Rice Flowering in Relation to Plant Size Under Different Levels of Water Stress

By

ELSHIR ELRAYES MOHAMED ELHAMIN
B.Sc.(Hons.) (University of Khartoum, Sudan) 1977

THESIS

Submitted in partial satisfaction of the requirements for the degree of

MASTER OF SCIENCE

in

Water Science

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA

DAVIS

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ACKNOWLEDGEMENTS

I am deeply indebted to Dr. D. W. Henderson for his guidance, patience, valuable advice, help, and suggestions, and for providing facilities and materials needed for carrying out this work.

I want also to express a very sincere thanks and appreciation to Dr. W. Silk and C. Tucker for their helpful suggestions, interest, and for reviewing this thesis. Thanks and appreciation are also extended to L. Flores for his continuous help and assistance. I wish also to express my gratitude to Evelyn Martinelli for typing the thesis.

The financial assistance of the Sudan Government is gratefully appreciated. My appreciation goes also to the University of California, Davis for making this study possible.

Very special and sincere appreciation goes to my family for their kindness, love, and encouragement.
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1. Introduction

The objective of the work presented here is to study the effect of irrigation treatments on the flowering of beans (*Phaseolus vulgaris*) and to discover the relationship between the number of flowers produced and the plant size. Another goal is to find which plant size parameter is most effective in determining the number of flowers produced and hence the final yield because the leaf area and TDM, as taken by many researchers, may be poor predictors of final yield.

Water is one of the important environmental factors in plant growth. Water is known as a solvent in which most of the metabolic reactions take place. It is also one of the reactants in many important metabolic reactions such as photosynthesis, hydrolysis, and ionization of acids and bases. In most plants, cell enlargement can only occur when there is adequate water supply. It is also known that the loss of water by transpiration helps in keeping the leaf temperature of the plant below the damaging level. Also the flow of the transpiration stream carries ions absorbed by the roots to the leaves, while the flow of phloem stream carries photosynthetic assimilates from the leaves to the growing points and roots. Strong cohesion and adhesion of liquid water are responsible for capillarity by which water is held in soil pores and for the ability of thin columns of water in the plant xylem to withstand tension. In addition water plays a key role in maintaining the complex structure of biological membranes of the plant cells.

The general effect of water availability on plant growth can be shown clearly by comparing the type and density of vegetation in
arid and semiarid zones with that in tropical regions. Usually arid and semiarid zones are characterized by very poor soil cover while the tropical zones support a very rich soil cover. And this difference is mainly due to amount of rainfall in each zone.

Many studies have shown that water stress adversely affects many physiological growth processes of plants. Photosynthesis is reduced by partial or complete closure of stomata which reduces the CO₂ supply. Translocation of carbohydrates and growth regulators is decreased. The effect of a given soil moisture stress conditions on crops are often dependent upon the state of plant growth, the nature of the root system, and any soil factor which affects root density or depth. Also meteorological factors—light, temperature, humidity and wind—are known to control the rate of water loss by transpiration from plant leaves and evaporation from the soil surface (Hagan, 1957).

Plant species show great variation in their abilities to withstand water deficit. Also they vary in their abilities to recover after the release of the water deficit. Even on the same plant, the impact of water stress is not uniform; some plant processes are known to be very sensitive such as cell enlargement and expansion, others, such as photosynthesis and stomatal closure are less affected. The common view of plant response to water stress is that transpiration and net photosynthesis are decreased by stomatal closure when the leaf water potential decreased beyond a critical value (Boyer, 1970).

Series of fractional resistances are known to be involved in the movement of water from the soil, through the plant to the atmosphere.
For such resistances to be overcome, gradients of water potentials along the flow path must be established. These gradients are initiated by the loss of water from the leaves through the stomata to the atmosphere. This water loss continues until the water status of the plant reaches a threshold value at which the stomata start to close. Therefore irrigation should always take place while the soil water content is still high enough to supply the crop with its water requirement to meet the local atmospheric conditions without subjecting it to any kind of water stress that may cause a reduction in yield or quality. Akluwat et al. (1978) found that irrigation at 75, 50 and 25% available soil moisture gave seed yield of 1.53, 1.19 and 0.83 ton/ha in spring compared.

It was known that only a very small fraction of the water taken up by the plant is retained in the plant tissue (12). And this retained water is dependent on the balance between the water uptake and the water loss by transpiration. Hence any decrease in available water can offset this balance between water uptake and water loss due to the increase in the resistance to flow of water through the soil-plant system as the water content of the soil decreases. In addition to the soil water content, resistance to water flow is also determined by root density. In the literature there is an agreement that the best growing and yielding condition can be achieved only if crops are supplied with their full ET (evapotranspiration requirement). No further improvement in crop production was found if full ET was exceeded, and instead the reverse may occurred. Siddique and Goodwin (1980) found that heavy watering of bean plants (P. vulgaris L. cv.
Apollo) with seed ready to harvest caused a reduction in seed vigour. For optimum seed quality, it appeared essential that the seed developed and matured at cool temperature in a dry environment.

Sipos (1981), using data collected during 8-12 year from irrigated crops of barley, wheat, oil seed flax, common bean, potato, sunflower, soybean, maize, sugar beet, clover + ryegrass, clover + cocksfoot and fodder beet, found that uptake of water by these species correlated positively and significantly with increase in growing period ($r = 0.93$).

Plant response to the reduction in the available water depends on the sensitivity of the plant to the water deficit. Generally it was found that deep-rooted crops were more tolerant to water stress than shallow-rooted crops. In many crops the effect of water deficit at certain growth stages was found to be more pronounced than at other and hence water stress during these critical stages should be avoided, to minimize the impact of water stress on crop yielding capacity.
II. Literature Review

A. Introduction:

Effect of water stress is one of the areas which has received considerable attention by researchers due to its impact on growth and yield of many crops. Generally, there is agreement in the literature that the effect of water stress on plant growth and final yield depends on the degree of stress to which the plant is subjected, its duration, and the stage of growth at which it takes place. Plant growth diminishes progressively as the soil moisture content falls below the field capacity with growth ceasing at the wilting point (Hagan, 1957).

Water stress affects the growth rate of a plant in at least two ways: the rate of increase of leaf area is slowed by loss of turgor, and the rate of photosynthesis is decreased by the closing of the stomates and other means (McCree, 1974).

Kramer (1963) reported that plant growth is controlled by the internal water balance and the turgidity of the plant. This balance depends on the relative rates of water loss and water absorption. He also showed a lag in water absorption behind transpiration and he attributed that lag to the high resistance to water movement which exists in roots. He also pointed out the uncertainty of the assumption that a certain level of soil water stress is accompanied by an equivalent degree of plant water stress because plants in moist soil may be subjected to water stress when transpiration is rapid and similarly, plants in dry soil may be subjected to little water stress if transpiration is very low.
Begg and Turner (1976) found that when symptoms of water stress appeared in plant, the soil water content was well above the permanent wilting point (P.W.P.), and that appearance of these symptoms occurred as a result of an imbalance between the water absorbed from the soil and the water lost to the atmosphere. The cause of water stress was attributed to be either excessive loss or inadequate absorption of water or a combination of the two processes.

8. Effect of water stress on rooting pattern and water-nutrient uptake:

Neuman (1974), from his investigations on the rooting density-water relations in P. vulgaris, including three irrigation treatments, (wet, intermediate and dry), concluded that root length density decreased vertically with increasing depth and horizontally with increasing distance from the r.w. Among the three irrigation treatments, he found that the total length density was greater in the intermediate treatment than in the wet treatment. At the same time it was greater in the wet then in the dry treatment, in which there is a reduction in root development throughout the growing season as a result of the severity of the stress.

Normally water uptake or absorption tended to lag behind transpiration because of the resistances (from soil to roots, roots to stem and stem to leaves) involved in the flow of water from the soil into and through the plant to the atmosphere, and because the two processes are controlled by different factors, their rates are different.

Tosso (1978) observed a considerable reduction in soil-water
extraction from saline soil even when there was enough water left in the available range. The failure of roots to extract the available water in the saline conditions was reasoned to be additional effect of osmotic potential produced by the salts.

Prota et al. (1978), investigated the absorption patterns of \( \text{NH}_4^+ \) and \( \text{NO}_3^- \) by \( P. \ vulgaris \) determined under normal conditions (control), NaCl treatment (salt stress) and carboxax treatment, using an inverse isotope technique with \( ^{15}N \). They found that salt and water stress inhibited absorption of both \( \text{NH}_4^+ \) and \( \text{NO}_3^- \). And no difference between these two stress treatments was observed in the uptake of \( \text{NH}_4^+ \), but a restriction in the uptake of \( \text{NO}_3^- \) was noticed in the carboxax treatment. Under NaCl salinity it was observed that the plant absorbed the same amount of \( N \) independently of its source, but under water stress the absorption of \( \text{NH}_4^+ \) was more than \( \text{NO}_3^- \). A high correlation between \( N \) and water uptake was reported.

Erickson and Kirkham (1979) concluded that growth of wheat plants was increased if the root system was split between a moist soil and a nutrient solution rather than plants having all of their roots in a moist soil or all in solution. They suggested that the best condition for maximum growth is zero potential (aerated nutrient solution) for part of the root system.

Sharp and Davies (1979) reported that the maintenance of turgor in the expanding zone of maize roots growing in a drying soil allowed root growth to continue as the drying cycle progressed. In the water stress treatment, no significant reduction in root growth was observed. And their data suggested that on days 4 and 5 of the drying cycle, the
water stressed plants showed a net increase in root growth compared to non-stressed plants.

Champorros (1980) found that mild water stress had non lethal effects. The response was attributed to the regenerative ability of both the root growth and ultrastructure of the epidermal cells. While in severe water stress no regeneration was observed, but instead more structural damage in the cortical cells was observed. He also reported that the more differentiated the cortical cells, the more expansive ultrastructure damage could be when compared with the more-structured non-aerenchymatous cells. And similarly the cells of the peripheral layers of the cortex suffered more from water stress than the cells of the central layers.

Robertson et al. (1980), studying the effect of water stress on root distribution of corn, soybean and peanut, concluded that grain yield of corn is favored by irrigation while root length is favored by mild stress. They also reported that since the highest root length did not correspond with the highest grain yield, the treatment which gave the highest root length was still under a considerable stress. For soybean no significant difference in yield and root length was observed between the three water levels applied. And for peanut, they found that like corn, peanut yield increases as the water input increases. But peanut root penetration was found to be better than that of corn.

C. Effect of water stress on expansible growth and photosynthetic area:
The response of leaf elongation to soil water depletion was dynamic, with the rate decreasing continuously as the soil water
potential decreased from maximum (Azevedo et al., 1971). They found that the highest elongation was at the highest soil water potential (~0.1 bar), and the rate was reduced by 19% when the soil water potential dropped to ~0.1 bar, by 50% when it dropped to ~0.8 bar, and stopped completely when soil water potential decreased to about ~2.5 bar. And they reported a leaf water potential of ~1.8 to ~7.0 bars as a corresponding range to that of the soil water potential. And referring to the adverse effect of water stress, they pointed out the importance of duration of stress as well as its severity.

Begg and Turner (1976), from their review on crop water deficits, reported a drastic reduction in leaf elongation of beans when the leaf water potential reached a value of about ~9.0 bars. Claassen and Shaw (1970) showed that water stress during leaf expansion caused a reduction in source size rather than significant changes in assimilation rate, and this was considered the main factor in explaining the reduction in crop yield.

Remende (1978) reported irrigation regime, temperature, leaf resistance, turgor pressure, and leaf angle as the main factors affecting leaf elongation rate. But Toso (1978) investigated the relationship between leaf temperature and leaf elongation and found no correlation between the two parameters. And the lowest elongation was found to be between 11:00 A.M. and 5:00 P.M. Corresponding to the period of the highest leaf temperature 31-34°C.

Snap bean plants grown under conditions of ample soil water were taller, had more branches and leaves and produced greater fresh weight than stressed plants (Maurer et al., 1965).

Shinn and Lemon (1968) reported that leaf water potential of
corn would have continued to increase with drought until stomatal closure slowed water loss. But growth was being limited when the soil moisture tension in the major part of the root zone was between 0.75 and 1.5 bars, corresponding to a maximum leaf water potential of about 3.5 bars. The reduction in plant growth was assumed to be due to the decreasing leaf water potentials. But apparently the conductivity of the system had not decreased to the point that plant could not sufficiently adjust its water potential and yet growth was being seriously affected.

Beyer (1968) reported that recovery of stressed plants occurred in two phases. The first was associated with elimination of water deficits; and the second with cell enlargement. And this second phase was characterized by a steady rate of water uptake and relatively constant leaf water potential. He also concluded that leaf growth occurred in sunflower only when leaf water potentials were above -3.5 bars. The high water potentials required for growth favored rapid leaf growth at night and reduced growth during the day.

Acevedo et al. (1971), from their investigations on the growth responses of maize leaves to changes in water status, observed that as stress develops in maize, growth is completely stopped before $\text{CO}_2$ assimilation is affected noticeably.

It was found that in a range of water stress the most important processes affected are cell growth, cell wall synthesis, nitrate reductase level, stomatal opening, $\text{CO}_2$ assimilation, respiration, sugar and proline accumulation (Maio and Acevedo, 1974). And they concluded that if water stress is severe and long enough almost any
plant process can be affected.

Cell expansion was found to be the most sensitive plant process to water stress (Usai, 1973). Also it was found that growth and tuber were very closely related. And cell enlargement stopped with loss of turpitude resulting in small plants.

Gouto (1977) concluded that vegetative growth of beans seemed to be the most sensitive plant parameter to water stress. Rapid senescence in severely stressed plants was observed.

Irrigation frequency did not affect canopy development when the crop was irrigated to meet full ET. But it was affected by the degree of water stress (Remenda, 1978). He reported that vegetative growth of kidney bean in the early stages is highly sensitive to water stress.

D. Effect of water stress on leaf water potential, stomata and photosynthetic rate:

Leaf water potential is one of the parameters used to show the effect of water stress on plant growth. The leaf water potential threshold value, at which the stomata closed, was found to vary from crop to crop. Carlson et al. (1979), from their investigations on the relationship between leaf water potential and leaf conductance in soybean, found that leaf conductance was not influenced by the leaf water potential until it became more negative than -13 to -14 bars. But the conductance dropped rapidly after that critical value was exceeded.

A growth chamber study carried out by Jordan and Ritchie (1971) indicated that stomatal closure occurred at potentials near -16 bars. They also reported that stomatal resistance of individual cotton leaves during the day light hours remained nearly constant.
at 2.3 sec per cm even though leaf water potentials approached -30 bars. For unirrigated sorghum it was found that no stomatal closure even though leaf-water potential reached -20 bars late in the season (Pererez et al., 1978). And under similar conditions they reported that stomata closed at -14 to -16 bars in younger plants where water stress was made to develop much faster. For beans, a rapid increase in stomatal resistance was observed by Millar and Gardner (1972) as the leaf water potential declined from -8 bars to lower leaf water potentials. Newman (1974) found that at day 29 (DAP), the minimum mean leaf water potential, measured early in the morning, was -8.9 and -9.3 bars for the wet and intermediate treatment. And the corresponding values obtained at midday (on the same day) were -12.5 and -13.1 bars. At day 73, the minimum mean leaf water potential recorded early in the morning was -6.0 and -6.5 bars for the wet and intermediate treatment. And the corresponding values obtained at the midday were -10.3 and -11.2 bars. Couto (1977) found that the minimum mean leaf water potential at day 42 was -14.7 bars for wet treatment and -15.5 bars for the dry treatment, while at day 79 he found that the minimum mean leaf water potential was slightly lower for the wet than for the dry treatment, and -12.3 and -11.7 bars, respectively, were recorded. The minimum mean leaf water potential at the beginning of the flowering stage obtained by Flores (1980) was -1.3, -4.7, -6.3 and -8.2 bars for the four irrigation levels he applied (100% ET, 75% ET, 50% ET and 25% ET) respectively. While

the values he obtained at the end of the flowering stage were -2.8, -7.1, and -10.7 and -13.3 bars for the same irrigation levels respectively. Flores (1981) found that the minimum mean leaf water potential at the beginning of the flowering stage was -3.6, -5.3, -7.2 and -9.0 bars. While the values obtained at the end of the flowering stage for the 100% ET, 50% ET and 25% ET were -3.1, -11.9 and -14.9 bars, respectively.

On sugarcane it was found that a -4.4 bar stress reduced photosynthesis by 18% and translocation by 93% and it was thought that the primary influence of water stress was on translocation, but Moobinot et al. (1979) suggested that the primary influence of water stress was on photosynthesis. Stomata of corn and sorghum responded to changes in leaf water potential during the vegetative growth phase. But during reproductive growth, leaf resistances were minimal and stomata were no longer sensitive to bulk leaf water status even when leaf water potentials approached -27 bars (Ackerson and Krieg, 1977). They also found that under non-limiting soil water conditions, sorghum exhibited the greatest efficiency of water transport compared to cotton and corn, while under limiting soil moisture conditions, cotton appeared most efficient. For corn it was found to be the least efficient with respect to stomatal regulation of water use. It is generally recognised that the stomata do not respond to changes in leaf water potential until a critical threshold value is reached, and they close over a range of leaf water potential. However it was found that there was no unique value of leaf water potential for
stomatal closure in any particular species or cultivar, but the leaf water potential for stomatal closure varies with position of the leaf in the canopy.

Neuman (1974) found that the differences in leaf water potential between the wet and intermediate treatments were relatively small and did not reflect the marked difference observed in plant growth. Similar results were obtained by Couto (1977) who reported that there was no significant difference between irrigated and unirrigated plants, although the stressed plants showed always slightly lower values of leaf water potentials during midafternoon hours.

The effect of low leaf water potential in reducing production of new leaf area and reducing photosynthetic activity per unit area was reviewed and it was found that leaf production was most sensitive to water deficit since lack of turgor inhibited leaf expansion and that prolonged stress induced leaf senescence.

McCree (1974), from his investigations on sorghum under water stress, reported that the responses of plant leaves grown in "hot, dry" and "warm, humid" atmospheric conditions were different. Plant leaves which had been subjected to five cycles of moderate soil moisture stress, as well as "hot, dry" atmospheric conditions, had stomates which were less sensitive to decreasing leaf water potential than the stomates of plant leaves grown under well-watered conditions.

Resende (1978) found that irrigation regimes at different levels of water used by beans did not affect the leaf resistance values. A similar result was obtained by Tossas (1978) who reported that stomatal resistance did not vary for different irrigation levels but it varied
with time. And a delay in reaching a certain ground cover was observed in the treatment which received less water.

A study by O'Toole et al. (1977) showed that as the stress increased, net photosynthesis and transportation rates were near zero at -9 to -10 bars while the CO\textsubscript{2} compensation point reached its highest level in this leaf water potential range.

Bunce (1977) found that mild water stress increased leaf area by increasing the number of epidermal cells per leaf while more severe stress, although also increasing the number of cells per leaf, did not alter leaf area because cell size was reduced.

Boyer (1976) and Hsiao (1973) showed that a reduction in respiration rate per unit leaf area occurred as the leaf water potential decreased.

Couto (1977), from his wet, symptom, pod and dry treatments, found a maximum leaf area index (LAI) of 4.3 for the wet treatment and 3.2, 2.2 and 1.6 for the other three treatments respectively. And this illustrates the reduction effect of water stress on LAI.

There is indirect evidence that water stress inhibits not only transport of CO\textsubscript{2} from the atmosphere to carboxylation sites in chloroplasts, but also its conversion into photosynthate. Both transport and biochemical processes were influenced at the level of leaf water potential (Pospišilova et al., 1976).

Millar and Gardner (1972) concluded that factors such as light level, nutritional status and CO\textsubscript{2} concentration controlled the transpiration rate in snap beans in the field until the leaf water potential decreased below -8 bars; below that the transpiration rate declined
with reduction in leaf water potential. It can be concluded that photo-
synthesis declines initially as a result of stomatal closure, but
prolonged and severe water stress can lead to depression of chloro-
plant and enzyme activity and to nont stomatal effects on photosynthesis
(Mego and Turner, 1976).

E. Effect of water stress on flowering:

In the literature, most of the findings concerning the effect
of water stress on flowering of beans are related to the sensitivity of
the flowering stage compared to other developmental stages, or to
the general effect of reduced source size, as a result of water
stress, on production of flowers and other reproductive structures.

Hauer et al. (1968) found that snap bean plants growing under
conditions in which irrigation was applied when the soil water fell
to 88% of available were taller, heavier and produced more pods than
plants irrigated when the soil water fell to 60%. They also reported
that plants irrigated when the soil water reached 32% of available
were small and had a low yield. And from their investigations they
concluded that plants grown under high water stress conditions before
bloom recovered if ample water was provided after blooming, but didn’t
yield as well as plants provided with ample water throughout the
growing period. The reason for the greatest yield of pods reported
in the ample soil water treatment was mostly the production of greater
number of seeds and secondarily to increased size of bean plants.

While the differential response to water at various stages of
growth has not been reported for all plants, there is considerable
evidence that most determinate crops are especially sensitive to

water deficits from the time of floral initiation, during flowering, and, to a lesser extent, during fruit and seed development. But in indeterminate crops, where these stages overlap, the situation is less clear. Perennial crops are sensitive to water deficits at the same stages, but it is doubtful whether the sensitivity during fruit development is more pronounced than it is during vegetative development (Begg and Turner, 1976). Miller et al. (1972) investigated the response of southern peas to different levels of water deficit at three different stages of growth (vegetative, flowering and early pod formation stage) and from their investigations they reported the flowering period as the most sensitive stage, regardless of the deficit level, followed by the vegetative stage, while the pod development stage was found to be the least sensitive to the levels of water deficit applied.

On a sandy loam soil, no increase in yield of peas resulted from irrigation before flowering (Saltar, 1962). Phaseolus vulgaris cv. IPN-74-18 was given optimum irrigation except for period of 8-29 days starting at the beginning of flowering. Seed yields decreased from 2.22 t/ha (with no stress) to 1.02 t/ha (with stress period of 29 days). With a 26-day stress period, the number of pods/plant decreased from 9.65 to 6.42, and the number of seeds/pod decreased from 5.67 to 4.83 in the same treatment (Magalhaes and Miller, 1978). From a separate study, Magalhaes et al. (1979), reported the beginning of flowering as the most critical period for water stress which, at this stage, caused a seed yield reduction of 36.8%; stress at full flowering reduced seed yield by 33.6%. 
Lahmauskas et al. (1981) found that water stress, during flowering and pod filling stages, reduced seed yield by 44 and 29%, respectively, compared with an adequately irrigated treatment. Water stress during the vegetative period did not significantly affect seed production. Water stress during both flowering and pod filling stages reduced yield by 67%. A series of glasshouse and growth-cabinet experiments was carried out to show aspects of flowers and pod production in *P. vulgaris*. Abscission of flowers and immature pods varied between 45-80% in 7 cultivars tested, with flowers which opened first being most likely to produce mature pods (Binnie and Clifford, 1981). Similar results were obtained by Subbaiah and Subbaiah et al. (1979). Flowering and pod setting in *P. vulgaris*, cv. Tambo and Rostihaift, were investigated by Silveira et al. (1980). In both cv. the flower set and the number of seeds per pod decreased with increasing plant age.

Bennett et al. (1977) pointed out the importance of high number of nodes per branch and branches per plant on yield component of *P. vulgaris*.

Bean plants which received less water in the preirrigation and did not receive any irrigation were stunted, and flowering was delayed (Ozaso, 1977). He also found that the number of flowers was less on the smaller plants in stressed treatments. Flores (1980) found that as the amount of irrigation water applied reduced to 75% ET, 50% ET and 25% ET, the corresponding reduction in number of flowers per plant of bean produced, relative to the control (100% ET), was 21.9%, 59.7% and 75.0% respectively.
Walker and Hatfield (1980) reported that kidney bean yield was more sensitive to crop water deficits prior to the seed-filling stage. Water stress restricted canopy light interception and yield through its effect on leaf number and size.

The response of several growth parameters of bean plants, including leaf area, number of pods, root weight, N production, yield, to water stress and N fertilizer was measured, and from these measurements, it was found that all growth parameters except root weight were significantly affected by either water stress, N fertilizer, or both (Sims et al., 1980). And they concluded that water stress during the flowering period had the greatest negative effect on most plant size parameters.

F. Effect of water stress on dry matter (D.M.) accumulation

Dry matter accumulation is essentially determined by the source intensity and the photosynthetic rate. Mauer et al. (1968), from an experiment with five soil-water regimes, concluded that D.M. content of bean pods was highest in treatments receiving high soil water stress during the post-blossom period. Millar and Gardner (1972) showed a curvilinear reduction in transpiration and D.M. production rates as the water stress increased and a 47% reduction in D.M. production rate was observed when the soil water potential decreased from -0.28 to -0.68 bar, and this reduction was attributed to reduced turgor-pressure. McPherson and Boyer (1977), working with maize under controlled environment, found that translocation was less inhibited than photosynthesis during drought, and the total photosynthetic accumulation for the growing season controls yield during drought that does
not disrupt the flowering processes. Resende (1978) reported that total D.M. accumulation decreased by about the same proportion as the reduction in ET, independent of irrigation frequency, indicating the importance of source size as affected by the degree of water stress in determining the total D.M. Similar results were achieved by Tosso (1978).

Couto (1977) reported that the partitioning of assimilates to different plant parts was not affected by mild stress and gradually increasing water stress, but with very strong water stress the pattern of D.M. distribution was markedly disrupted. He also reported that the total D.M. production for dry treatment was reduced by 66% in comparison with the control treatment. Thus the stress was severe enough to affect drastically the formation of reproductive organs, reducing assimilate sink size, which in turn allowed more assimilates to be diverted to other plant parts (leaves, stems, and roots).

G. Effect of water stress on yield:

Final crop yield, which is closely related to D.M. accumulation during the growing season, is directly affected by changes in CO₂ assimilation, which is mainly controlled by the stomata. But when a nonstomatal effect is present it is considered as important as the stomatal effect. And the stomata remain unaffected until the leaf water potential drops to a threshold value (Haiso, 1973).

Yoshida (1972) reported that leaf area growth is closely correlated with spikelet formation and grain yield. He also showed existence of a close correlation between leaf area index at flowering and number of spikelets per unit land area. 20% reduction in yield of dry
beans was reported by Robins and Domingo (1956) when a visible moisture stress persisted for 15 days prior to blooming, 18-22 days at blooming, and about 75 days prior to ripening of the first pod. Vegetative yields were reduced to a greater degree and by shorter stress intervals during blooming and late in the season.

Horn and Hajebadi (1970), from their work with chickpeas, cow peas, and dry beans grown under different soil moisture levels, found that moisture stress (irrigated when 2/3 of available water was depleted) reduced grain yields 18 to 20% below the maximum value. The yield reduction was observed to be most pronounced when the moisture stress occurred during blooming and early maturity.

Miranda and Belman (1977), from 2-year study on the effect of water stress and frequency of irrigation on beans, found that irrigation frequency significantly affected seed yield in both years. When two irrigation regimes were imposed (75% and 50% available soil moisture), it was found that the effects of water stress were greater under the 30% available soil moisture. Arruda et al. (1980), from their investigations on the effect of rainfall on yield of beans reported that the greatest yield increase per mm increase in rainfall was 66 kg/ha—during the period 30 to 40 days after sowing.

On sandy soil, no increase in yield resulted from irrigation before flowering, provided that the soil was at or near field capacity when the seed was sown. But application of small quantity of water a few days before harvest, when the pods were swelling greatly increased the yield of marketable pods and shelled peas (Salter, 1962 and 1963).

In a greenhouse experiment, Miller et al. (1972) investigated
the response of southern peas to different levels of water deficit (-14, -21 and -38 bars) at three different stages of growth (vegetative, flowering and pod development), and from their investigation they found that the flowering period was the most sensitive stage, regardless of the deficit level, while the pod development stage was found to be the least sensitive.

Lewis et al. (1974), studying the effect of water stress on grain yields of sorghum, found that yields were reduced by 17% when the soil water potential dropped to -12.9 bars during the late vegetative to boot stage while the reduction in yield was 34% and 19% when the same drop in soil water potential occurred during the boot through bloom stage, and the milk through soft dough stage, respectively.

Plants stressed during flower induction and flowering of soybean produced fewer flowers, pods, and seeds than controlled plants because of a shortened flowering period and abortion of some flowers (Slavit and Kramer, 1977). They also reported that stress during early pod formation caused greatest reduction in number of pods and seed at harvest. However, yield measured by weight of seeds was reduced most by stress during early formation and pod filling. Water deficit at a critical stage of development in a determinate crop can markedly reduce the economic yield with a smaller effect on total above ground dry matter yield (Begg and Turner, 1976). And a 70% reduction in grain yield of wheat was reported from a water deficit imposed five weeks prior to ear emergence, but the reduction in total DM, by the same treatment was found to be only 52%. Hoffman et al. (1978) found that growth and pod yields of L. vulgaris exposed to a hot, dry
environment for two weeks during the vegetative stage were similar to the plants continuously in a cool, humid environment. Exposure to hot, dry conditions during flowering reduced yields significantly, but not to the level of plants continuously in a hot, dry environment. They also reported that increasing salinity reduced growth of all plant parts and reduced pod yield more than vegetative growth. Beans grown in a cool, humid environment were more tolerant to high salt levels.

Tolenaar and Daynard (1978) indicated that an increase in leaf area corresponded to an increase in final yield of maize. And they suggested that the source size duration (during grain filling stage) as a major limitation on grain yield. They concluded that an improvement in grain yield, analyzed in terms of assimilate supply to the grain and the potential of the grain to accommodate assimilate, can be achieved by extending the leaf area duration after flowering stage and by an increase in leaf area per unit plant. Facts (1978), from his comparison between high and normal irrigation frequency on sorghum, found that leaf area, percentage of ground cover, total D.M., and yield were drastically reduced in the treatments that were irrigated at rates equal to 50% of maximum ET as compared to nonstressed treatments. Flores (1980) found that when four levels of irrigation water was applied (100% ET, 75% ET, 50% ET and 25% ET), the percentage reduction in number of bean pods produced, relative to the control (100% ET), was found to be 0, 14.5, 51.1 and 73.5 respectively. Tossa (1974) showed a linear relationship between total D.M. and seasonal ET in kidney beans, and a similar relationship between ET and final yield. Newman (1976) found that seed yields of beans
in the wet treatment were significantly higher than in the intermediate and dry treatments, followed by the intermediate and the dry treatments gave the lowest seed yield. And be concluded that the plant symptoms of water stress were not good indicators for timing irrigation, since a significant reduction in yield occurred. He also noticed that the total D.N. produced by the plant tops at time of harvesting followed the same tendency as seed yields, and with severe water stress there was a general reduction in tops and roots growth and a proportional seed reduction.

As many studies pointed out the adverse effect of water stress severity, timing and duration on plant development and crop yield, the importance of water stress is also dependent on whether the economic yield is based on the fresh weight or on the dry weight component of the yield.
III. Materials and Methods

A. Treatments and experimental design:

The experiment was conducted during the summer of 1981 (from August 7 to September 27). Two varieties of bean (Phaseolus vulgaris), of different growth habits, were used to show their response to the different levels of water stress applied.

The experiment consists of five treatments and each treatment was replicated six times. And a complete randomized design was used. For the treatments description see Table 1.

Sixty plastic pots, (thirty pots for each variety) of equal sizes and weights, were used. And each pot has the following dimensions:

- A base diameter = 18.1 cm
- A top diameter = 20.5 cm
- Pot height = 21.0 cm

B. Location and soil-crop description:

The experiment was carried out at the University of California, Davis, in the water science greenhouse. Columbia silt loam soil was used and it is characterized by its light grayish brown color, friable silt loam texture. Water content at different soil water tensions is shown in Table 2 and by Figure 1.

The soil was sterilized before being placed in the pots. In order to avoid variation in amount of soil between pots, total weight of each pot was 7.0 kgm (soil + pot). The soil surface was about 3.2 cm below the top of the pot for application of irrigation water. Hence the soil was compacted to the same level on each pot.

A mixture of the fertilizer (16-20-0 and 21-0-0) was prepared in a ratio of 3:1 and 4.0 gms of this mixture was added to each pot.
<table>
<thead>
<tr>
<th>Treat. No.</th>
<th>Amount of irrigation water applied (%)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>preirrigation + daily 20% of ET applied</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>preirrigation + daily 40% of ET applied</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>preirrigation + daily 60% of ET applied</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>preirrigation + daily 80% of ET applied</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>preirrigation + daily 100% of ET applied</td>
</tr>
</tbody>
</table>

ET = evapotranspiration
Table 2: The moisture content of the Columbia silt loam soil at different soil water tensions.

<table>
<thead>
<tr>
<th>Soil water tension (-bara)</th>
<th>% of water content by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/10</td>
<td>39.3</td>
</tr>
<tr>
<td>1/3</td>
<td>19.91</td>
</tr>
<tr>
<td>1/2</td>
<td>15.66</td>
</tr>
<tr>
<td>1</td>
<td>13.67</td>
</tr>
<tr>
<td>2</td>
<td>10.98</td>
</tr>
<tr>
<td>5</td>
<td>8.38</td>
</tr>
<tr>
<td>15</td>
<td>6.70</td>
</tr>
</tbody>
</table>

*Data from laboratory of D. W. Henderson, University of California, Davis.*
Fig. 1. The moisture content of the Columbia silt loam soil at different soil water tensions.

Soil water tension (cm. abs.)

Water content by weight (%)
and mixed thoroughly with the soil.

The varieties of Phaseolus vulgaris were: variety (A)—Sacramento light red kidney. Variety (B)—pink type 79/63. Variety (A) is a vining bean, with determinate growth habit, long internodes, large trifoliate leaves, and purple flowers, while variety (B) is a bushy type, with indeterminate growth habit, relatively small trifoliate leaves thick stem, very short internodes and white flowers.

C. Preferrigation, planting and cultural practices:

On August 7, 1981, the total weight of each pot was increased to 8.5 kg by adding one litre of Hoagland solution followed by half litre distilled water. Three days later, five seeds from each variety were sown per pot, and five days after planting (DAP), emergence of the seedlings started. At 7 DAP, complete seedling emergence was observed. At this time a small volume of distilled water was added to each pot to maintain good establishment of seedling. At 9 DAP the seedlings were thinned to 1 plant per pot, and two days later to one plant per pot by selecting a well established and centrally located plant. Then each pot was weighed and the weight again raised to 8.3 kg by adding distilled water. The pot surfaces were covered with an aluminum foil to cut down the loss of water due to evaporation to a minimum value, and this considered the beginning of the treatments (11 DAP).

During the growing period the plants were usually sprayed twice a week with malathion because of the infestation of white flies, and half concentration was used to avoid damage to the plants.
D. Evapotranspiration determination and application of irrigation water:

Evapotranspiration (ET), which is the combination of the water loss due to evaporation from the soil surface and the water loss due to transpiration, was determined by a daily weighing of the control pots and comparing the weight of each pot to its weight 24 hours earlier. Hence the daily water loss was measured and the water needed to be applied to each treatment was calculated. Then each pot was irrigated according to the ET level it was supposed to receive.

This water management was done manually, and it was carried on throughout the experimental period. The irrigation water used was distilled water to avoid the salinity effect of the tap water. Also the temperature and the relative humidity inside the greenhouse, as a major climatic factor in determining the energy supply needed for ET, were recorded, and the daily maximum and minimum values are shown in Table 3.

E. Measurements of plant growth and flowering:

At the end of the flowering period, the number of branches, height of the plant, number of leaves, leaf area and plant tops total dry matter (TDM) were measured as parameters for plant size.

Flowers began to appear at 30 DAP. No difference in the flowering time was observed between the two varieties. During the flowering period, the daily emerging flowers were counted and recorded. Then the total and average number of flowers produced by each treatment were calculated. After cessation of emergence of flowers, the plants were cut from the soil surface in the pot. Each plant was placed in
Table 3: Daily maximum and minimum temperature and relative humidity inside the greenhouse.

<table>
<thead>
<tr>
<th>Date</th>
<th>Temp. (°F)</th>
<th>R. Humidity</th>
<th>Date</th>
<th>Temp. (°F)</th>
<th>R. Humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>max.</td>
<td>min.</td>
<td>max.</td>
<td>min.</td>
<td>max.</td>
</tr>
<tr>
<td>8/20</td>
<td>93</td>
<td>67</td>
<td>76</td>
<td>42</td>
<td>9/9</td>
</tr>
<tr>
<td>8/21</td>
<td>100</td>
<td>68</td>
<td>72</td>
<td>33</td>
<td>9/16</td>
</tr>
<tr>
<td>8/22</td>
<td>98</td>
<td>67</td>
<td>72</td>
<td>36</td>
<td>9/11</td>
</tr>
<tr>
<td>8/23</td>
<td>87</td>
<td>67</td>
<td>72</td>
<td>10</td>
<td>9/12</td>
</tr>
<tr>
<td>8/24</td>
<td>91</td>
<td>68</td>
<td>74</td>
<td>17</td>
<td>9/13</td>
</tr>
<tr>
<td>8/25</td>
<td>94</td>
<td>68</td>
<td>72</td>
<td>42</td>
<td>9/14</td>
</tr>
<tr>
<td>8/26</td>
<td>98</td>
<td>68</td>
<td>78</td>
<td>14</td>
<td>9/15</td>
</tr>
<tr>
<td>8/27</td>
<td>110</td>
<td>68</td>
<td>76</td>
<td>12</td>
<td>9/16</td>
</tr>
<tr>
<td>8/28</td>
<td>98</td>
<td>68</td>
<td>75</td>
<td>38</td>
<td>9/17</td>
</tr>
<tr>
<td>8/29</td>
<td>92</td>
<td>68</td>
<td>75</td>
<td>18</td>
<td>9/18</td>
</tr>
<tr>
<td>8/30</td>
<td>88</td>
<td>68</td>
<td>80</td>
<td>52</td>
<td>9/19</td>
</tr>
<tr>
<td>8/31</td>
<td>92</td>
<td>67</td>
<td>77</td>
<td>65</td>
<td>9/20</td>
</tr>
<tr>
<td>9/1</td>
<td>90</td>
<td>67</td>
<td>78</td>
<td>48</td>
<td>9/21</td>
</tr>
<tr>
<td>9/2</td>
<td>90</td>
<td>67</td>
<td>77</td>
<td>30</td>
<td>9/22</td>
</tr>
<tr>
<td>9/3</td>
<td>90</td>
<td>67</td>
<td>77</td>
<td>31</td>
<td>9/23</td>
</tr>
<tr>
<td>9/4</td>
<td>92</td>
<td>68</td>
<td>79</td>
<td>44</td>
<td>9/24</td>
</tr>
<tr>
<td>9/5</td>
<td>91</td>
<td>67</td>
<td>78</td>
<td>46</td>
<td>9/25</td>
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<tr>
<td>9/6</td>
<td>92</td>
<td>63</td>
<td>77</td>
<td>17</td>
<td>9/26</td>
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<tr>
<td>9/7</td>
<td>88</td>
<td>67</td>
<td>80</td>
<td>12</td>
<td>9/27</td>
</tr>
<tr>
<td>9/8</td>
<td>90</td>
<td>67</td>
<td>74</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>
a plastic bag and all the samples were transported to UC Davis field house where the number of branches and number of leaves for each sample were counted and recorded. Also the plant height and leaf area for each sample were measured and recorded too. For the leaf area measurement a photoelectric leaf area meter was used and the cumulative leaf area for each sample was obtained. Only green leaves, excluding the petioles, were used in the leaf area measurement.

After the leaf area measurement, the tops of each sample were placed in a paper bag and used for dry matter determinations after being dried in an oven for 72 hrs at 60°C. And hence the T.D.M. for each sample was recorded.

F. General Observations:

The overall plant growth and development was followed by visual observations, and it was noticed that the stressed plants of the two varieties, regardless of their genetic differences, showed a reduction in their expansive growth and this reduction was observed to be greater as the amount of irrigation water (expressed as percentage of ET) was decreased, especially with advance of the growth period. Also stressed plants showed a change in color to a darker green with increasing level of water stress and its duration.

Toward the end of the flowering period, slight leaf senescence was observed on the more stressed plants than on the less stressed ones.

Also two weeks from planting, the plants representing the first and second replication in the control treatment for variety (b) showed stunted growth, smaller plant size and at the flowering time the
number of flowers produced was observed to be very small compared to other control plants.

G. Calculations and statistical analysis:

At the end of the experiment the data were tabulated and for each plant size parameter (number of branches, plant height, number of leaves, leaf area and plant tops T.D.M.) the treatment totals and means were calculated. The same is done for the number of flowers produced by each treatment. Also analysis of variance for the effect of the five levels of irrigation water applied on source size and number of flowers produced was worked out. Because the F-test (at 5% level) was found to be highly significant, a pair wise comparison procedure was performed using Fisher's protected least significant difference (PLSD) to detect the presence or absence of significant differences between pairs of treatment means. Also t-test was used for the comparison between the two varieties, regarding their flower-yielding capacities.

To show the effect of the five water levels applied (ET) on plant source size a number of regression models were selected, according to the best fitting to the data, to illustrate the relationship between each plant size parameter and the water levels applied. The same was done to illustrate the relationship between each plant size parameter and the number of flowers produced. Also the number of flowers produced was correlation to ET levels applied, and in each case the regression equation and coefficient of determination ($R^2$) were shown.
IV. Results and Discussion

1. Effect of water stress on expansive growth:

The effect of application of five levels of irrigation water on expansion growth of two varieties of beans was evaluated by measuring the number of branches, plant height, number of leaves, leaf area and above ground total dry matter.

a. Effect of water stress on the number of branches produced:

The result of this effect is given in Table 4, which showed that the mean number of branches was maximum in the control treatment (100% ET), and the value decreases continuously as the water applied decreased from full ET. For example the percentage reduction in number of branches produced, relative to the control, was found to be 18, 35, 44, and 57 for variety (A) when the water applied was 80, 60, 40 and 20% ET. The corresponding reductional response shown by variety (B) was 2, 18, 25 and 46 at the same ET levels. From these values it appeared that branch initiation in variety (A) is more sensitive to water stress than in variety (B) since the same levels of water stress resulted in different reductional effect on number of branches produced. The table also showed the result of the PLSD test, where similar letters were used to indicate that no significant difference existed between the treatment means, and different letters were used to indicate the existence of a significant difference between treatment means.

In Figures 2-A and 2-B, the effect of water stress on number of branches produced by variety (A) and (B), respectively, was shown. The two parameters were found to be highly correlated in both varieties. The predicting equations were also given.
<table>
<thead>
<tr>
<th>Treat. No.</th>
<th>Treat. level</th>
<th>No. branches applied (C)</th>
<th>No. branches produced (D)</th>
<th>PLSD mean level</th>
<th>Reduction in no. of branches produced (E)</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>30</td>
<td>47.0 a</td>
<td>32.2 a</td>
<td>8.2</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>36.50 b</td>
<td>28.50 a</td>
<td>8.00</td>
<td>14.67 a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>30.67 b</td>
<td>22.83 c</td>
<td>7.84</td>
<td>18.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>28.47 b</td>
<td>22.83 c</td>
<td>5.64</td>
<td>18.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>20.00 c</td>
<td>23.33 ab</td>
<td>3.33</td>
<td>12.37</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 2-2. Effect of ET levels applied on number of branches produced.

**Variety A**

\[ y = 16.6 + 0.16x + 0.00143x^2 \]

\[ r^2 = 0.997 \]
Fig. 2-B. Effect of ET levels applied on number of branches produced.

Y = 14.0 + 0.53 x - 0.00232 x^2

r^2 = 0.973
b. Effect of water stress on plant height:

Plants of both varieties were reduced in height by water stress conditions. As shown in Table 1, the highest plants were those receiving full ET while other plants which were subjected to water stress at 80, 60, 40 and 20% ET, appeared to be shorter. It was found that at the 4 stress levels mentioned earlier, the corresponding reduction in plant height was 5, 14, 19 and 19% (in relation to the control) for variety (A). But plant height shown by variety (B) seemed to be more sensitive to water stress, since more reduction was observed for the same water stress levels applied.

The LSD result (Table 5) showed that there was a significant difference between treatment means, except between the third and fourth treatment means where there is no significant difference between the two means. For variety (B) there is no significant difference between the third and fourth treatment means and between second and third treatment means.

The treatment means were plotted versus the five levels of ET applied and the relationship was shown in Figure 3-A and 3-B for variety A and B respectively.

c. Effect of water stress on the number of leaves produced:

Compared to the number of leaves in the control treatment, stressed treatments showed a reduced number, and the reduction was found to be greater with the increasing level of water stress. Except for the number of leaves produced by the 80% ET, the reduction in number of leaves at the other water stress levels was observed to be nearly the same in the two varieties (See Table 6). The
Table 5: (Plant Height) Treatment means, PLSD, plant height obtained (%), and percentage reduction in height of the plant.

<table>
<thead>
<tr>
<th>Treat. No.</th>
<th>ET level applied (%)</th>
<th>Treat. mean</th>
<th>PLSD (SE)</th>
<th>Treat. mean</th>
<th>PLSD (SE)</th>
<th>Plant height obtained (%)</th>
<th>Percentage Reduction in plant height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>62.33</td>
<td>b</td>
<td>31.33</td>
<td>b</td>
<td>92.23</td>
<td>81.30</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>58.17</td>
<td>b</td>
<td>29.25</td>
<td>bc</td>
<td>86.08</td>
<td>75.72</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>55.00</td>
<td>c</td>
<td>27.16</td>
<td>c</td>
<td>81.39</td>
<td>70.31</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>45.50</td>
<td>d</td>
<td>21.50</td>
<td>d</td>
<td>67.33</td>
<td>55.66</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>67.58</td>
<td>a</td>
<td>38.63</td>
<td>a</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

PLSD: Standard Error
Fig. 3-A. Effect of ET levels applied on plant height.

**Yield A**

\[ y = 38.5 + 0.418x - 0.00134x^2 \]

\[ R^2 = 0.477 \]
- Effect of El levels applied on plant in mg.

\[
Y = 1.7 + 0.223x + 0.000054x^2
\]

\[
R^2 = 0.950
\]
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean level (μg)</th>
<th>Treat. level applied (μg)</th>
<th>No. of leaves produced (2)</th>
<th>Reduction in % of leaves produced (3)</th>
<th>Reduction in % of leaves produced (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.6</td>
<td>a</td>
<td>34.50</td>
<td>36.70</td>
<td>100</td>
</tr>
<tr>
<td>B</td>
<td>2.6</td>
<td>a</td>
<td>38.33</td>
<td>30.40</td>
<td>100</td>
</tr>
<tr>
<td>C</td>
<td>2.6</td>
<td>a</td>
<td>34.50</td>
<td>36.70</td>
<td>100</td>
</tr>
<tr>
<td>D</td>
<td>2.6</td>
<td>a</td>
<td>38.33</td>
<td>30.40</td>
<td>100</td>
</tr>
<tr>
<td>E</td>
<td>2.6</td>
<td>a</td>
<td>34.50</td>
<td>36.70</td>
<td>100</td>
</tr>
</tbody>
</table>
Fig. 4-A. Effect of ET levels applied on number of leaves produced.

Variety A

\[ y = 16.6 + 0.187x + 0.000518 x^2 \]

\[ R^2 = 0.997 \]
4.4 Effect of ET levels applied on number of leaves produced.

**Variety B**

\[ Y = 13.4 + 0.306x - 0.000536x^2 \]

\[ R^2 = 0.997 \]
Table also showed that for variety (A), there is a significant difference between treatment means while for variety (B) no significant difference between each two adjacent treatment means.

At 80% ET level the effect of water stress on number of leaves produced was noticed to be more adverse on variety (A) than on (B) since about 91% leaves (relative to the control treatment) were produced by (B) and only about 84% were produced by variety (A).

The relationship between the ET levels applied and the number of leaves produced by each variety was shown in Figure 4A and 4B for variety (A) and (B) respectively.

d. Effect of water stress on leaf area (LA):

From the data in Table 7, the leaf area seemed to be very sensitive to water stress, especially at severe water stress. When 30, 60, 40 and 20% ET were applied, the corresponding leaf area reduction was found to be about 26, 49, 69, and 75% for variety (A), and 20, 49, 65, and 79% for variety (B). The mean LA obtained by each treatment was much greater in (A) than in (B). And a significant difference between the treatment means in (A) was observed. The same was found true for variety (B) except for the first and second treatment means where no significant difference was observed (See Table 7).

Figures 4A and 5B showed the effect on LA as the irrigation water applied increased from 20% ET to full ET. The LA and the amount of water supplied showed a very high correlation relationship ($R^2 = 0.995$ and 0.993) for A and B respectively.

e. Effect of water stress on plant top dry matter:

The TM also seemed to be very sensitive to severe water stress.
Table 7: (Leaf area) Treatment means, PLSD, leaf area produced (%), and reduction in leaf area (%).

<table>
<thead>
<tr>
<th>Treat. No.</th>
<th>ET level applied (%)</th>
<th>Treat. mean (cm²) A</th>
<th>PLSD (%) level</th>
<th>Treat. mean (cm²) B</th>
<th>PLSD (%) level</th>
<th>Leaf area produced (%) A</th>
<th>Leaf area produced (%) B</th>
<th>Reduction in leaf area (%) A</th>
<th>Reduction in leaf area (%) B</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>100</td>
<td>6507.96 a</td>
<td></td>
<td>4767.87 a</td>
<td></td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>4812.24 b</td>
<td></td>
<td>3818.70 b</td>
<td></td>
<td>73.94</td>
<td>80.09</td>
<td>26.96</td>
<td>19.91</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>914.22 c</td>
<td></td>
<td>2435.31 c</td>
<td></td>
<td>60.15</td>
<td>51.06</td>
<td>39.85</td>
<td>48.94</td>
</tr>
<tr>
<td>Z</td>
<td>40</td>
<td>2622.32 d</td>
<td></td>
<td>1659.07 d</td>
<td></td>
<td>40.29</td>
<td>36.80</td>
<td>59.71</td>
<td>65.20</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>1607.83 e</td>
<td></td>
<td>1006.09 d</td>
<td></td>
<td>24.71</td>
<td>21.10</td>
<td>75.29</td>
<td>78.90</td>
</tr>
</tbody>
</table>
Fig. 9. Effect of ET levels applied on leaf area.

**Variety A**

\[ Y = 121 + 6.03 \times 10^{0.0263 \times x^2} \]

\[ R^2 = 0.995 \]
and the reductive response of TDM to water stress followed approximately the same pattern as the effect on leaf area. At the 80, 60, 40, and 20% ET levels applied, the corresponding percentage reduction in T.D.M. was found to be 27, 40, 60 and 77 for variety (A) and 22, 40, 65 and 78 for variety (B) (Table 8). The table also showed that the mean TDM produced by variety (A) at each water level applied was higher than the value obtained by variety (B) at the same water levels. The table also showed the result of LSD test at 5% level. The effect of ET levels applied on TDM production was shown graphically in Figures 6A and 6B for the two varieties and the regression models used for representing these data were found to be similar.

From Tables 4, 5, 6, 7 and 8 it seems that the leaf area and the total dry matter of tops were the most sensitive plant size parameters compared to the others. While the height of the plant seemed to be the least sensitive to water stress as applied in this experiment.

As was reported by Hsiao and Acevedo (1974), and Hsiao (1973), the reduction in plant source size with increasing level of water stress can be reasoned to the fact that under water stress conditions many plant processes were affected like cell growth, cell expansion, cell wall synthesis, nitrate reductase level, stomatal opening and closing, CO₂ assimilation, respiration, sugar and proline accumulation. The increasing sensitivity of LA and TDM shown by the data in Tables 7 and 8 can be attributed partially to leaf senescence which was observed only on the more stressed plants (first, second and third treatments), knowing that these dropped leaves were not included in the LA measurement and the TDM determination. According to Begg and
Table 8: Tops total dry matter (gm) Treatment means, PLSD, tops TIM produced (%), and reduction in tops TIM (%).

<table>
<thead>
<tr>
<th>Treat. no.</th>
<th>PT level applied (%)</th>
<th>Treat. mean PLSD (%) level</th>
<th>Treat. mean PLSD (%) level</th>
<th>Tops TIM (%) produced</th>
<th>Reduction in tops TIM (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>100</td>
<td>101.48 a</td>
<td>64.33 a</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>74.43 b</td>
<td>49.87 b</td>
<td>73.34</td>
<td>77.52</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>60.58 b</td>
<td>38.68 b</td>
<td>59.70</td>
<td>60.13</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>40.98 c</td>
<td>22.65 c</td>
<td>40.38</td>
<td>45.21</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>23.02 d</td>
<td>14.32 e</td>
<td>22.68</td>
<td>22.26</td>
</tr>
</tbody>
</table>
Fig. 6-A. Effect of ET levels applied on total dry matter (TDM) produced.

Variety A

\[ y = 9.20 + 0.685x + 0.00222x^2 \]

\[ R^2 = 0.994 \]
Fig. 6 Effect of CT levels applied on total dry matter (TDM) y = 3.51 + 0.477x + 0.0013x^2

\[ y = 3.51 + 0.477x + 0.0013x^2 \]

\[ R^2 = 0.995 \]
Turner (1976), drastic reduction in leaf elongation of beans occurred when the leaf water potential reached a value of about -9.0 bars. The sensitivity of vegetative growth of kidney bean was also reported by Rosende (1978) and Couto (1977). Hilar and Gardner (1972) observed rapid increase in stomatal resistance of beans as the leaf water potential declined below -8 bars. According to Newman (1974) the minimum mean leaf water potential he obtained was -12.5 bars for the wet treatment and -13.3 bars for the intermediate treatment. The value obtained by Couto (1977) was -14.7 bars for wet treatment and -15.5 bars for the dry treatment (at day 3). While at day 79 he obtained a minimum value of -12.3 for the wet treatment and -11.7 bars for the dry one.

In this study the leaf water potential was not measured but Flores (1980), from closely similar water application levels, found that the minimum leaf water potentials at the beginning of flowering of beans were -1.3, -4.7, -6.3 and -8.2 bars when the irrigation levels applied were 100% ET, 75% ET, 50% ET and 25% ET, respectively. While the values he obtained at the end of the flowering period were -2.9, -7.1, -10.7 and -13.1 bars at the same irrigation levels. In 1981 he obtained these values at the beginning of the flowering period, using the same irrigation levels (100% ET, 75% ET, 50% ET and 25% ET), -1.6, -5.1, -7.2 and -9.0 bars. While at the end of the flowering period he obtained a value of -3.9 bar (for 100% ET), -11.9 bars (for 50% ET), and -14.9 bars (for 25% ET).

2. Effect of water stress on flowering:

The two varieties showed a significant difference in terms of the number of flowers produced by each treatment. Table 9 showed that variety (B) produced more flowers than variety (A) at all
Table 9: (No. of flowers) Treatment means, PLSD, no. of flowers produced (%), and reduction in no. of flowers produced (%).

<table>
<thead>
<tr>
<th>Treat. no.</th>
<th>KT level applied (%)</th>
<th>Treat. mean (PLSD a)</th>
<th>Treat. mean (PLSD b)</th>
<th>No. of flowers produced (%)</th>
<th>Reduction in no. of flowers (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>7.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>81.33 a</td>
<td>99.0 a</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>64.83 b</td>
<td>96.17 a</td>
<td>79.71</td>
<td>97.24</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>52.33 c</td>
<td>88.33 a</td>
<td>64.34</td>
<td>89.22</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>45.17 cd</td>
<td>69.67 b</td>
<td>55.54</td>
<td>70.37</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>38.83 d</td>
<td>44.67 c</td>
<td>47.74</td>
<td>45.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 7-A: Effect of EY levels applied on number of flowers produced.

**Variety A**

\[ \gamma = 37.9 - 0.0266 \times 40,00658 \times \delta^2 \]

\[ \delta^2 = 9.999 \]
Fig. 7-8. Effect of ET levels applied on number of flowers produced.

Variety B

\[ Y = 11.4 + 1.86 x -0.00925 x^2 \]

\[ R = 0.999 \]
Fig. 7-6. Effect of ET levels applied on number of flowers produced.

Variety A and B

- **Variety A**
  \[ Y = 37.9 - 0.0266x + 0.00058x^2 \]
  \[ R^2 = 0.999 \]

- **Variety B**
  \[ Y = 11.4 + 1.86x - 0.00985x^2 \]
  \[ R^2 = 0.999 \]
levels of applied water. In the stressed treatments, the percentage reduction in number of flowers in variety B was found to be about 3, 11, 20 and 55%, relative to the control, at the 80, 60, 40 and 20% ET applied. The corresponding reduction in number of flowers due to water stress at the same stress levels for variety A was found to be 20, 34, 44 and 32%. This showed that at all levels (except 20% ET level) variety (B) seemed to be less affected by the water stress levels applied compared to variety (A). For the PLSD test result see Table 9.

The effect of irrigation water levels applied on the number of flowers produced by each variety was shown by plotting the treatment means (Table 9) vs. the five levels of irrigation water applied (see Figs. 7A and 7B). Figure 7C was introduced to show the difference in response of flowering to ET levels applied between the two varieties.

The overall effect of water stress on source size and flowering of beans as shown by these two varieties is that both expansive growth and number of flowers produced decreased as the level of water stress increased. The sensitivity of each plant size parameter measured to water stress differ with the variety, i.e. the two varieties responded differently to water stress and this was found true for the number of flowers produced.

To illustrate the relation between the plant size and the number of flowers produced, each of the plant size parameters (at the five ET levels) was plotted against the number of flowers produced at the same ET levels. This was shown by Figures 8A, 8B, 9A, 9B, 10A, 10B, 11A, 11B, 12A and 12B. From these figures it seems that Figures 8A
Fig. 8-A. Number of flowers vs. number of branches.

**Variety A**

\[ y = 22.2 e^{0.0277x} \]

\[ R^2 = 0.999 \]
Fig. 8A. Number of flowers vs. number of branches.

Variety A

$y = 19.3 + 0.0386x$

$R^2 = 0.929$
Fig. 8-6. Number of flowers vs. number of branches.

**Variety A and B**

- Variety A
  \[ Y = 22.2 \times 0.0277 \times \]
  \[ R^2 = 0.999 \]

- Variety B
  \[ Y = 19.3 \times 0.0386 \times \]
  \[ R^2 = 0.929 \]
Fig. 9-A. Number of flowers vs. plant height.

**Variety A**

\[ y = 235 - 8.54x + 0.0928x^2 \]

\[ R^2 = 0.997 \]
Fig. 9-B. Number of flowers vs. plant height.

Variety B

\[ y = -222 + 17.3x - 0.232x^2 \]

\[ r^2 = 0.962 \]
Fig. 10-A. Number of flowers vs. number of leaves.

**Variety A**

\[ Y = 37.8 - 0.972x + 0.0498x^2 \]

\[ r^2 = 0.994 \]
Fig. 10B. Number of flowers vs. number of leaves.

**Variety B**

\[ Y = -121 + 11.4 \times x - 0.147 \times x^2 \]

\[ R^2 = 0.996 \]
Fig. j: A. Number of flowers vs. leaf area.

Variety A

\[ Y = 32.5 + 0.0172 \times +0.0000313 \times^2 \]

\[ R^2 = 0.992 \]
Fig. 11-8. Number of flowers vs. leaf area.

Variety B

\[ y = 3.93 + 0.313x - 0.000254x^2 \]

\[ R^2 = 0.982 \]
Fig. 12-A. Number of flowers vs. total dry matter (TDM).

Variety A

\[ Y = 33.2 + 0.161 \times + 0.00314 \times^2 \]

\[ R^2 = 0.991 \]
Fig. 12-B. Number of flowers vs. total dry matter (TDM)

Variety B

\[ Y = 6.95 + 3.21 x - 0.0279 x^2 \]

\[ R^2 = 0.986 \]
and 88 were the only figures which showed approximately similar relationships. And to make the comparison between the two varieties more easy, Figure 4C was introduced.

This similar relationship shown by Figure 8A and 8B indicated that among plant size parameters measured, number of branches seemed to be the more effective plant size parameter in terms of the number of flowers produced. For the other plant size parameters the relation was found to be different with the variety (different curves).

By comparing the data in Tables 4, 5, 6, 7, and 8 with the data in Table 9 it is clear that the percentage of flowers produced at the five levels of ET, is more similar to the percentage of number of branches produced at the same ET levels. But for the other plant size parameters that is not true. Table 9 also showed that the mean number of flowers produced by variety (B) is much greater than that of (A).

The higher flower yielding capacity of variety (B) can be attributed to the greater number of branches produced by that variety, since the number of branches is the only plant size parameter which is produced more by variety (B) than by (A). For the leaf area and TDM, Tables 7 and 8, respectively, show that these two parameters are produced much more by variety (A) than (B) and hence these two parameters can be excluded as a good parameter for plant size in relation to the number of flowers produced. The same can be said for the plant height since the mean plant height for variety (A) is greater than that of (B) at all ET levels applied. For the number of leaves, the number is approximately the same for the two
varieties and hence if the reason for the better yielding capacity of variety (B) compared to (A) is due to the number of leaves produced, the two varieties can be expected to give approximately the same number of flowers.

In summary it can be said that the number of branches is the main plant size parameter in relation to the number of flowers produced and this can be attributed to the flowering sites in beans (at the axil of the branches).

According to Couto (1977), the source size as an indication of the number of reproductive structures produced can be measured as LAI, LRM or total DM but from this experiment it seems that these are not good parameters for measuring plant size in relation to the number of reproductive structures produced.

The results concerning the expansive growth seemed to be in agreement with the results obtained by Thomas et al. (1976) and Maurer et al. (1964), who reported that plants grown under conditions of ample soil water were taller, had more branches and leaves and produce greater fresh weight then stressed plants.

The results were also found to be in agreement with the results obtained by Couto (1977); Remence (1978); Kulaq and Acevedo (1974); Acevedo et al. (1971), but according to Bunce (1977), who reported that leaf area increased by mild stress, the results seemed to be in disagreement.

The sensitivity of expansive growth is also pointed out by Claassen and Shaw (1978). One of the most obvious consequences of sensitivity of expansive growth to water stress is remarkable
reduction in leaf area and hence reduction in the capacity of the photosynthetic surface to produce assimilates for growth and storage (Shariat, 1981). According to Manaka and Fujita (1979), determinate cv. of *P. vulgaris* generally had a higher pod setting percentage than indeterminate or semi-determinate cv., but semideterminate cv. response better to adverse conditions than did determinate cv.
V. Conclusion

From a greenhouse study, the effect of five applied levels of irrigation water, expressed as percentage of ET (100% ET, 80% ET, 60% ET, 40% ET and 20% ET) on the flowering of two varieties of beans, of different growth habit, was investigated.

The results showed that the growth and development of plants from both varieties were found to be sensitive to water stress. The effect was observed to be more pronounced as the level of water stress increased and the stressing period prolonged.

The plant size, expressed as number of branches, plant height, number of leaves, leaf area and above soil surface total dry matter, was found to be significantly reduced as the level of water stress increased. The maximum expansive growth was given by the plants in the treatment which receive full ET (100%), and the minimum expansive growth was given by the plants in the treatment which receive the lowest level of ET (20%). Plants in the intermediate treatments showed intermediate expansive growth compared to the control plants and the highly stressed ones. The same reduction pattern was observed on the number of flowers produced at the same ET levels applied.

When each of the plant size parameters measured in this study was plotted against the number of flowers produced at the same ET levels, it was found that among the different plant size parameters measured, number of branches was found to be the most important parameter since this parameter, like number of flowers, is decreased less in variety B than in variety A. The data of this experiment suggested that the number of flowers and hence the yielding capacity
of bean (P. vulgaris) can be improved by breeding for highly branching plants. While the TSM and LA as used by many research workers as indication of the plant size, were found to be not good in representing the plant size in relation to yield. And therefore the use of leaf area and total dry matter as a measure for plant size, in relation to the final yield may be misleading for breeding purposes.
VI. Literature Cited


