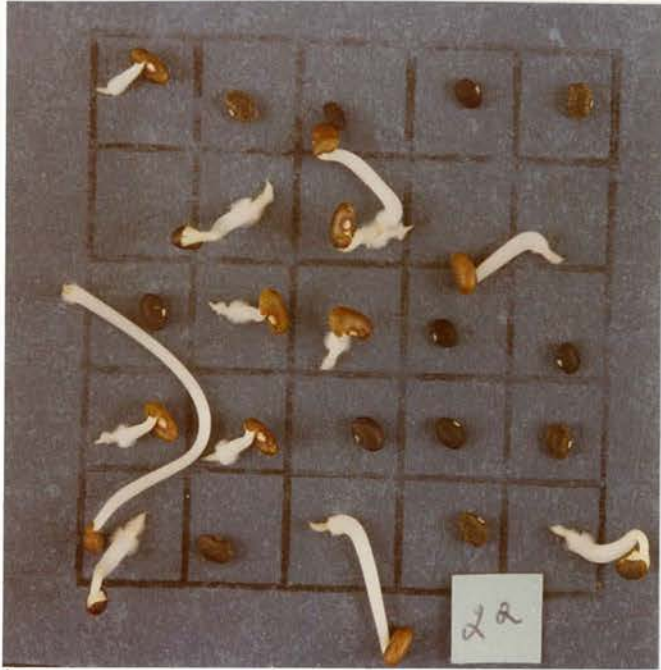


TREATMENT W3

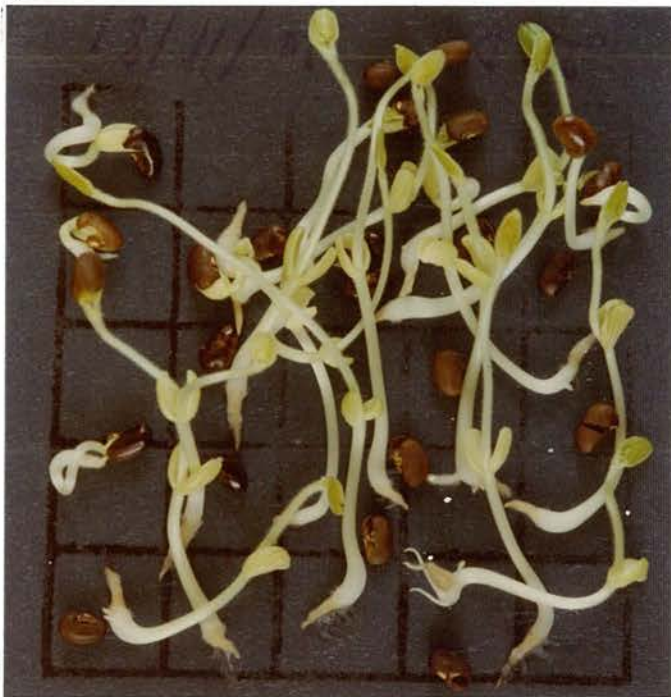
APPENDIX PLATE 14

GERMINATION CAPACITY.

COMPARISON BETWEEN SEEDS
FROM TREATMENT W1 AND W3
(CONTROL) FROM PODS AT
20 DAYS AFTER ANTHESIS.



TREATMENT W1



TREATMENT W3

APPENDIX PLATE 15

GERMINATION CAPACITY.

COMPARISON BETWEEN SEEDS
FROM TREATMENT W1 AND W3
(CONTROL) FROM PODS AT
22 DAYS AFTER ANTHESIS.



TREATMENT W1



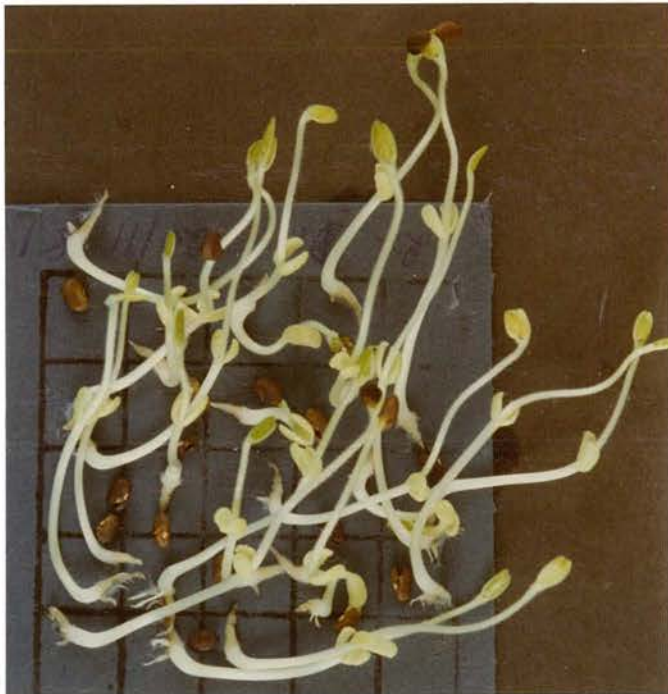
TREATMENT W3

APPENDIX PLATE 16

GERMINATION CAPACITY.
COMPARISON BETWEEN SEEDS
FROM TREATMENT W1 AND W3
(CONTROL) FROM PODS AT
24 DAYS AFTER ANTHESIS.



TREATMENT W1



TREATMENT W3

APPENDIX PLATE 17

GERMINATION CAPACITY.

COMPARISON BETWEEN SEEDS
FROM TREATMENT W1 AND W3
(CONTROL) FROM PODS AT
26 DAYS AFTER ANTHESIS.