A STUDY OF THE RELATIONSHIP BETWEEN DROUGHT RESISTANCE AND ROOT GROWTH OF THREE CULTIVARS OF COMMON BEANS (*PHASEOLUS VULGARIS* L.)

by

ISAIAH MASINDE TABU

A thesis submitted to the University of Nairobi in partial fulfillment of a Master of Science degree in Agronomy.

1988

DECLARATION

This thesis is my original work and has not been been presented for a degree in any other University.

ISAIAH MASINDE TABU

4/10/89
DATE

This thesis has been submitted for examination with our approval as University supervisors.

DR. C.L. COULSON

5/10/89
DATE

DR. J.O. NYABUNDI

4/10/89
DATE

DEDICATION

I dedicate this work to my parents Jackson Tabu and Beitah Nelima and to my children.

ACKNOWLEDGEMENT

I would like to express my sincere thanks to my supervisors Dr. C.L. Coulson and Dr. J.O. Nyabundi for the constructive criticism, guidance, suggestion and advice they offered me during this study.

I also wish to acknowledge the help rendered to me by my brother, wife and friends during the data collection, Jane N. Mbugua for typing the work and the financial assistance offered by DAAD (German Academic Exchange Service) through the University without which this study would not have been possible.

I am also indebted to my parents, brothers, sisters and friends for the encouragement they offered me during my study. Finally, I extend my thanks to everybody who might have helped me directly or indirectly during this study.

TABE OF CONTENTS

Content

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Appendix | Page

ABSTRACT

A study was carried out to investigate the relationship between the depth of root penetration and drought resistance in three cultivars of common beans (Phaseolus vulgaris L.), namely GLP 2 (Rosecoco), GLP x-92 (Mwitemania) and GLP 1004 (Mwezi Moja). The varieties have been recommended for high, low to high, and low rainfall areas, respectively. A technique which involves herbicide placement at a given depth in the soil and monitoring of the herbicide toxicity symptoms on the above ground organs was used to evaluate root penetration. The bean cultivars were studied and compared at three different irrigation levels. Four experiments were carried out, two in the glasshouse and two in the field.

The glasshouse experiments showed that all the cultivars were similar in their sensitivity to [illegible] herbicide. A bioassay test carried out showed that there was no upward or downward movement of this herbicide in the field. The glasshouse experiment agreed with the field experiment in that, in both cases GLP 1004 had the highest root penetration rate. In the field total amount of water applied was inversely related to the root penetration rate (RPR) in all the cultivars. Water stress substantially reduced the dry matter accumulation,

number of pods/plant and 100-seed weight. GLP 1004 outyielded GLP x-92 and GLP 2 at all watering levels. Results further indicate that GLP 1004 which escapes drought through early maturity can also employ other drought resistance mechanisms, i.e. drought avoidance through high root growth rate if faced with periods of drought during the season.

INTRODUCTION.

Kenya's population is increasing at a rate of 4% per annum. To maintain an adequate food supply food production would have to increase by about two-fold from 1980-1989 (Anonymous, 1981). In Kenya the semi-arid area with low agricultural potential (rain/evaporation ratio less than 30%) comprises about 75% of the total agricultural land (Sombroek et. al., 1982). Because of the increasing shortage of high potential arable land there is need to grow crops in these unfavourable areas where rainfall is not only low but also uncertain. Crop yields in these areas may be increased by improving practices like careful tillage, using optimal plant population and use of improved and adapted varieties. Adapted varieties are the ones that will give high yields compared to others in the same environment. The development of such crops offers considerable promise for increasing food production in the semi-arid areas of Kenya. An understanding of crops behaviour is of obvious importance when seeking to improve their performance under semi-arid conditions.

The common bean (Phaseolus vulgaris L.) is a staple food for most Kenyans. The per capita income of most Kenyans does not allow the consumption of animal proteins such as milk, eggs or meat but beans, having a high protein content, can contribute substantially to the dietary balance of millions of Kenyans. Moreover beans are high in lysine and so can supplement cereal proteins which are generally low in lysine. The total area under beans in Kenya is estimated to be between 300,000 and 500,000 hectares per season with an average yield of about 500 kg per hectare (Mukunya, 1984). The yields are low considering the yield potential of 1500 kg per hectare as an average (Mukunya, 1984). Drought is one of the most important factors responsible for low bean yields in Kenya. Consequently any research work on increasing bean production in the low rainfall areas will be a step towards improving food supply in the country. The ability of a crop to grow satisfactorily in areas subjected to periodic water deficits has been termed as drought resistance (May and Milthorpe, 1962). It is generally recognized that plants are resistant to drought because they either avoid the development of severe internal water deficits or tolerate them (May and

Milthorpe 1962, Levitt, 1972). Common beans, although not known to be drought tolerant are usually subjected to a high probability of water stress in many environments where they are grown (Laing et. al., 1983). Literature on resistance mechanisms in beans suggest that they are able to maintain a higher leaf water potential under conditions where soil water supply is limited and/or under high evaporative demand, (Laing et. al., 1983). This could suggest that resistant cultivars have a deeper root system which is better able to exploit available water reserves during possible stress periods. Indeed of the varieties surveyed by CIAT in 1980 drought resistance was associated with deeper rooting characteristics. While other physiological factors could be suggested in explaining the differences in drought resistance it seems clear that a priority area for research should be the root systems. In the past lack of suitable techniques for root studies has hampered such investigations.

2. LITERATURE REVIEW.

Drought stress, due to lack of water, is the second most important yield limiting factor in beans (Norman et. al., 1984). One of the solutions to the problem would be the use of drought resistant cultivars. Drought resistance in this case refers to the ability of a crop to grow and yield satisfactorily in areas subjected to periodic water deficits (May and Milthorpe, 1962, Turner, 1979). Drought resistance may be the resultant of many physiological and morphological characteristics and it is doubtful if any one criterion will be adequate for selection. A combination of factors may need to be selected for (Sullivan and Ross, 1979; Anayoba et. al., 1979). Attempts therefore must be made to define specific physiological and morphological characteristics that are indicative of drought resistance. Among these characteristics could be listed low stomatal conductance (Sullivan, 1971; Masumba, 1984; Begg and Turner, 1976) low leaf transpiration and low leaf water potential (Turner, 1974; Coulson, 1984) and different rooting depth (Robertson et. al., 1985; Markhart, 1985 Masumba, 1984). Low stomatal conductance, though indicative of drought

resistance fluctuates considerably depending on the weather and root activity (Jones, 1979) thus making it difficult to be used alone as a drought resistance indicator especially where the differences between the cultivars is small (Masumba, 1984). Leaf/air temperature differentials have been used (Coulson, 1984; Idso et. al., 1981; Levitt, 1972) as indicators of drought tolerance in plants. Direct measurement of the required temperatures however are not easy because different methods may give different interpretation of the kind of resistance exhibited (Coulson, 1985; D'Souza and Coulson, 1987).

Traits such as low stomatal conductance though theoretically indicative of drought resistance have practical problems in their measurement because they fluctuate very much over a short time and also may be associated with decrease in yield (Turner, 1979). Thus there is need to search for traits that do not lead to reduction in yield. Some of the traits that have been suggested are development plasticity, rapid phenological development, and maintenance of water uptake by increased root density and depth. Unfortunately increased root density and depth leads to reduction in yield by preferential partitioning

of photosynthates to the roots in some crops whereas the major concern is for the cultivars to partition the photosynthates towards the economic yield component. Developmental plasticity facilitates the matching of crop growth and development to the constraints of the environment especially in terms of minimising the occurrence of the critical reproductive phase during the drought periods.

2.1 DROUGHT RESISTANCE IN BEANS.

Drought resistance could obviously be an important crop characteristic in beans grown in the semi-arid zone of Kenya. Apart from little work by Floor-Drees (1983) limited attention has been paid to selection for drought resistance in beans using root growth as a selection criterion. The reactions of the promising varieties like GLP 1004 (Mwezi Moja) to moisture stress in the soil combined with hot and dry atmospheric conditions need investigation. In addition to root growth (Floor-Drees, 1983, Robertson et. al., 1985) plant characteristic such as vegetative development, flower and pod abscission, yield and yield components have been given some attention (Coulson, 1984; Itulya, 1984). Attempts at selection for drought resistance has shown that there is con-

siderable genetic diversity (CIAT, 1979; 1980; Ttulya, 1984; Floor-Drees,1983).

Beans are particularly sensitive to water stress during flowering (Dubetz and Mahalle, 1969; Stoker, 1974). One explanation is that root growth is retarded during anthesis thus water supply to the root depends mainly on water movement through the soil to the existing roots (El Nadi et. al., 1969; Norman et, al., 1984; D'Souza and Coulson, 1987). However this is in contrast to the findings of Doorenbos (1979) that root growth continues even after flowering. The major component of yield that is affected by drought is the number of pods per plant (Robins and Domingo, 1956; Stoker, 1974). This suggests that podset is a prime factor involved in drought resistance.

Basal and taproot weights of beans have been shown to increase upto seed initiation stage followed by a significant decrease during full pod fill (Stoffella et. al., 1979; El Nadi et al., 1969; D'Souza, 1985; D'Souza and Coulson, 1987). This suggests that it is not flowering that reduces root growth but probably fruit setting and fruit growth. A root study by Stoffella et. al. (1979) showed that the tap root

and the basal roots are the most important parts of the root system. Beans have an extensive root system concentrated mainly in the first 30 cm of soil. At flowering the root depth is 30-40 cm (Doorenbos, 1979). This implies that the lateral root system is most important in drought resistance because after flowering root growth cease (El Nadi, 1969; D'Souza and Coulson, 1987; Stoker, 1974) and it is during this period that water requirement is highest (Doorenbos, 1979).

The ability to recover from stress is found particularly in indeterminate beans which have the capacity to continue flowering after stress (Laing et. al., 1983). Norman et. al., 1984). The capacity to do this is associated with delayed and uneven maturity. Mid and late season drought is a feature of the rainfall pattern of the bean growing areas of Kenya (Mukunya, 1984) and therefore ability to recover after drought is a significant advantage.

2.2 IMPORTANCE OF ROOTS IN DROUGHT RESISTANCE.

The most important characteristic of the root systems of many crop plants is the ability to extend sufficiently rapidly to maintain continual contact

with soil water. For example, tepary beans (Phaseolus acutifolius) which are known to be drought resistant exhibit rapid root growth (Markhart, 1985. Masumba, 1984).

The extent of root development within a species is governed by genetic as well as environmental factors such as soil moisture and soil structure. Studies with crop plants generally indicate greater root proliferation near the soil surface in irrigated or moist environments than in dry environments (Mayaki et. al., 1976; Miller, 1986). However other studies show that water deficits appear to affect water uptake by roots quicker than it affects root elongation (Pearson, 1966).

The benefit of deep root systems in avoiding water stress due to limited soil water has been documented by several studies (Kaspar et. al., 1984; Sullivan and Ross, 1979). Preferential relative development of the root over the shoot can therefore be considered an adaptive mechanism which enables the root to explore a greater soil volume for water (Hsiao and Bradford, 1983). Although there is little quantitative information, root development is enhanced relative to the shoot development during stress (Coulson, 1984; Salim et. al., 1965). If soil water

is available at lower soil depths the development of a deeper root system would clearly be a useful adaptive feature in maintaining favourable water relations (Passioura, 1974). While root growth has been used in screening for drought resistance (Atmonson, 1978), this approach is not popular because most methods of root study are inaccurate and time consuming (Bohm, 1979).

Varietal differences in rooting depth have been demonstrated in wheat (Hurd, 1968; Derera et. al., 1969) beans (Laing et. al., 1983 Floor-Drees, 1983) soybeans (Raper and Barker, 1970) and tomato (Zobel, 1975). Thomas et. al. (1983) showed that deeper rooting tepary beans yield better than the common beans under drought stress. The genetic control of root systems has been studied in much less detail than shoot systems (Zobel, 1986). Roots of legumes have been found to differ in their ability to branch, thicken and elongate (Lawn, 1982) although genotypes have been found to behave differently between the field and glasshouse situation (Stoffella et. al., 1979; Waters et. al., 1980).

Studies to examine relationship between drought resistance and root systems among cultivars have been performed with cowpeas (Robertson et. al., 1985), common beans and tepary beans (Markhart, 1985 Masumba, 1984; Thomas, et. al., 1983). Their results indicate genotypic differences in rooting depth of the cultivars. Genotypic differences in the development of root systems are believed to be of major importance in drought stress avoidance. However, many methods for studying roots are unsuitable for evaluating quantitatively the soil environmental effects on root behaviour (Pearson, 1974; Taylor, 1986).

2.3 INDICES OF ROOT BEHAVIOUR.

In addition to root length, surface area, root weight and root water extraction suggested by Bohm (1979) and Pearson (1974) in their reviews, root mass density (grammes of root/cm^3 soil) and root length density (cm of root/cm^3)of soil have also been suggested as indices for quantitatively evaluating soil environmental effects on root behaviour (Taylor, 1986). Though such indices seem quite useful, difficulties are encountered in their use. Root

weight is not well-established as an index of water absorbance capacity because of the assumption that it is related to root activity in a direct and well defined way. This however is not always true because roots grown in soil can never be all physically recovered and the poorest recovery is with the fragile and most active roots.

There is a high correlation between water depletion and rooting density (Bennet and Doss, 1960; Doss et. al., 1960; Davis et. al., 1965). Therefore soil water extraction has been used to evaluate root distribution of beans and maize in the field (Lenga, 1979, Mugah, 1984; Nyabundi, 1985). In fact it appears the soundest way of measuring root distribution since it is non-destructive. However, some assumptions must be made, for instance that there is no appreciable transfer of water from one part of the soil profile to another and there is no water loss except by transpiration.

During the last one and half decades an increasing number of research workers have used root length as a preferred measure in root studies. One reason for this is the possibility for rapid deter-

mination (Robertson et. al., 1985). Other research workers believe that root length per unit soil volume is the best parameter for calculation of water uptake by plants (Gardner, 1964; Molz, 1971; Taylor and Klepper, 1973, 1975; Nye and Tinker, 1969).

It is generally accepted that increasing soil water deficit in the surface layers of the soil induces compensatory root extension to deeper unexploited soil layers (Newman, 1966; Klepper et. al., 1973). El Nadi et. al. (1969), working with broad beans (Vicia faba) grown in deep containers, found that progressive soil drying promoted deeper root growth although the total dry weight of the root system was the same under wet and dry conditions. This happened because root extension in the deeper layers occurred at the expense of formation of new roots in the layers close to the soil surface. Though root length has been used in many agricultural studies information on the crop rooting characteristics (especially beans) that can be related to capacity to take up water is still scanty (Mugah, 1984). This is because most quantitative studies on roots have used weight as a means of assessing the amount of roots in the soil. However in the field this is not easy because of the diffi-

culties involved in their recovery from the soil (Hendricks and Veihmeyer, 1931; Coley and Watson, 1966). It is generally accepted that the capacity for a crop to take up water is more closely related to surface area or total length of the root system than the root weight (Gardner, 1964). Therefore a deep penetrating root system is a characteristic which if incorporated into beans might increase their drought resistance through avoidance (Markhart, 1985; Hall et. al., 1979) leading to increased production in the semi-arid areas.

The techniques that have been used to measure root length are not only very time consuming but vary in accuracy (Newman, 1966). The main difficulty in determining root length arises from the great length which can occur in even small volumes of soil. For example 18 metres/litre of soil and 90 metres/litre of soil have been reported in the case of sugarcane and beans by Evans (1938) and Floor-Drees (1983), respectively.

The best approach to drought avoidance is to develop plants with characteristics such as deep root systems which postpone desiccation. In

such screening there is need to examine large numbers of plants for root growth and unfortunately many methods for studying root growth are not very accurate. What is necessary is to have a reliable field method for study of root growth.

A new indirect method of Robertson et. al. (1985) involving herbicide placement at varying depth in the soil and monitoring symptoms on the leaves allows the rapid measurement of root length thus allowing screening of large numbers of plant cultivars.

2.4 OBJECTIVES

(i) To assess the new method of root growth analysis as proposed by Robertson et. al. (1985) under Kenyan field conditions.

(ii) To assess possible differences in root penetration among bean cultivars which have been found to react differently to water deficits.

3. MATERIALS AND METHODS.

Two glasshouse, one laboratory and two field experiments were carried out at Kabete field station, University of Nairobi between July, 1986 and March, 1987. These experiments were aimed at studying root penetration of three cultivars of common beans (Phaseolus vulgaris L.) using the herbicide placement method. The cultivars used were GLP 2 (Rosecoco), GLP x-92 (Mwitemania) and GLP 1004 (Mwezi Moja). These cultivars had been recommended as suitable for high, medium and low rainfall areas, respectively (MALD, 1983).

The herbicide used was Metribuzin (4 amino-6(1,1-dimethyl 9-3-(methythio)-1,2,4 triazin-5 (4H)-one) a member of the as-triazinone herbicides which are heterocyclic nitrogen derivatives (see Appendix 1 for structure). The herbicide is usually soil-applied as a pre-emergence herbicide in sugarcane, alfalfa and soybeans. It is rapidly absorbed by roots and readily translocated throughout the plant in the transpiration stream. It is considered to be transported exclusively in the apoplast system (Fedke, 1982).

In the leaf the herbicide is transported along the veins and tends to be concentrated at the lamina margins.

II binds on the thylakoid surface and blocks electron transport in photosystem II thus inhibiting photosynthesis as well as destroying chlorophyll. The symptoms exhibited by the affected plant may vary depending on the concentration of herbicide and the environmental conditions (Fedtke, 1982). The symptoms range from necroses and bleaching along the leaf margins and veins to drying up of the plant. The three bean cultivars are sensitive to the herbicide and exhibit symptoms when the herbicide is applied.

3.1 GLASSHOUSE/LABORATORY EXPERIMENTS.

3.1.1 Sensitivity and Symptom Characterisation Test.

To assess if the cultivars differed in their sensitivity to the herbicide the three bean cultivars were pre-germinated and grown in the laboratory in beakers containing Long Ashton (1978) formula nutrient solution (Appendix 16). They were aerated using the aeration pumps. The solution was maintained at constant volume by addition of distilled water on a daily basis. The solution was changed after every three days during the experimental period. Three weeks after germination the herbicide Metribuzin (dissolved in water) was added to the beakers containing

the bean cultivars. The herbicide was in varying application rates of 4, 6 and 9 kg/ha. The time taken for the appearance of the symptoms was recorded as well as the symptoms themselves.

3.1.2 Root Growth.

The objective of this experiment was to verify the assumption implicit in the herbicide placement method of Robertson et. al. (1985) that the deeper the placement the longer it would take the symptoms to appear. The experiment was also used to verify the symptoms.

Forest soil (eutric Nitosol) was mixed with di-ammonium phosphate (18% N, 46% P_2O_5). The equivalent fertilizer rate was 100 kg/ha. The soil was placed in twenty-litre plastic pots. This experiment had three replications and was repeated twice.

The field capacity of the soil in the pot had earlier been determined to be about 40% (weight/volume) by taking a known weight of soil and pouring in a given volume of water until excess water just started flowing out then weighing the soil.

During filling of the pots the herbicide

was mixed with finely ground soil and placed in a thin layer at a depth of 10 cm in one set of pots and 20 cm deep in another set of pots. Six seeds were planted in each pot at a depth of 5 cm. The soil was then watered to field capacity. One week after emergence the plants were thinned to three per pot. They were watered twice a week with 700 ml of water (equivalent to an average of 500 mm rain per season). The plants were monitored daily for herbicide toxicity symptoms. The time for 50% emergence was used as a reference time in indicating the time in days taken for the symptoms to appear.

Movement of the herbicide in the soil was monitored twice during the growing period by taking soil samples from 5 cm above and 5 cm below the herbicide placement level and planting pre-germinated beans on these soil samples to see if herbicide toxicity symptoms appeared. This was done to find out whether water had any effect on the time of appearance of the toxicity symptoms either by leaching or upward capillary action. Appearance of herbicide toxicity symptoms in the beans grown on these soil samples would indicate either downward movement by leaching

or upward movement by capillary action.

3.1.3 Dry and Wet Absorption Test.

The objective of this experiment was to find out if the appearance of herbicide toxicity symptoms in the field was dependent on soil moisture. If the herbicide could not be taken up by the roots under dry conditions then under dry field conditions it would not be possible to tell if the roots had reached a particular depth since the herbicide toxicity symptoms would not appear if uptake had not taken place.

The three bean cultivars were planted in plastic pots 8 cm in diameter and 10 cm high. The pots were perforated at the base to allow roots to grow through. After the roots had grown through the base of the pots the pots were put on large pots containing soil mixed with herbicide. The soil in the larger pots was at field capacity or quarter field capacity. The time taken for the herbicide toxicity symptoms to appear was then recorded.

3.2 FIELD EXPERIMENTS.

Two field experiments were conducted at the University of Nairobi, Kabete Campus field station

situated at latitude 1° 15'S, longitude 36° 44' E and an altitude of 1800 m. The site has two rainy seasons, long rains and short rains between which are dry spells. The short rains start mid October and end early December while the long rains commence in mid March and continue upto the end of May. The soil is a Kikuyu friable clay (Nitosol) with a deep profile and high porosity.

Experiment 1 was carried out during the dry period between July and October, 1986 and experiment 2 during the period December, 1986 and March, 1987. The amount of rain that occurred during experiments 1 and 2 was 20 and 110 mm respectively.

The land was ploughed, harrowed and left for two weeks to allow the moisture to evaporate before planting. To accommodate all the different treatments the experiment was laid out as a split-split-plot randomised complete block design (Little and Hills, 1974) with three replications. The main plots were the irrigation levels, the sub-plots each of which was arranged parallel to the line source sprinkler were the three bean cultivars. The sub-sub-plots were the three different depths of herbicide placement. A sub-sub-plot was (2 x 2)m^2. The variable used for analysis

was the number of plants which developed herbicide toxicity symptoms. For herbicide placement two furrows 10 cm wide, 2 m in length and 40 cm apart per subplot were dug manually. The depth of the furrows varied as follows; 20, 40 and 60 cm. After this the herbicide Metribuzin at the equivalent rate of 9 kg/ha was placed at the bottom of the furrows. The furrows were then refilled with soil, compacting it in the process. The bean cultivars, dressed with aldrin 40% wettable powder, were planted at a depth of 5 cm and a spacing of 10 x 40 cm in furrows 10 cm of the herbicide furrows that had been dressed with di-ammonium phosphate (18% N: 46% P_2O_5) at the rate of 100 kg/ha. There was a uniform post-planting irrigation of 115 mm in the first experiment and 77 mm in the second experiment to ensure crop establishment. The post-planting irrigation was less in the second experiment because there was some natural rain.

The cultural practices which included weekly spraying of the plants with dimethoate 40% (Rogor E) to control beanflies were carried out as described by Acland (1971).

The crop was irrigated using a line source sprinkler system of 5 cm diameter alloy pipes with sprinklers on 2 m risers. The pressure in the line was controlled at about 1.8 kg/cm^2. Although higher pressures could be used, previous work by Coulson et al. (1984) showed consistent gradient could be produced with this pressure which represented a frequent minimum pressure in the line. With this method it was possible to define three water levels ranging from high (H), medium (M) and low (L) with increasing distance from the sprinkler line.

Irrigation was carried out as early as 6.00 a.m. in the morning to alleviate wind effects and to avoid pressure changes brought about by other users on the system. Amount of water received by the plots was monitored by means of catch cans supported on stands 50 cm high. Water received by the plots was applied so that the ground 4 m at right angles to the line received the equivalent of the accumulated evaporation for a given period (measured by class A pan) minus any rainfall for that period. Pan and rainfall data were obtained daily from Kabete meteorological station located about 200 m from the plot. The irrigation gradient produced zero

TABLE 1. THE TOTAL AMOUNT OF WATER APPLIED DURING THE TWO EXPERIMENTS AT VARYING DISTANCES FROM THE SPRINKLER LINE.

Experiment	Irrigation level and(distance from line)		
	L (12 m)	M (8 m)	H (4 m)
1	145 mm	187 mm	240 mm
2	105 mm	229 mm	340 mm

TABLE 2: PERCENT SOIL MOISTURE CONTENT AT DIFFERENT IRRIGATION LEVELS AND DEPTH DURING EXPERIMENT 2.

	Irrigation level		
Depth	L	M	H
10 cm	20.9	24.0	26.55
30 cm	24.9	27	31

LSD 5% for 10 cm = 1.98
LSD 5% for 30 cm = 2.29

CV (10 cm) = 17.41%
CV (30 cm) = 5.41%

water application at about 14 m from the line and the increase in water from the line was essentially linear ($r^2 = 0.88$) (Figure 2 and table 2). The mean soil and air temperatures during the two experiments were different (figures 1a and b).

The effect of different irrigation levels on soil moisture was monitored once every week just before irrigation by determining the soil moisture content using the gravimetric method (Table 2). This involved weighing the wet samples and drying them to constant weight in an oven at 110°C. Percent moisture content was calculated as:

$$\frac{\text{Weight of wet sample - Weight of dry sample}}{\text{Weight of dry sample}} \times 100$$

Monitoring of the herbicide toxicity symptoms in each sub-sub-plot was done on the two centre rows in experiment 1 and the three centre rows in experiment 2. These rows of beans were planted 10 cm off the centre of the herbicide furrow. This was done to avoid the disturbed "soft" soil. The plant leaves were observed daily and the time (days post-emergence) of appearance of toxicity symptoms was noted. Differences among plants in time of development of symptoms were assumed to indicate differences in time for roots to reach the herbicide at a particular depth. Greater root penetration or root density would increase the probability

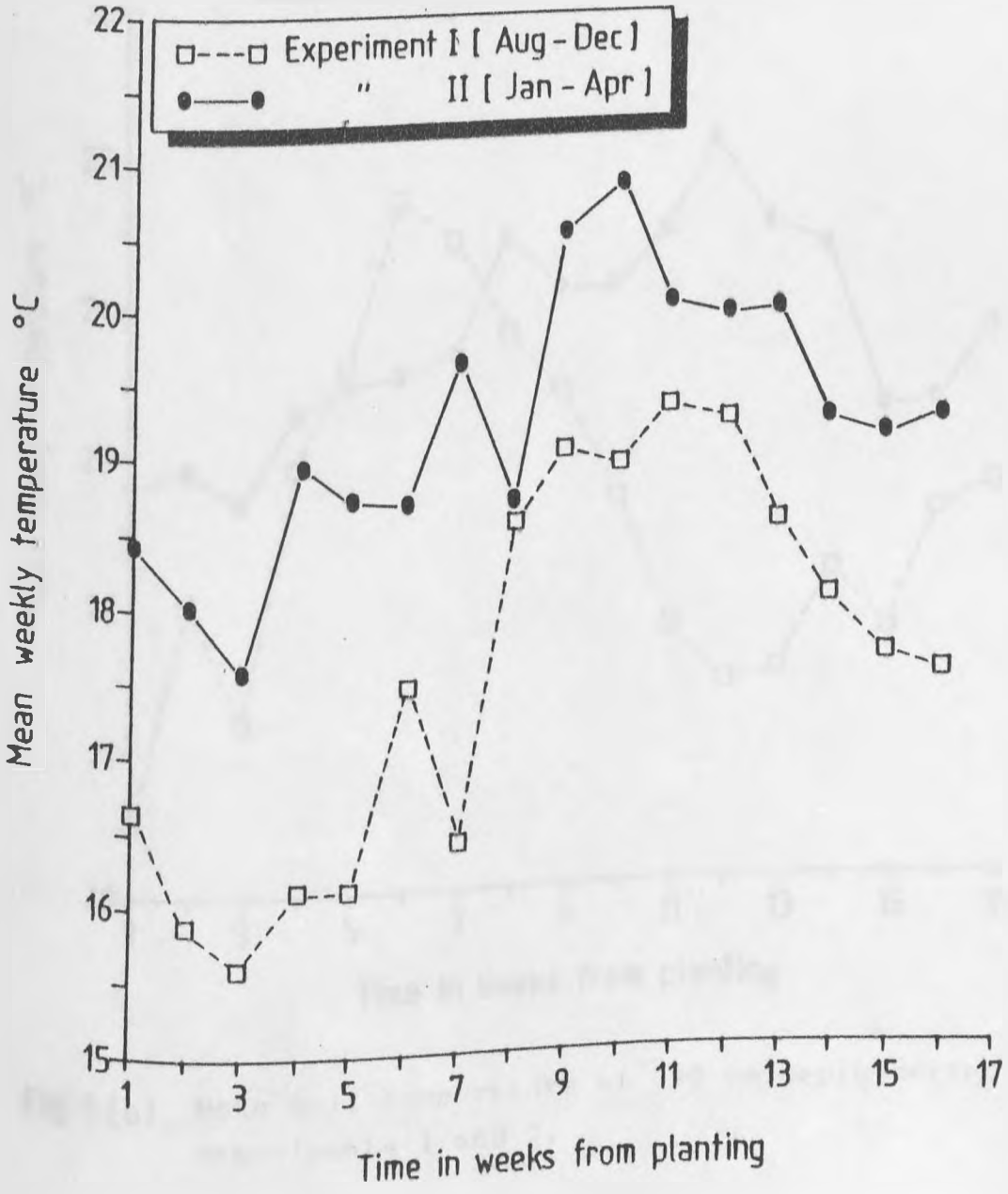


Fig. 1[a]. Mean air temperature (°C) during experiment 1 and 2.

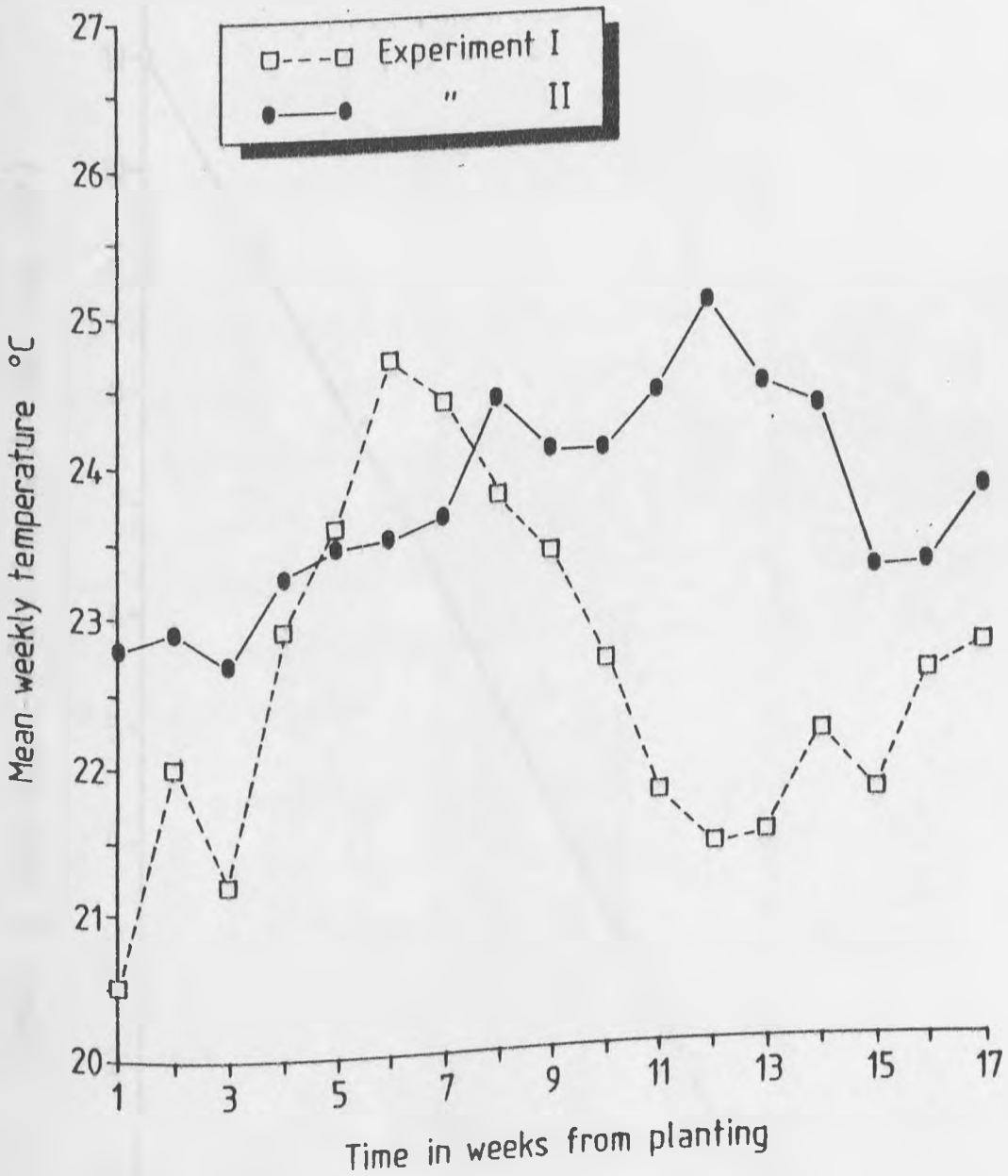


Fig. 1 [b]. Mean soil temperature at 20 cm depth during experiments 1 and 2.

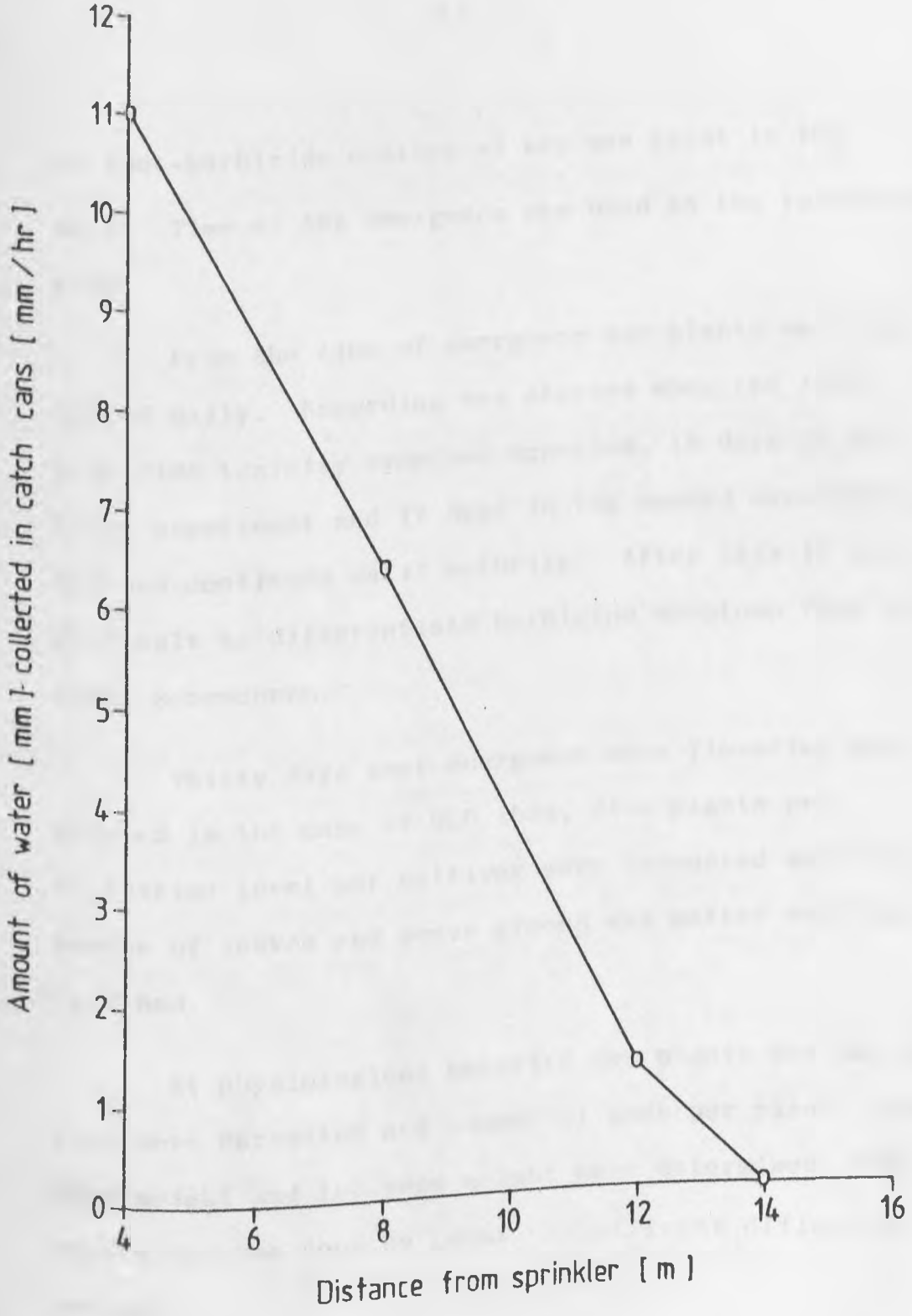


Fig. 2. Relationship between water applied/hr and distance from the irrigation line at line pressure of 1.8 kg/cm^2.

of root-herbicide contact at any one point in the soil. Time of 50% emergence was used as the reference time.

From the time of emergence the plants were observed daily. Recording was started when the first herbicide toxicity symptoms appeared, 19 days in the first experiment and 17 days in the second experiment, and was continued until maturity. After this it was difficult to differentiate herbicide symptoms from natural senescence.

Thirty days post-emergence when flowering had started in the case of GLP 1004, five plants per irrigation level per cultivar were harvested and total number of leaves and above ground dry matter were determined.

At physiological maturity ten plants per sub-sub-plot were harvested and number of pods per plant, total seed weight and 100-seed weight were determined. Mean separation was done by Least significant difference (L.S.D.) method.

4. RESULTS

The results presented here are from the glass-house and laboratory experiments and the two field experiments.

4.1 GLASSHOUSE AND LABORATORY EXPERIMENTS.

4.1.1 Sensitivity and Symptom Characterisation Test.

Compared to the control (no herbicide) the herbicide caused leaf chlorosis starting along the veins then progressing outwards to cover the entire leaf lamina. The symptoms generally started on the young-est fully expanded leaves. About 5 days after the appearance of the symptoms the leaves developed les-ions ultimately curling up and drying. Following this the whole plant dried up. The symptoms were similar for all the three cultivars. There was no disease or pest infestation.

There were no significant difference among the cultivars in their sensitivity to the herbicide (Table 4).For the three cultivars, it took about 72 hours for the symptoms to appear under the conditions of the experiment (Table 3).

TABLE 3: AVERAGE TIME IN DAYS TAKEN FOR THE SYMPTOMS TO APPEAR ON THE PLANTS AFTER ADDITION OF HERBICIDE TO THE HYDROPONIC BEAN CULTURE.

Cultivar	Time (days) for 50% of plants to show symptoms.
GLP 2	2.8
GLP x-92	2.9
GLP 1004	2.9

LSD 5% = 2.43

CV = 21.7%.

TABLE 4: NUMBER OF DAYS TAKEN FOR 50% OF THE PLANTS TO SHOW SYMPTOMS DURING THE GLASSHOUSE EXPERIMENT.

Cultivar	Depth of herbicide 10 cm (days)	20 cm (days)
GLP 2	12.67	16.55
GLP x-92	8.33	14.78
GLP 1004	10.22	14.11

LSD 5% (10 cm) = 1.12
LSD 5% (20 cm) = 0.82

CV (10 cm) = 19.18%
CV (20 cm) = 9.77%

4.1.2 Root Penetration.

Based on the time taken for appearance of the symptoms on 50% of the plants, the cultivars were significantly different (P = 0.05) in the time taken for their roots to reach 10 cm and 20 cm (Table 4). There was no significant difference between GLP 1004 and GLP x-92 in the times taken to reach 10 and 20 cm but GLP 2 took significantly longer than the other two varieties at both depths (Appendix 3 and 4).

Using the average time in days, taken by 50% of the plants to show the toxicity symptoms and the depth of herbicide placement, the root penetration in cm/day was calculated as depth of herbicide placement divided by the average time taken for 50% of plants to show toxicity symptoms (Table 5). GLP x-92 and GLP 1004 had similar rates of root penetration. GLP 2 had a significantly lower rate of root penetration than the other two cultivars.

4.1.3. Dry and wet absorption test.
There was no significant difference in appearance of symptoms at different water levels (Table 6b)

TABLE 5a. THE RATE OF ROOT PENETRATION OF THE THREE BEAN CULTIVARS DURING THE GLASSHOUSE EXPERIMENT.

Depth	Cultivar	Penetration rate (cm/day)
10 cm	GLP 2	0.87
	GLP x-92	0.95
	DLP 1004	0.99
20	GLP 2	1.11
	GLP x-92	1.32
	GLP 1004	1.42

TABLE 5b. DRY AND WET TEST (G2)

Cultivar	Field capacity	$\frac{1}{4}$ - Field capacity
GLP x-92	2.75	2.25
GLP 1004	2.75	2.5
GLP 2	3	2.5

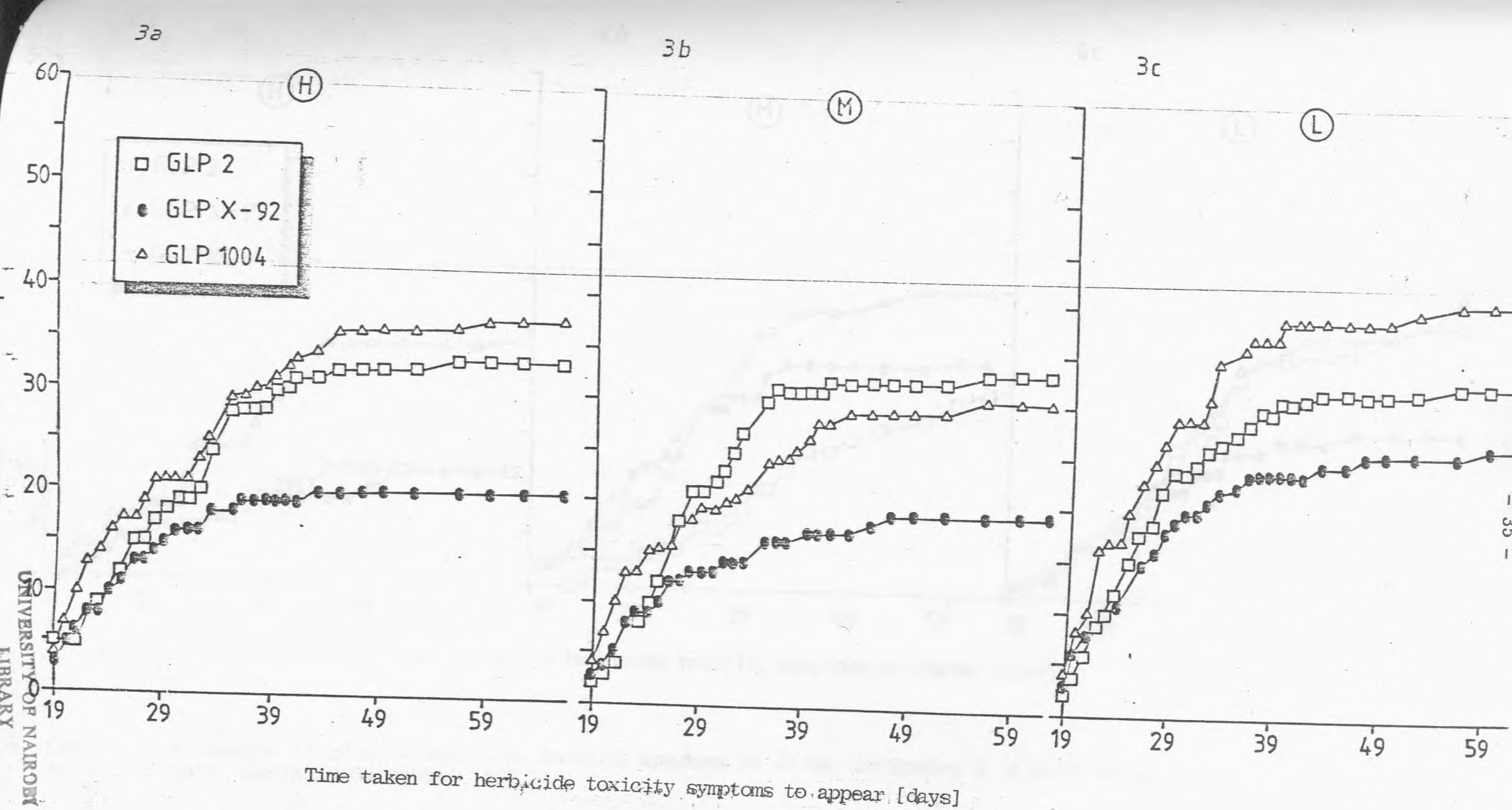
CV =0 4.6%

LSD = 2.5

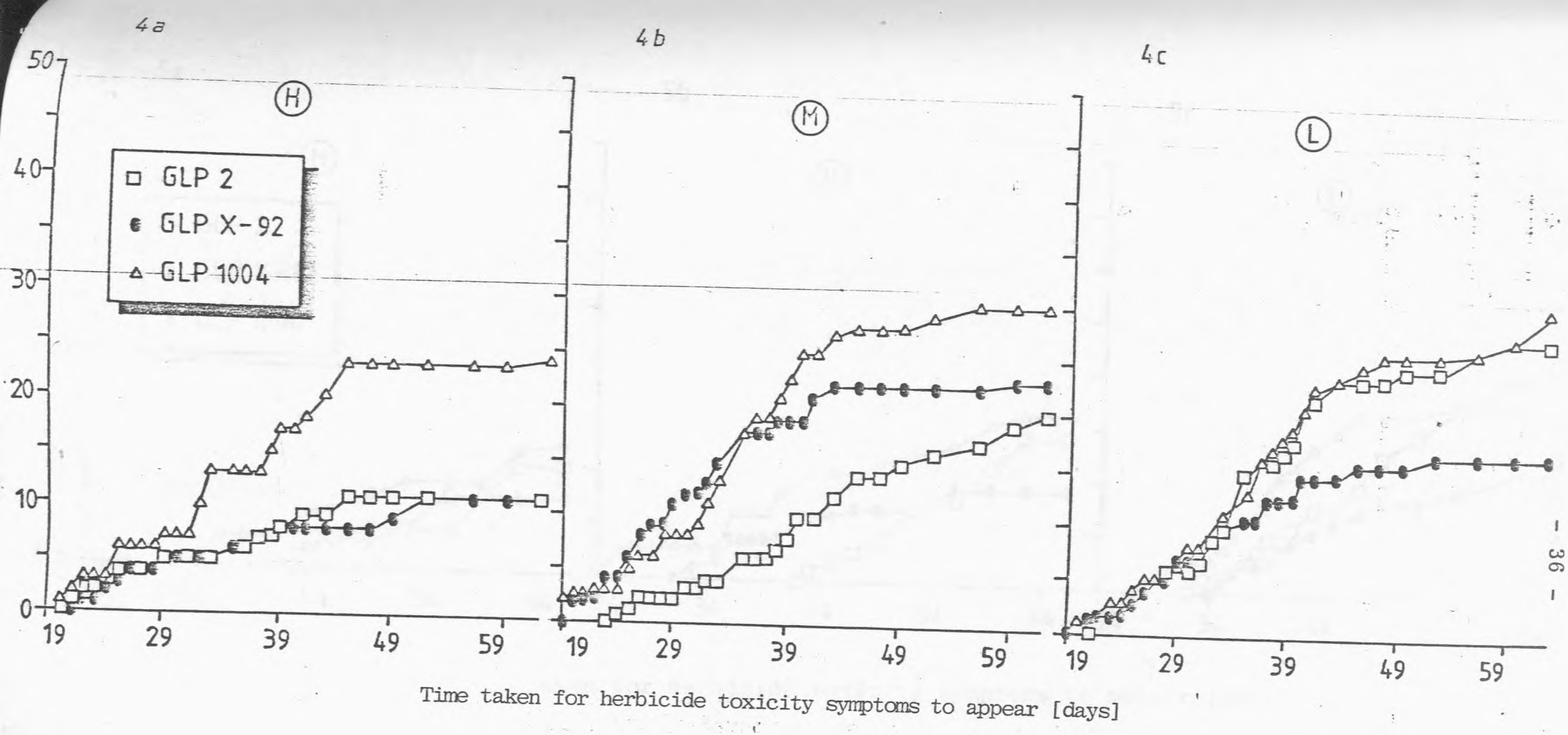
4.2 FIELD EXPERIMENT.

4.2.1 Root Penetration.

The cumulative number of plants showing symptoms increased with time upto flowering. After flowering there was no further increase in the number of plants showing symptoms (Figures 3 - 8). More plants reached 60 cm depth in the case of irrigation L compared to irrigation H (Figures 5 and 8). At depths of 20 cm and 40 cm, however this difference was not very apparent. Figure 3 and 4 show that roots grew to at least 40 cm. At the lowest irrigation level (L) all plants grew down to 60 cm while at the highest irrigation level (H) only 70% of the plants reached 60 cm depth in experiment 2 and about 60% in experiment 1 (Figures 5 and 8).GLP 1004 generally had the greatest number of plants which ultimately reached 60 cm followed by GLP 2 and lastly GLP x-92. Although GLP 2 had a lower number of plants showing symptoms than GLP 1004 during experiment 2 there was no significant difference between them (Appendix 8a and 8b).



ig. 3. Cumulative number of plants showing herbicide toxicity symptoms at 20 cm versus time taken.



4. Cumulative number of plants showing toxicity symptoms at 40 cm, irrigation H, M and L versus time taken in days during experiment 1.

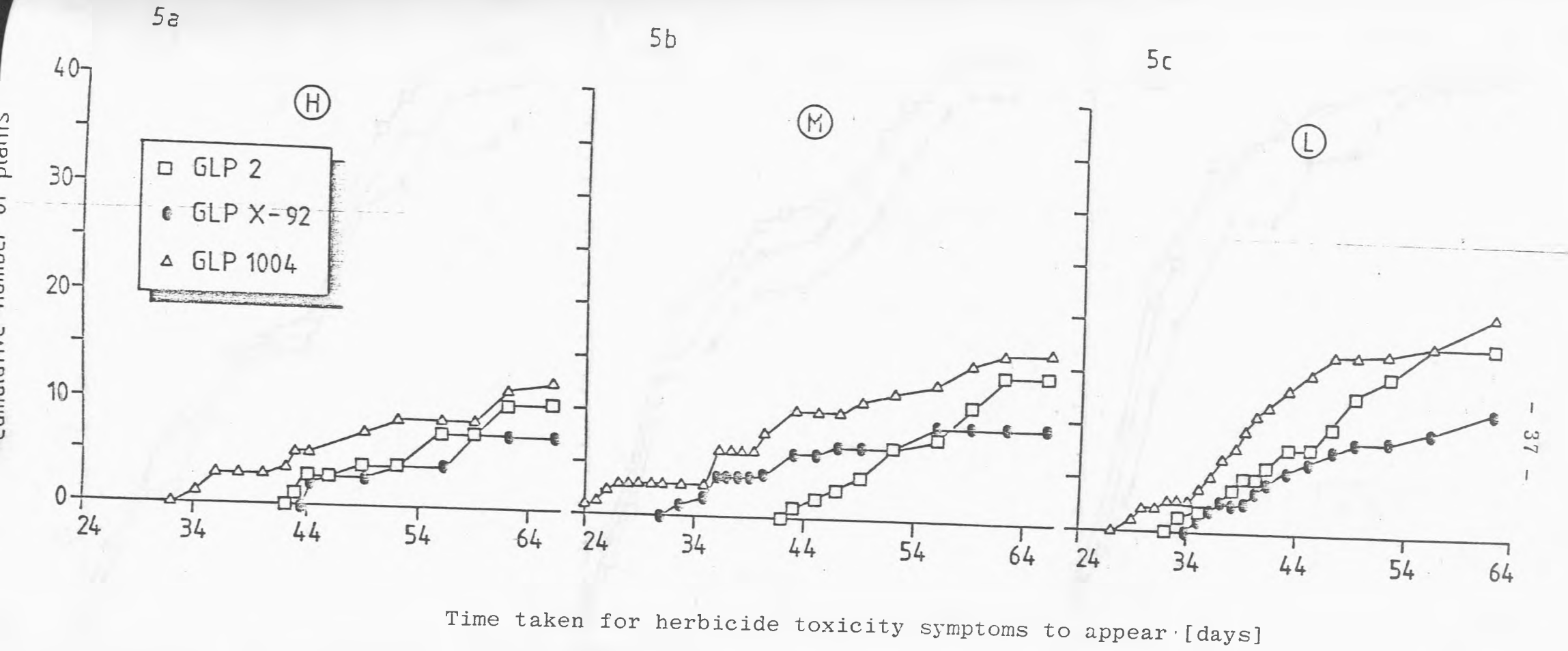


Fig. 5. Cumulative number of plants showing herbicide toxicity symptoms at 60 cm, irrigation H, M and L versus time taken in days during experiment 1.

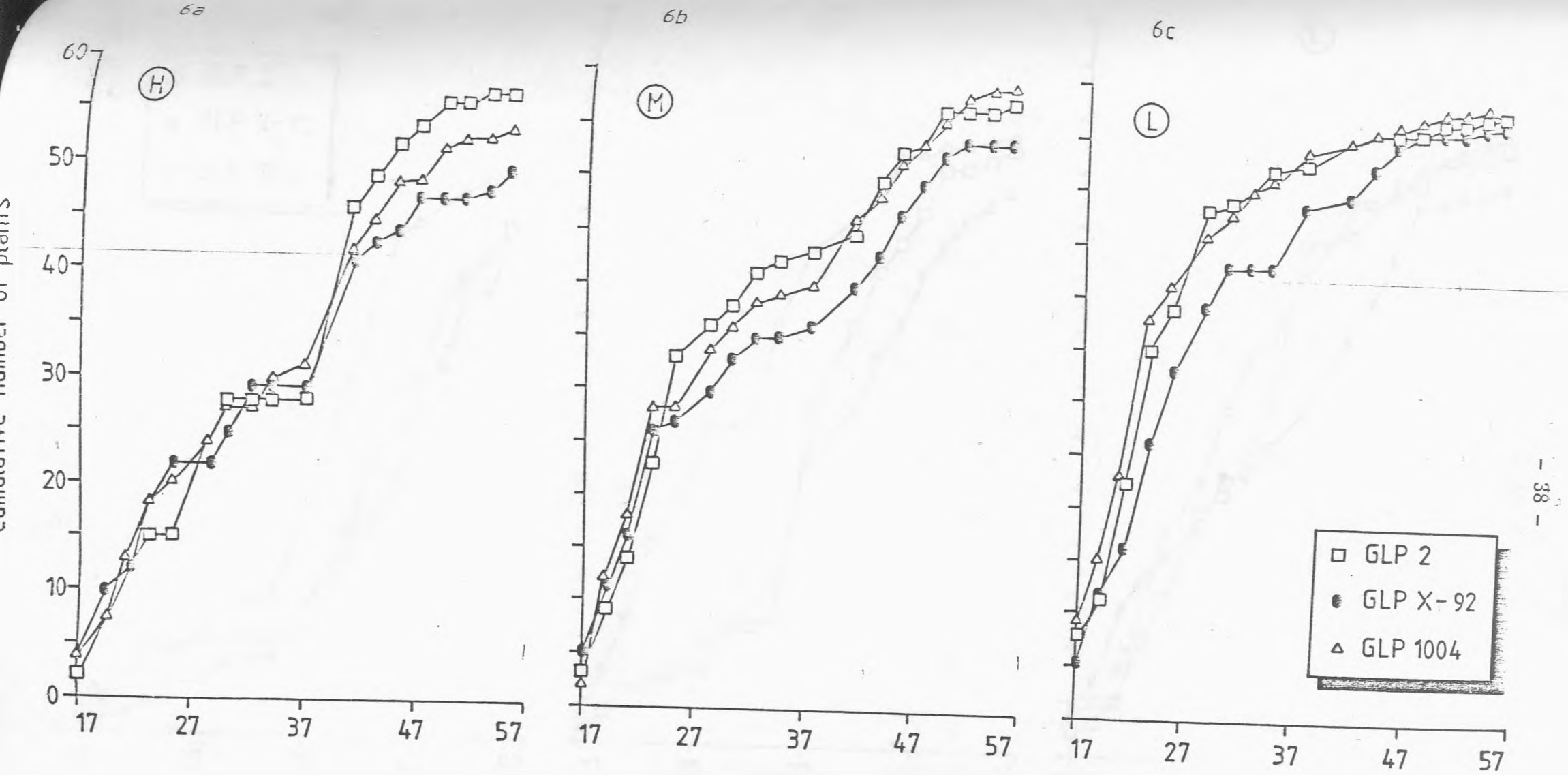


Fig. 6. Cumulative number of plants showing herbicide toxicity symptoms at 20cm irrigation H, M and L versus time in days during experiment 2.

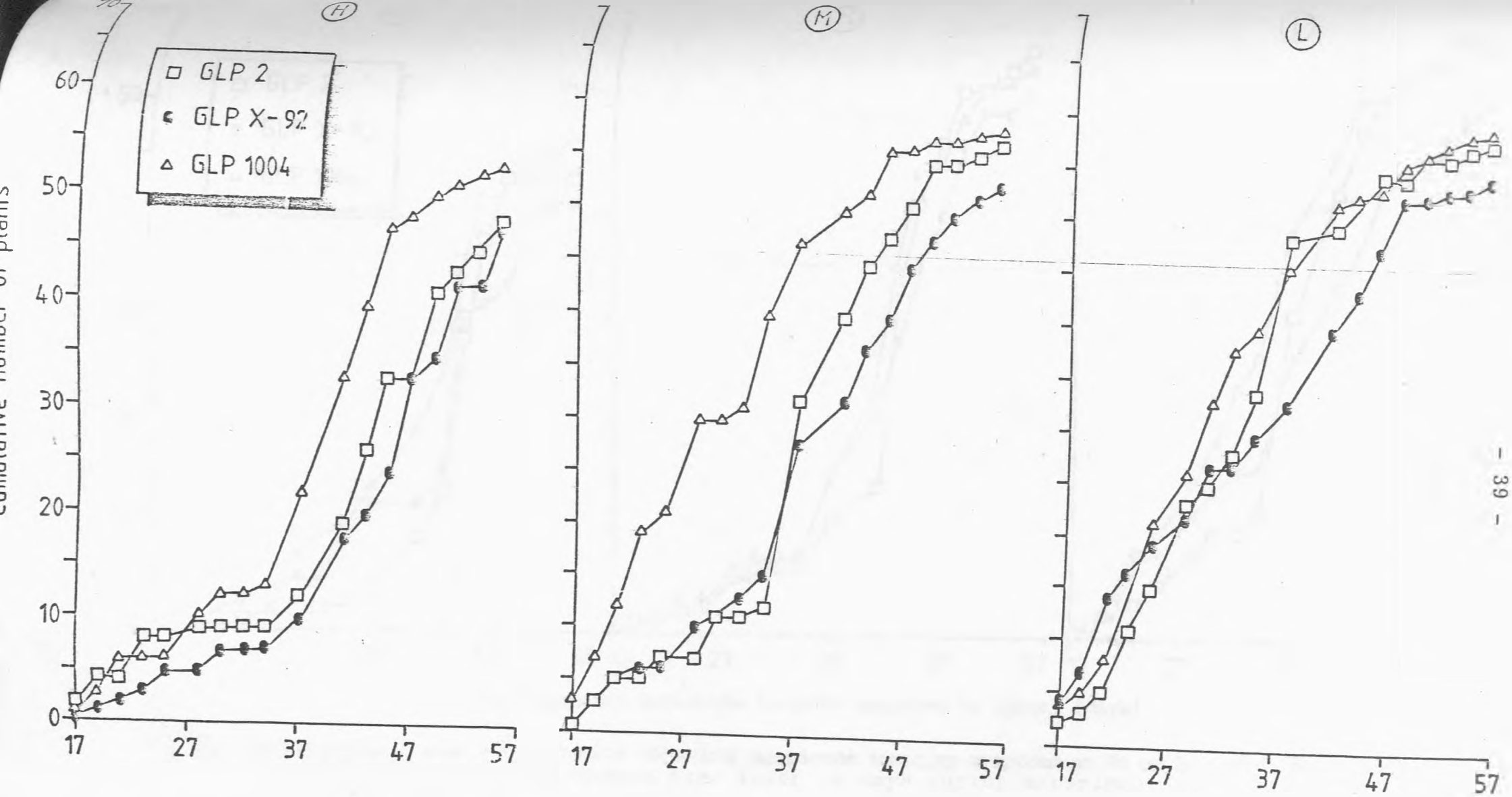


Fig. 7. Cumulative number of plants showing herbicide toxicity symptoms at 40 cm herbicide depth, irrigations H, M and L versus time taken in days during experiment 2.

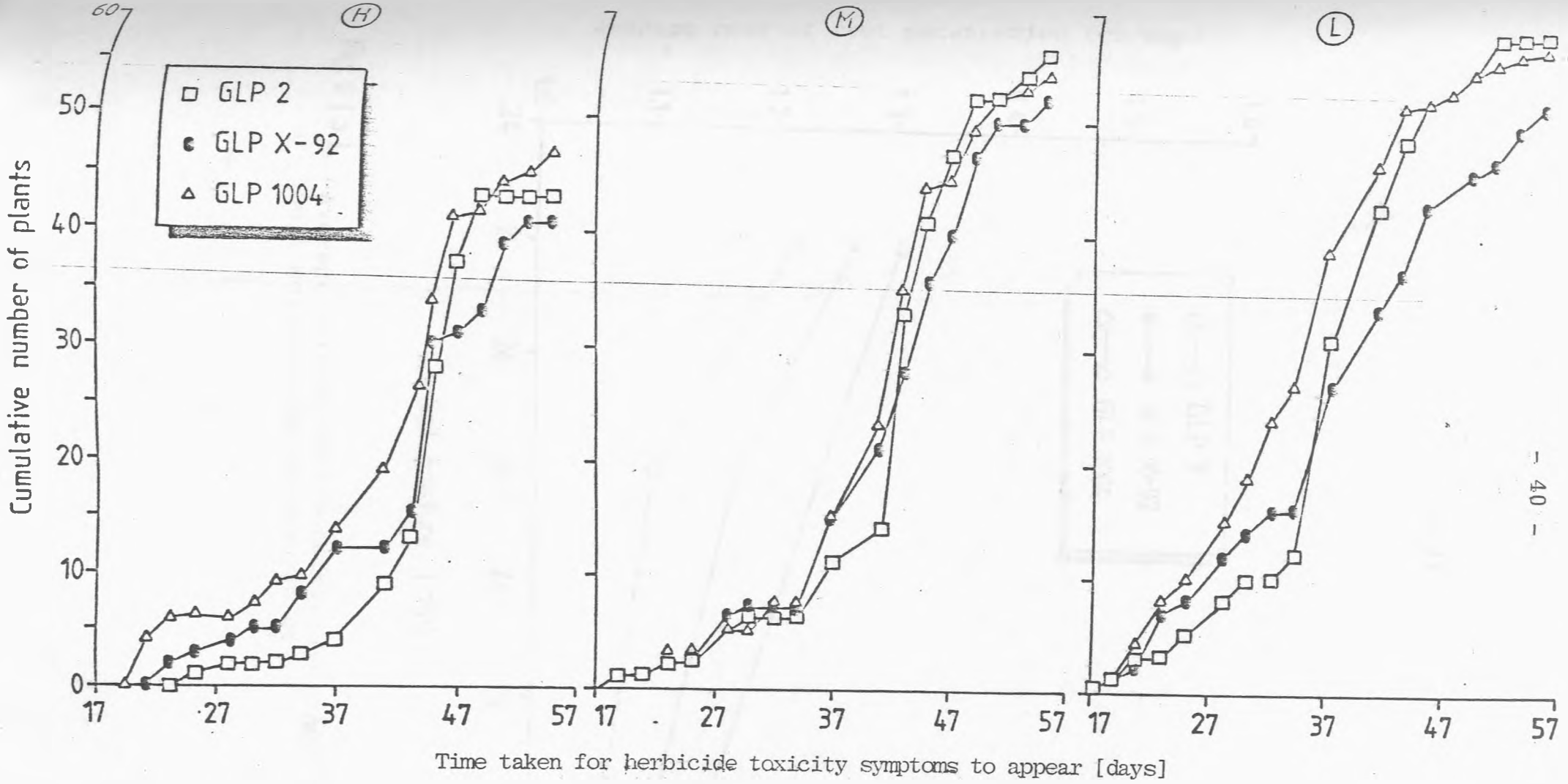


Fig. 8. Cumulative number of plants showing herbicide toxicity symptoms at 60 cm herbicide depth and irrigations H, M and L versus time taken in days during experiment 2.

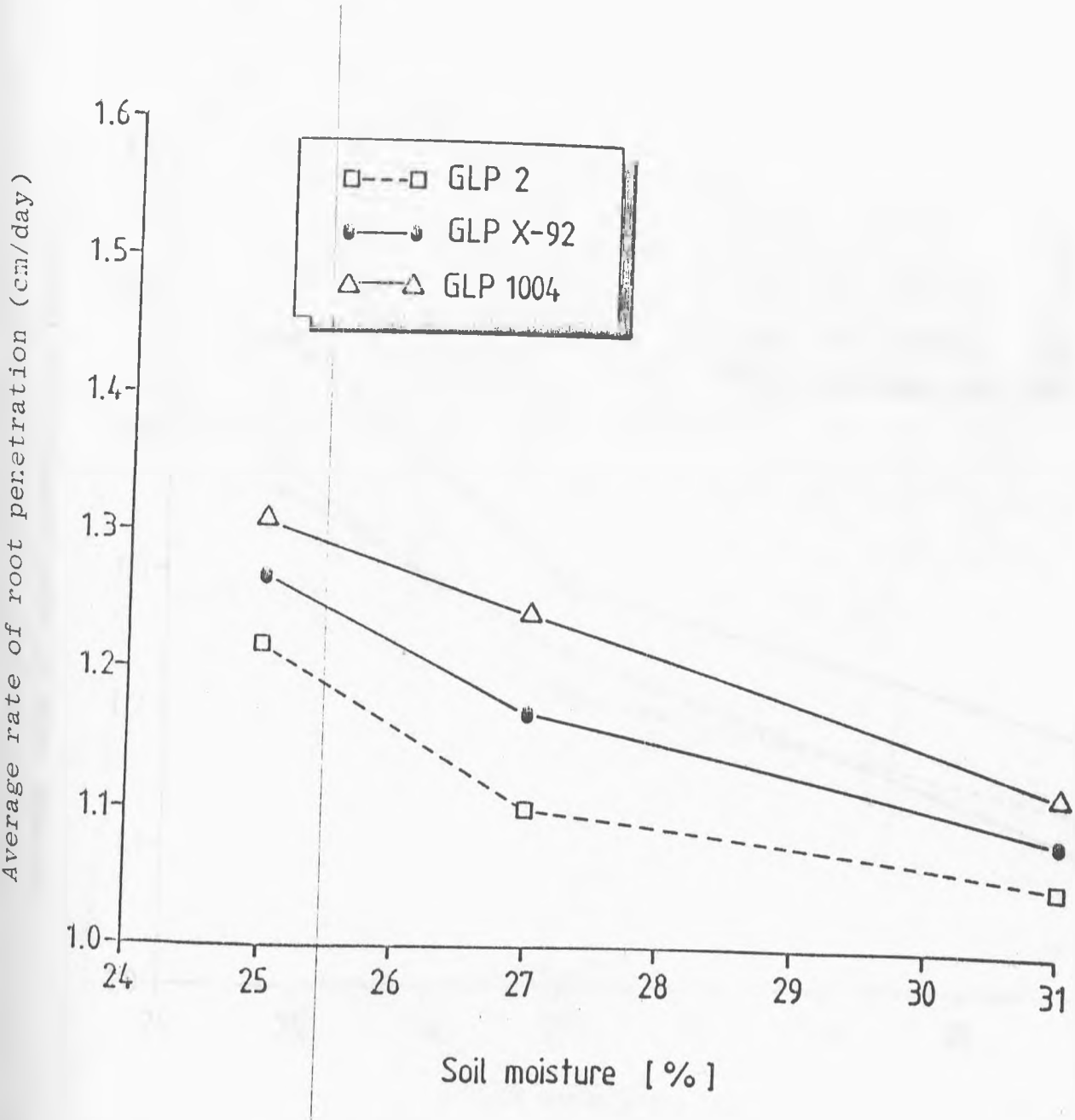


Fig. 9 [a]. Average rate of root penetration (cm/day) versus soil moisture during experiment 1.

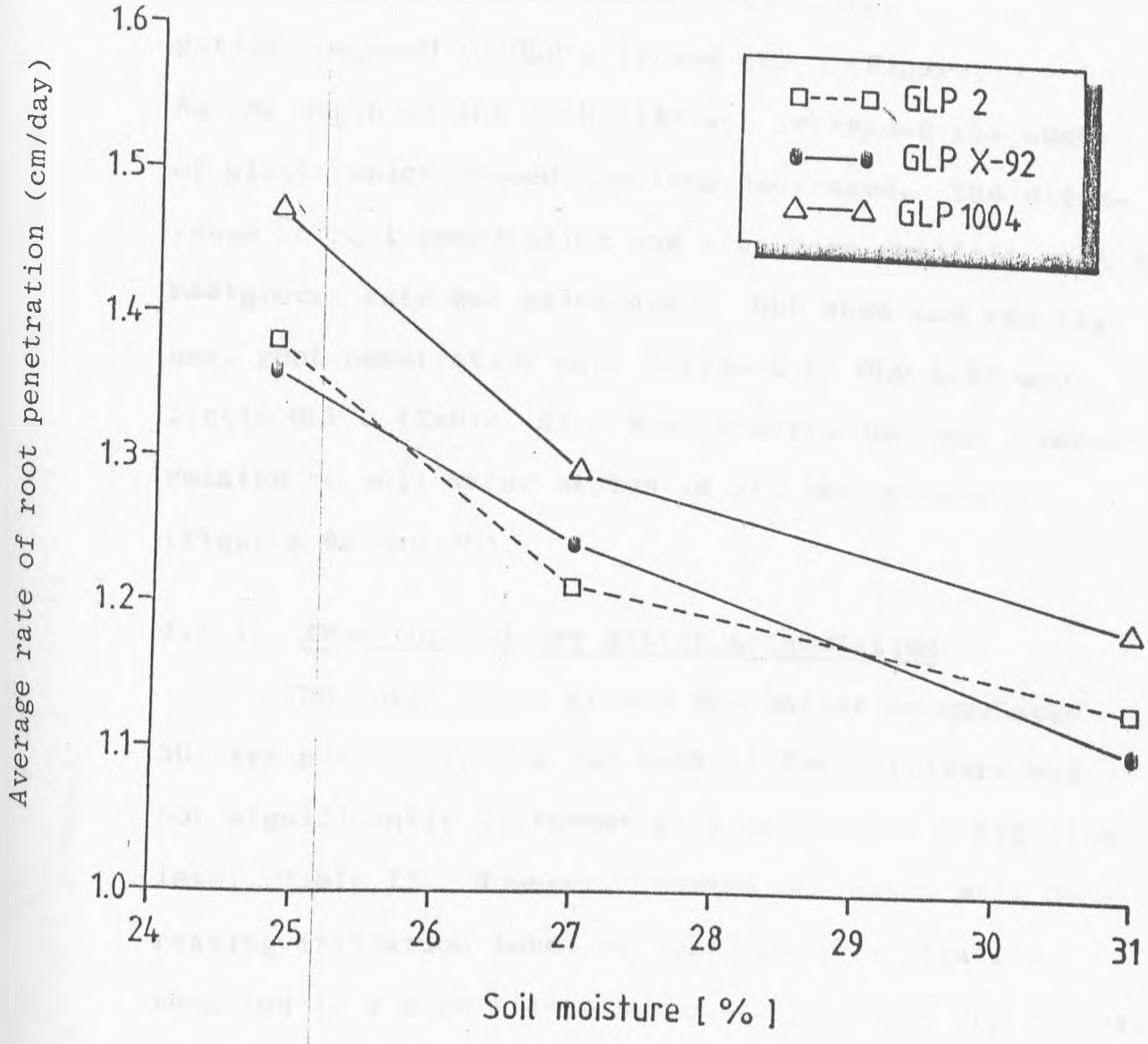


Fig. 9 [b]. Average rate of root penetration (cm/day) versus soil moisture during experiment 2.

Irrigation x cultivar and irrigation x depth interactions were highly significant (Appendix 9a and 9b). GLP 1004 roots penetrated the soil faster at low irrigation compared to GLP x-92 and GLP 2 (Figures 3 - 8). As the depth of the herbicide was increased the number of plants which showed symptoms decreased. The difference in root penetration was even more explicit when the rootgrowth rate was calculated. GLP 1004 had the highest root penetration rate followed by GLP x-92 and lastly GLP 2 (Table 6). Root penetration was inversely related to soil water status in all the cultivars (Figures 9a and 9b).

4.2.2. Above Ground Dry Matter Accumulation

The total above ground dry matter accumulated 30 days post-emergence for each of the cultivars was not significantly different at a particular irrigation level (Table 7). However, biomass decreased with decreasing irrigation level so that lowest irrigation resulted in a significant reduction in shoot dry matter.

At 30 days post-emergence irrigation level showed very significant ($P = 0.05$) effect on the number of leaves formed per plant (Table 8).

TABLE 6. THE AVERAGE PENETRATION RATES (CM/DAY) OF THE THREE BEAN CULTIVARS AT DIFFERENT IRRIGATION LEVELS.

EXPERIMENT 1

Cultivar	Irrigation L	M	H
GLP 2	1.22	1.11	1.05
GLP x-92	1.27	1.17	1.09
GLP 1004	1.31	1.24	1.12

EXPERIMENT 2

Cultivar	Irrigation L	M	H
GLP 2	1.38	1.21	1.13
GLP x-92	1.36	1.24	1.11
GLP 1004	1.47	1.29	1.19

TABLE 7: ABOVE GROUND DRY MATTER ACCUMULATED 30 DAYS POST-EMERGENCE (g/m^2) DURING 1987 EXPERIMENT.

Cultivar	Irrigation L	M	H
GLP 2	122	186	196
GLP 1004	130	212	234
GLP x-92	124	170	262

LSD 5% within rows = 12.07
CV (Irrigation) = 85.7%
CV (Cultivar) = 15.4%

TABLE 8: TOTAL NUMBER OF LEAVES PER PLANT 30 DAYS POST-EMERGENCE DURING THE 1987 EXPERIMENT.

Cultivar	Irrigation		
	L	M	H
GLP 2	7	9.3	10.7
GLP 1004	10	11	16.7
GLP x-92	14.3	19.3	33

LSD 5% = 2.44.

CV (Irrigation) = 19.36%

CV (Cultivars) = 18.77%

The cultivars also had significantly different numbers of leaves and the irrigation x cultivars interaction was also significant. (Appendix 10b).

4.2.3 Seed Yield.

The yield data presented here is only for the 1987 experiment because the 1986 one was adversely affected by too much rain after flowering.

In terms of seed yield the cultivars were significantly different from each other (Table 9) GLP 1004 was highest yielding followed by GLP x-92 and lastly GLP 2. However, the difference between GLP x-92 and GLP 2 was not significant. Reduced irrigation significantly ($P = 0.05$) reduced the seed yield in all the cultivars and there was a significant difference between cultivars in this respect (Appendix 11).

Irrigation did not have a significant effect on number of pods per plant (Table 10). The cultivars were however significantly different from each other in terms of number of pods per plant (Appendix 12).

Reduced water application significantly reduced total seed yield and 100-seed weight (Tables 9 and 11).

4.2.4 Relationship Between Economic Yield and the Parameters Measured.

A linear regression was computed with general assumption in the order of:

$$Y = a + bX$$

Where Y = Economic yield estimate (g)

a = Constant

b = Coefficient of parameter X

(i) Root growth: (cm/day) versus irrigation.

The coefficients, r of root penetration were negative. The relationship was significant for GLP 1004 and GLP x-92. (Appendix 17)

Equation 1

GLP 2:	Y = 1.66 - 0.05x	r^2 = 0.8
GLP x-92	Y = 3.79 - 0.12x	r^2 = 0.7
GLP 1004	Y = 7.47- 0.23x	r^2 = 0.75

The negative regression coefficient suggests a negative influence of root penetration over eco-

TABLE 9:. TOTAL SEED YIELD(g/m^2)FOR THE 1987 EXPERIMENT.

Cultivars	Irrigation		
	L	M	H
GLP 2	378.6	392	484
GLP 1004	444	630	692
GLP x-92	438	482	528

LSD 5% within rows = 12.1

CV (Irrigation) = 18.12%

CV (Cultivars) = 18.26%

TABLE 10: THE NUMBER OF PODS PER PLANT FOR EXPERIMENT 2 ANALYSED AS A SPLIT-PLOT DESIGN.

Cultivar	Irrigation level		
	L	M	H
GLP 2	8	8.3	7.6
GLP x-92	16.33	14.33	13
GLP 1004	12.67	9	12.33

LSD 5% within rows = 5.26

CV (Irrigation) = 18.26%
CV (Cultivar) = 52.35%.

TABLE 11: THE EFFECT OF IRRIGATION LEVEL ON 100-SEED WEIGHT DURING EXPERIMENT 2

	Irrigation		
Cultivar	L	M	H
GLP 2	38.22	43.8	49.34
GLP x-92	32.76	32.46	32.24
GLP 1004	37.08	39.71	41.51

LSD 5% within rows = 2.26

CV (Irrigation) = 1.15%

CV (Cultivar) = 21.98%.

nomic yield. That is the highest root penetration occurred at irrigation L and it is here where the seed yield was lowest.

(ii) Shoot dry matter 30 days post-emergence versus economic yield.

GLP 2:	$Y = 1168.2 + 25.54X$	$r^2 = 0.39$
GLP 1004	$Y = 1368.05 + 9.96X$	$r^2 = 0.02$
GLP x-92:	$Y = 1953.32 - 0.02X$	$r^2 = 0.03$

The coefficients above are low possibly because the roots had not translocated dry matter to the stem which would later be translocated to the seed. This led to low correlation between the parameters.

(iii) Relationship between root growth and economic yield.

GLP 2:	$Y = 1831.37 - 33.42X$	$r^2 = 0.613$
GLP x-92	$Y = 1949.56 - 18.81X$	$r^2 = 0.4$
GLP 1004:	$Y = 2564.0 - 3.31X$	$r^2 = 0.66$

The correlation coefficients are comparatively low and negative. This implies that increasing root growth had a negative influence over economic yield. The relationship is not significant for GLP 2 but significant for GLP 1004 and GLP x -92. Appendix 17

5. DISCUSSION

In this study the root penetration rate (RPR) had a similar pattern in all the experiments (Figures 3-8). Experiment 2 had a higher RPR than experiment 1. Only about 30% of the plants penetrated to 60 cm in 1986 compared to 75% in 1987. These differences could be attributed to environmental conditions. Air and soil temperature and evapotranspiration were higher in 1987.(Figures 1 and 2).The higher soil temperatures may have encouraged root growth and thus penetration. The higher evaporation could have made the soil drier and encouraged downward growth of the roots.

In both experiments a greater number of plants penetrated at irrigation L, fewer at M and even less number at H. All the cultivars penetrated upto 40 cm irrespective of the irrigation level. Irrigation had a great effect on the number of plants whose roots penetrated to 60 cm. At irrigation L and M nearly 100% of the plants reached 60 cm, but at irrigation H only 70% reached this depth. An increase of 7% soil moisture caused a reduction of 30% in the number of plants penetrating to 60 cm. There was a significant cultivar difference in root penetration. Addition of the herbicide to hydroponic bean culture and the bioassay test showed that the diffe-

rence in time taken for herbicide toxicity symptom expression was not due to differences in herbicide uptake between cultivars or the upward or downward movement of the herbicide in the field or differences in uptake between wet or dry conditions but was due to difference in root penetration rate of the cultivars. This showed that this technique portrayed the true depth of root penetration into the soil. The average penetration rates achieved in the field by this technique were lower than those reported by Markhart (1985) using tubes. High rates of root penetration in plastic tubes have also been observed by Coulson (unpublished) and would seem to be due to roots being artificially contained in narrow tubes or loose soil packing. GLP 1004 had the highest root penetration in both the glasshouse and field experiment, followed by GLP x-92 and lastly GLP 2.

Root penetration was inversely related to soil water status in all cultivars (Figures 9a and 9b) both field experiments the number of plants showing herbicide toxicity symptoms increased with increasing time. After flowering no new plants showed herbicide toxicity symptoms indicating that root growth had ceased. This proposition is supported by the work of D'Souza and Coulson (1987),

Roots absorb and translocate water and nut-

rients, synthesize and transport some organic compounds, are a sink for carbohydrates and support the plant. The extent of their development and functioning is governed by genetic as well as environmental factors such as moisture. Plants, however, have mechanisms to combat stress conditions. With respect to water stress it has been observed that plants root deeper in an attempt to maintain continual contact with water (Kaspar et al., 1984; Sullivan and Ross, 1979). This is likely to be achieved by preferential partitioning of photosynthates towards roots. Under mild stress roots have the ability to adjust osmotically. Whereas preferential partitioning towards roots might improve water status of the plant it might reduce crop yield. D'Souza and Coulson (1987) have observed that bean yield is slightly dependent on remobilisation of dry matter from the roots and stem to the developing seeds and that such remobilisation is less efficient under dry conditions compared to wet conditions.

Since all the cultivars were exposed to the same environmental conditions it is possible that the differences observed were a manifestation of their genetic makeup. The cultivars are adapted to different environmental conditions. GLP 1004 is developed

for areas of limited water supply, GLP 2 for areas with adequate water while GLP x-92 is developed for a wide range of water supply (MALD, 1983). The higher RPR of GLP 1004 could account for this. In fact fast root penetration has been correlated with early maturity (Atmonson, 1978) and GLP 1004 is an early maturing cultivar. Derera et al., (1969) also observed that early maturing cultivars of wheat developed a large root system early in the season and were better suited to the dryland conditions. The high RPR at irrigation L was probably because the photosynthates were preferentially distributed towards the roots leading to greater root penetration. Doorenbos, (1979) and Lenga (1979), working with beans found that roots generally grew deeper than 40 cm and that seasonal variation in rooting depth occurred depending on the rainfall. The weather condition differences during experiment 1 and 2 could be the cause of the difference in rooting depth between them. evapotranspirational demand and temperature were higher in 1987 than 1986. This adverse environmental conditions in 1987 might have caused more stress. Roots ceased penetrating deeper at flowering probably because root growth had ceased. Root growth cessation at flowering has

been reported by El Nadi et al. (1969), Norman et al. (1984) and D'Souza and Coulson (1987).

The results of the field experiment were similar and consistent with those of the glasshouse experiment i.e. GLP 1004 had a greater root penetration compared to other cultivars. This is in agreement with the finding of Kaspar et al., (1984) and Sullivan and Ross (1979) that deep rooting is a mechanism of drought avoidance and that of Robins and Domingo (1956), Norman et al. (1984), D'Souza (1985) that root growth cease at flowering.

Dry matter production was influenced by water application. The dry matter at 30 days post emergence when GLP 1004 and GLP x-92 had reached 50% flowering, showed that irrigation had a significant effect. Reduction in applied water decreased the dry matter accumulated. Reduction in applied water significantly reduced the number of leaves produced. Leaves being the primary photosynthetic organs are important for dry matter production. The process most sensitive to water stress in most crops is leaf expansion (Hsiao, 1973). Apparently this is a consequence of the critical role of turgor in the growth processes. Stress too mild to close stomata and inhibit photosynthesis has been shown to readily reduce leaf area development (Hsiao et al., (1976). Prolonged suppression of cell expansion could however have a negative feedback on cell division which could lead to slowing down of rate of leaf initiation. The decrease in number of leaves formed is likely to be the result of prolonged water stress. The dry matter produced was directly related to soil moisture. The number of leaves, in addition to leaf area, have been reported to play an important role in determining the pod number per plant (Ishag, 1973). Thus a decrease

in leaf number and leaf area might have been the cause of decrease in dry matter accumulation at the lowest irrigation level. Above ground dry matter contributed directly to the increase in economic yield. The regression coefficients were low, however although positive, probably because little photosynthates was being retranslocated from the roots at this time. Root growth and economic yield were negatively correlated implying that roots were growing at the expense of economic yields, except in the case of GLP 1004 where the correlation was low.

A decrease in the amount of irrigation water resulted in a decrease in economic yield in all the cultivars. There was a significant difference in yield between the cultivars. GLP 1004 was the highest yielding followed by GLP x-92 and lastly GLP 2. Economic yield consists of dry matter. Dry matter production and distribution between the plant parts is of prime concern in considering effects of water stress on yield. Water stress occurring during vegetative growth phase has been observed to reduce leaf area, leaf initiation and may close stomata and thus inhibit photosynthesis. During the reproductive phase, in addition to decrease in dry matter accumulation water stress brings about poor fertilization, abortion of fertilized ovaries and fruit/flower abscission (Norman et al., 1984; Dubetz and Mahalle, 1969). Hsiao et al.,

(1976) observed that during water stress fruit or grain yield can be reduced while total dry matter production remains relatively constant. The key consideration here is the partitioning of assimilates among plant parts (Milthorpe and Moorby, 1974). Many researchers have reported relationships between plant dry matter and economic yield. D'Souza (1985), D'Souza and Coulson (1987), working with beans, reported that a retranslocation of dry matter occurred from the roots, stems and leaves to the reproductive organs and that water stress can reduce the retranslocation rate.

It is possible that the low yields experienced at irrigation L were a result of decrease in dry matter production accompanied by decrease in the rate of retranslocation of photosynthates from the roots. The yield difference between the two experiments might have been due to difference in environmental conditions. Mean day/night air temperatures varied significantly (Figure 1a). Average soil temperatures at 10 cm depth were higher in 1987 (19.2°C) compared to 1986 (17°C). Evapotranspiration was also higher in 1987 (Appendix 14 and 15). Seed yield in cowpeas has been correlated with accumulated day degrees (Heat units) (Turk et al., 1980). Temperatures greater than 25°C and water stress have been reported to be the

major causes of flower abscission and failure to set and fill pod in beans (Norman et al., 1984; Dubetz and Mahalle, 1969). It is therefore possible that temperature and water stress were manifesting themselves through low yields in 1987. Such seasonal variations have also been reported by Stansell and Smittle (1980) when they planted beans during spring and fall. They attributed the difference to environmental conditions.

There was a significant difference in number of pods per plant among cultivars (Table 11). However there was no significant difference among irrigation levels. GLP x-92, a semi-determinate cultivar had the highest number of pods per plant followed by GLP 1004 and lastly GLP 2. There was a significant difference among the cultivars and irrigation in 100-seed weight. GLP 2 had the highest 100-seed weight followed by GLP 1004 and lastly GLP x-92. Water stress significantly reduced the 100-seed weight.

The grain yield of food legumes can be represented as:

Yield per plant = Number of pods/plant * number of seeds/pod * seed weight. (FAO 1977). Most studies

indicate that number of pods is influenced most by different factors followed by grains per pod and lastly seed weight (Turk et al., 1980; FAO, 1977). This is not in agreement with the results arrived at during the experiment where irrigation did not have a significant effect on the pods per plant. This difference could have arisen because during flowering there was some rain. This must have ameliorated the stress built during the vegetative stage and provided conducive conditions for podset. Therefore the number of seeds/pod and seed weight must have been responsible for the yield difference. This agrees with El Nadi et al. (1969) who reported that beans can recover from stress which occur during vegetative stage provided subsequent environmental conditions are conducive to rapid recovery of growth and efficient podset. The significant decrease in 100 seed weight when irrigation was reduced might have resulted from a limitation in photosynthates source. Source limitation has been cited as the cause of seed weight reduction. D'Souza and Coulson (1987) working with beans observed that leaves have little direct contribution to the seed dry matter accumulation and a small amount of deflowering or removal of pods did not affect seed yield (Wein, 1973). Photosynthate from the leaves primarily

(1976)observed that during water stress fruit or grain yield can be reduced while total dry matter production remains relatively constant. The key consideration here is the partitioning of assimilates among plant parts (Milthorpe and Moorby, 1974). Many researchers have reported relationships between plant dry matter and economic yield. D'Souza (1985), D'Souza and Coulson (1987), working with beans, reported that a retranslocation of dry matter occurred from the roots, stems and leaves to the reproductive organs and that water stress can reduce the retranslocation rate. It is possible that the low yields experienced at irrigation L. were a result of decrease in dry matter production accompanied by decrease in the rate of retranslocation of photosynthates from the roots. The yield difference between the two experiments might have been due to difference in environmental conditions. Mean day/night air temperatures varied significantly (Fig. 1a). Average soil temperatures at 10 cm depth were higher in 1987 (19.2°C) compared to 1986 '17°C). Evapotranspiration was also higher in 1987 (Table 1). Seed yield in cowpeas has been correlated with accumulated day degrees (Turk et al., 1980). Temperatures greater than 25°C and water stress have been reported to be the

6. CONCLUSION

Decreased water application leads to deeper rooting. The rate of root penetration is inversely related to the water availability. GLP 1004 has a relatively higher RPR compared to GLP 2 and GLP X-92. Fast RPR appears to be one of the mechanisms utilised by GLP 1004 to avoid drought. Reduced water application substantially reduces dry matter accumulation. In addition to high RPR of the cultivars developed for areas of limited rainfall they are probably able to retranslocate more dry matter from the root towards the seed.

These results further indicate that crop varieties which escape drought through early maturity can also employ other drought resistance mechanisms (e.g. drought avoidance) if faced with periods of drought during the season. Given the erratic nature of rainfall in semi-arid tropical areas such drought avoidance and tolerance mechanisms need further studies so that they can be incorporated in crop improvement programs for marginal rainfall areas.

7. REFERENCES

Acland, J.D. East African crops. Longman. 1971.

Anonymous, 1981. National Food Policy Sessional Paper No. 4 Republic of Kenya.

Atmonson, D. 1978. Breeding for drought resistance in small grains. In search for selection criteria and genetic sources. pp. 126. In: Proceedings of a eucarpia workshop. Wageningen, Netherlands.

Anayoba, A., E.J. Littleton and H.C. Wein. 1979. Drought stress on cowpeas and soybeans under tropical condition. In: stress physiology in crop plants. (H.W. Mussel) and R.C. Staples eds). New York. John Wiley and Sons pp. 45-55.

Begg, J.E. and N.C. Turner, 1976. Crop water deficits. In: Advances in Agronomy 8: 161-217. N.C. Brady ed. Academic press.

Bennet, O.L. and B.D. Doss. 1960. Effect of soil moisture on root distribution of cool season forage species. Agron. J. 52. 204-207.

Bhan, S.H.G., Singh and A. Singh. 1973. A note on root distribution as an index of drought resistance in sorghum. Indian J. Agric. Sci. 43: 828-83.

Bohm, W. 1979. Methods of studying root systems. Ecological studies 33. Springer-Verlag Berlin Heldberg, New York.

Braun, H.W.H. Agro-climatic zones of Kenya. Paper presented at fourth A.G.M. for Soil Sci. Soc. E.A. Arusha. 27-28 October.

Carmi, A. and B. Heuer. 1981. The role of roots in the control of bean shoot growth. Ann. Bot. 48: 519-529.

CIAT, 1979. Annual report 1978. Bean program, pp. C1-C75 CIAT. Cali, Columbia.

CIAT, 1980. Annual report, 1979. Bean program, pp. 87. Cali, Columbia.

Coley, H.E. and R.D. Watson. 1966. A new gravimetric method for estimating root surface areas. Soil Sci. 102: 289-91.

Coulson, C.L. 1984. Nairobi/California, Bean - Cowpea CRSP report. Center for International Programs, Michigan State University, East Lansing, Michigan 48824-1035, USA.

Coulson, C.L. 1985. Nairobi/California Bean-Cowpea CRSP report. Center for International Programs, Michigan State University, East Lansing, Michigan 49924-1035, USA.

Davis, R.G., A.E. Wiese and L.J. Pafford. 1965. Root moisture extraction profiles of various weeds. Weeds 13: 98-100.

D'Souza, H.A. 1985. Quantitative analysis and partitioning in relation to economic yield at different watering levels in ebans (Phaseolus). M.Sc. Thesis, University of Nairobi.

D'Souza, H.A. and C.L. Coulson. 1987. Dry matter production and partitioning in two cultivars of Phaseolus vulgaris under different watering regimes. J. Trop. Agric. In press.

Derera, N.F., D.R. Masshall, L.N. Balam 1969. Genetic variability in root development in relation to drought tolerance in spring wheat. Expt. Agric. 5: 327-337.

Doorenbos, J. 1979. Bean. FAO Irrigation and drainage paper 33 yield response to water.

Doss, B.D., D.A. Ashley and O.L. Bennet 1960. Effect of soil moisture regime on distribution of warm season forage.

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: 179-181.

El Nadi A.H., 1966. Water relations of beans. 1. Effects of water stress on growth and flowering. Exp. Agric. 5: 195-207.

El Nadi, A.H.R. Brouwer and J.T. Locker, 1969. Some

response of root and shoot of Vicia faba plants to water stress. Net. J. Agric. Sci. 17: 133-142.

Evans, H. 1938. Studies on absorbing surface of sugarcane root systems. 1. Method of study with some preliminary results. Ann. Bot. N.S. 11: 159-182.

FAO, 1977. Plant production and protection paper 9. Food legume crops: Improvement and production. Rome 1977.

Fedke, C. 1982. Biochemistry and physiology of herbicide action. Springer-Verlag, Berlin Helderberg, New York.

Floor-Drees 1983. Investigations on drought resistance of beans developed by Grain legume project, Thika. In: Phaseolus bean newsletter for Eastern Africa No. 1 pp. 8-9.

Gardner, W.R. 1964. Relation of root distribution to water uptake and availability. Agron. J. 56: 41-45.

Hall, A.E., K.W. Foster and J.G. Waines. 1979. Crop adaptation to semi-arid environment. In: Agriculture in semi-arid environment. Ecological studies 34. Hall, A.E., G.H. Cannell, and H.W. Lawton (eds). Springer-Verlag Berlin Heidelberg, New York.

Hanks, R.J., J. Keller, V.P. Rasmussen and G.D. Wilson. 1976. Line source sprinkler irrigation for continuous variable irrigation crop production studies. Soil Sci. Soc. Am. J. 40: 426-429.

Hendricks, A.H., and F.J. Veihmeyer 1931. Influence of dry soil on root extension. Plant physiol. 6: 567-576.

Hsiao, T.C. 1973. Plant responses to water stress. Ann. Rev. Plant Phy. 24: 519-570.

Hsiao, T.C., E. Acevedo and D.W. Henderson. 1976. Water stress and dynamics of growth and yield of plants. In: water and plant life. Problems and modern approaches. Eds Lange O.L., L. Kappen and E.D. Schultz. Ecological studies 19. Spring-Verlag, Berlin, Heldeberg, New York.

Hsiao, T.C. and K.J. Bradford 1983. Physiological concequences of cellular water deficits pp. 73-85 In: Taylor, H.M., W.R. Jordan and T.R. Sinclair eds. Limitation to efficient water use in crop production. Amer. Soc. Agron., Madison Wis.

Humpries, E.C. 1963. Dependence of net assimilation rate on root growth of isolated leaves. Ann. Bot. 27: 175-183.

Hurd, E.A. 1968. Growth of seven varieties of wheat at high and low moisture levels. Agron. J. 60: 201 - 205.

Hurd, E.A. 1974. Phenotype and drought tolerance in wheat. Agric. Meteorol. 14: 39-55.

Idso, S.B., R.D. Jackson, P.J. Pinter, R.J. Reginato and J.L. Hatfield. 1981. Normalising the stress degree-day parameter for environmental variability. Agric. Meteorol. 24: 45 - 55.

Idso, H.B. 1982. Non water stressed baselines. A key to measuring and interpreting plant water stress. Agric. Meteorol. 27: 59 - 70.

Ishag, H.M. 1973. Physiology of seed yield in field beans Vicia faba L. II. Dry matter production. J. Agric. Sci. Camb. 80: 191 - 199.

Itulya, F.M. 1984. Nairobi/California, Bean-cowpea CRSP report. Centre for International programs, Michigan State University East Lansig, Michigan 48824 - 1035, USA.

Jones, H.G. 1979. Stomatal behaviour and breeding for drought resistance. In: Stress physiology of crop plants. Mussel, H.M.R.C. Staples (eds). New York Wiley Interscience.

Jordan, W.R., W.A. Dugas and J. Shouse 1983. Strategies for crop improvement for drought prone regions. Agric. Water Mgt 7: 281 - 299.

Khan, A.B., P.J. Stoffella. 1986. Root systems of vegetable crops. A brief introduction.

Hortscience 21(4): 952-955.

Kaspar, T.C., H.M. Taylor and R.M. shibbles 1984. Taproot elongation rates of soybeans cultivars in the glasshouse and their relation to field rooting depth. Crop Sci. 24: 916-920.

Klepper, B., H.M. Taylor, M.G. Huck and E.L. Fiscus, 1973. Water relations and growth of cotton in drying soil. Agron. J. 65: 307-310.

Laing, DR., P.J. Kretchmer, S. Zuluaga, and P.J. Jones 1983. Physiological studies on yield and adaptation in Phaseolus vulgaris. In: potential productivity of field beans under different environments, S. Yoshida (ed) pp. 526 IRRI Los Banos Phillipines.

Laing , D.R., Jones, P.G. and Davis, J.H.C. (1984). Common bean (Phaseolus vulgaris L.), in, The physiology of tropical field crops. (Eds Goldsworthy, P.R. and Fisher, N.M.). England, John Wiley and Sons, Chichester.

Lawn, R.J. 1982. Response of four grain legumes to water stress in South Eastern Queensland II plant growth and soil water extraction patterns. Aust. J. Agric. Res. 33: 497-507.

Lenga, F.K. Water use by eight annual crops at Kabete Kenya 1978/1979 M.Sc. Thesis 1980.

Levitt, J. 1972. Responses of plants to environmental stress. Academic press.

Little, M.T. and F.J. Hills. 1974. Agricultural experimentation, design

Makhart, H.A. 1985. Comparative water relations of Phaseolus vulgaris and P. acutifolius Gray. Plant Physiol. 77: 113-117.

Masumba, B.A.N. 1984. Physiological measurement for ranking bean cultivars with respect to relative drought and heat resistance. EAAFJ special issue Vol. 44: 290-296.

Mauk, S.C., P.J. Breen and H.J. Mack. 1983. Yield response of major pod bearing nodes in bush snap beans to irrigation and plant population. J. Amer. Soc. Hort. Sc. 108: 935 - 939.

Mauk, S.C. and P.J. Breen. 1986. Partitioning of C-photosynthate among competing sinks during flowering and early fruting in snap bean. J. Amer. Soc. Sc. 111(3): 416 - 421.

May, L.H. and F.L. Milthorpe. 1962. Field crops Abstr. 15: 1 - 9.

Mayaki, W.C., I.D. Teare, and L. Stone, Jr. 1976. Top and root growth of irrigated and non-irrigated soybeans. Crop Sci. 16: 92 - 94.

Millar, A.A. and W.R. Gardener. 1972. Effect of the soil and water potentials on dry matter production of snap beans. Agron.

J. 64: 559-562.

Miller, D.E. 1986. Root systems in relation to stress tolerance. Hortscience 21(4): 963-970.

Milthorpe, F.L. and Moorby, J. 1974. An introduction to crop physiology. London Cambridge University Press.

Ministry of Agriculture and Livestock Development (MALD). NHRS Grain legume project interim report No. 23, 1983.

Molz, F.J. 1971. Interactions of water uptake and root distribution. AGron. J. 63: 608-610.

Mugah, J.O. 1984. Rooting characteristics and water extraction by Katumani Composite B maize under varying moisture regimes. EAAFJ. Special Issue 44: 80 - 87.

Mukunya, D.M. 1984. In "Phaseolus Beans Newsletter for Eastern Africa". No. 2 pp. 57-60.

Newman, E.L., 1966. A method for estimating the total length of root in a sample. J. Appl. Ecol. 3: 139-45.

Norman, N.J.T., C.J. Pearson and P.G.E. Scarle 1984. Common bean (Phaseolus vulgaris L.): The ecology of tropical crops. Cambridge Univ. Press.

Nyabundi, J.O. 1985. Water stress effect on biomas production and partitioning in processing tomatoes. Ph.D. Thesis, University of California, Davis.

Nye P.H. and P.B. Tinker, 1969. The concept of a root demand coefficient. J. Appl. Ecol. 6: 293-300.

Parao, F.T., E. Paringbatan Jr. and S. Yoshida. 1966. Drought resistance of rice varieties in relation to root growth in Philipines J. Crop Sci. 1: 50-55.

Parsons, R.L. 1979. Breeding for drought resistance. What characteristics impart resistance. Hortscience 14: (5) 590-593.

Passioura, J.B. 1974. The effect of root geometry on the water relations of temperate cereals (wheat, barley oats). In: Structure and function or primary root tissues. J. Slovok Acd. Sci. 357-363.

Pearson, R.W. Significance of rooting pattern of crop production and some problems of root research. In: The plant root and its environment. Carson, E.W. (ed) Charlottesville, USA Univ. Press of Virginia 1974 pp. 247-270.

Pearson, R.W. 1966. Soil environment and root development. In plant environment and efficient water use.

Peirre, H.W., D. Kirkham, J. Pesek, R. Shaw (ed). Madison: Am. Soc. Agron. and Soil Sc. Soc. Am.

Prota, C.M. and H.M. Taylor. 1976. Growth and survival of young plant roots in dry soil. Soil Sci. 121: (3): 170-175.

Raper, C.D. and S.A. Barker, 1970. Rooting systems of soybeans. Differences in root morphology among varieties. Agron. J. 62: 581-584.

Robertson, B.M., A.E. Hall and K.W. Foster 1985. A field technique for screening for genotypic differences in root growth. Crop Sci. 25: 1084-1090.

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.

Robitaille, H.A. 1978. Dry matter accumulation patterns in indeterminate Phaseolus vulgaris cultivars. Crop Sci. 18: 740-743.

Salim, M.H., J.W. Todd and A.M. Schlehuber. 1965. Root development of wheat, oats and barley under conditions of moisture stress. Agron. J. 57: 603-607.

Sombroek, W.G., H.M.H. Braun and B.J.A. van de Pour. 1982. Exploratory soil map of Kenya. Report No.

Stansell, J.R. and D.A. Smittle 1980. Effects of irrigation regimes on yield and water use of snap beans (Phaseolus vulgaris). J. Amer Soc. Hort. Sci. 105(6): 869-873.

Stoker, R. 1974. Effect on dwarf beans of water stress at different phases of growth. N.Z.J. Expl. Agric. 2: 13-15.

Stoffella, P.J., R.F. Sandsted, R.W. Zobel and W.L. Hymes 1979. Root characteristics of black beans. In relations of root size to lodging and seed yield. Crop Sci. 19: 823-826.

Sullivan, C.V. 1971. Drought injury and resistance in crops (K.L. Larson and J.D. Easton eds) CSSA Special Pub. No. 2. Madison, Wisconsin pp. 1-18.

Sullivan C.V. and Ross, W.M. 1979. Selecting for drought and heat resistance in grain sorghum. In: Stress physiology in crop plants (H.W. Mussel and R.C. Staples, eds). New York, John Wiley and Sons pp. 263-281.

Taylor, H.M. 1986. Methods of studying root systems in the field. Hortscience 21 (4): 952-955.

Taylor, H.M. and B. Klepper. 1973. Rooting density and water extraction for corn. Agron. J. 65: 965-968.

Taylor, H.M. and B. Klepper. 1975. Water uptake by cotton root systems: An examination of the assumptions in the single rooted model. Soil Sci. 120: 57-67.

Thomas, C.V., R.M. Manshardt and J.G. Waines. 1983. Teparies as a source of useful traits for improving common beans. Desert Plants 5: 43-48.

Turk, J.K., A.E. Hall and C.W. Asbell 1980. Drought adaptation of cowpea: I. Influence of drought on seed yield. Agron. J. 72: 413-420.

Turner, N.C. 1974. Stomatal behaviour and water status of maize and sorghum and tobacco under field conditions at low soil water potential. Plant Phys. 53: 360-365.

Turner, N.C. 1979. Drought resistance and adaptation to water deficits in crop plants. pp 343-372. In: H. Mussel and R.C. Staples (eds). Stress physiology in crop plants. Wiley, New York.

Waters, L. Jr., P.J. Breen, H.J. Mack and P.H. Graham 1980. Translocation of c-photosynthate, carbohydrates content and nitrogen fixation in Phaseolus vulgaris L. during reproductive phase J. Amer. Soc. Hort. Sc. 105: (3) 424-427.

Weaver, J.E. Root development of field crops. McGraw-Hill, New York. 1926.

Webster, D.B. 1985. Improvement of drought and heat tolerance of disease resistant beans in semi-arid regions of Kenya. In: Bean-Cowpea collaborative program 1983-1984.

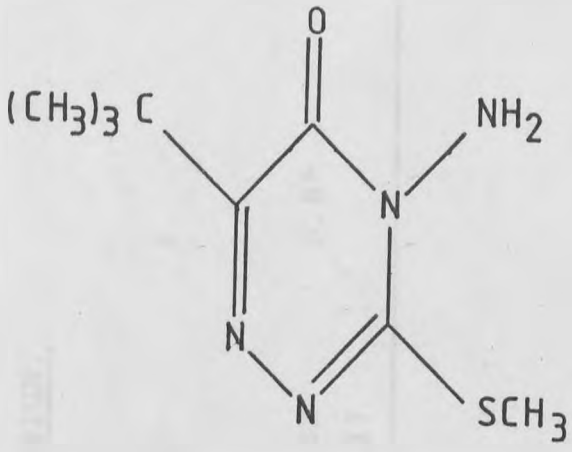
Wein, H.C. 1973. Grain legume physiology of IITA pp. 105-114. In: R.A. Luse and R.J. Williams eds. Proceedings of the first Grain Legume Improvement Workshop. Int. Inst. Trop. Agric. Ibadan, Nigeria.

Zobel, R.W. 1975. The genetics of root development. In: The development and function of roots. Eds., J.G. Torrey, D.T. Clarkson. London, new York, San Franscisco. Academic Press pp. 261 - 275.

Zobel, R.W. 1986. Rhizogenetics (Root Genetics) of vegetable crops. Hortscience 21 (4): 952-961.

7. APPENDICES

APPENDIX 1. STRUCTURE OF METRIBUZIN.



Source: Fedke C. Biochemistry and physiology of herbicide action Springer-Verlag, Berlin Heldenberg, New York.

Metribuzin is an as-Triazinone herbicide. It's chemical name is 4 amino-6(1,1-dimethyl 9-3-(melthythio)-1,2,4 triazin-5 (4H)-one). It is highly soluble in water and acts by inhibiting photosynthetic election transport. Toxicity symptoms are visually expressed as necroses and bleaching along the leaf margins and leaf veins.

APPENDIX 2. ANALYSIS OF VARIANCE TABLE OF THE PERCENT SOIL MOISTURE OF EXPERIMENT 2 ANALYSED AS A COMPLETELY RANDOMISED DESIGN.

10 cm depth

Variation	DF	SS	MSS	F
Total	35	765.99		
Irrigation	2	1924	99.62	5.8*
Error	33	566.7	17.17	

* = Significantly different at 5%

CV = 17.41%

30 cm depth

Variation	DF	SS	MSS	F
Total	35	982.33		
Irrigation	2	229.33	114.67	5.02*
Error	33	75.3	2.28	

* = Significantly different at 5%

CV = 5.41%.

APPENDIX 3. ANALYSIS OF VARIANCE TABLE FROM ANALYSIS OF THE GLASSHOUSE EXPERIMENT AS COMPLETELY RANDOMISED DESIGN.

Depth 10 cm

Source of variation	DF	SS	MSS	F
Cultivar	2	84.96	42.48	10.67*
Error	24	95.52	3.98	
Total	26	180.48		

.* = Significantly different at P = 5%.

CV = 19.18%.

APPENDIX 4. ANALYSIS OF VARIANCE TABLE OF THE GLASSHOUSE EXPERIMENT AS A COMPLETELY RANDOMISED DESIGN.

Depth 20 cm

Source of variation	DF	SS	MSS	F
Cultivar	2	28.74	14.37	6.54*
Error	24	52.56	2.19	
Total	26	81.3		

* = Significantly different at P = 5%.

CV = 9.77%.

APPENDIX 5. ANALYSIS OF VARIANCE TABLE FROM ANALYSIS OF THE SENSITIVITY TEST AS A COMPLETELY RANDOMISED DESIGN.

Source of Variation	DF	SS	MSS	F
Treatment	2	3.822	1.911	1.26^{NS}
Error	43	1404.81	32.67	
Total	45	1408.63		

NS = Not significant at P = 5%.
CV = 21.7%.

APPENDIX 6. ANALYSIS OF VARIANCE TABLE OF THE PERCENT MOISTURE OF FIELD EXPERIMENT 2 ANALYSED AS A COMPLETELY RANDOMISED DESIGN.

10 cm depth

Source of Variation	DF	SS	MSS	F
Irrigation	2	19.24	99.62	5.8*
Error	33	566.75	17.17	
Total	35	982.33		

CV = 17.41%

*. = Significant at 5%.

APPENDIX 7. ANALYSIS OF VARIANCE TABLE OF PERCENT SOIL MOISTURE OF THE FIELD EXPERIMENT 2 ANALYSED AS A COMPLETELY RANDOMISED DESIGN.

30 cm depth

Source of Variation	DF	SS	MSS	F
Irrigation	3	229.33	114.67	5.02*
Error	33	75.3	22.82	
Total	35	982.33		

* = Significantly different at P = 5%.

CV = 5.41%.

Appendix 8a. MEAN NUMBER OF PLANTS SHOWING SYMPTOMS UNDER DIFFERENT IRRIGATION LEVELS AND HERBICIDE DEPTH 66 AND 55 DAYS POST-EMERGENCE.

66 Days post-emergence (Experiment 1)

Cultivar	Depth	Irrigation L	M	H
GLP 2	20	34	34	34
	40	27	20	10
	60	24	15	11
GLP x-92	20	27	19	19
	40	27	25	14
	60	11	11	4
GLP 1004	20	41	30	37
	40	31	30	25
	60	22	18	12

LSD 5% in the rows is 2.3.

Appendix 8b. 55 Days post-emergence (Experiment 2).

Cultivar	Depth	Irrigation L	M	H
GLP 2	20 cm	59	57	57
	40 cm	59	57	49
	60 cm	59	57	33
GLP x-92	20 cm	57	55	48
	40 cm	57	52	47
	60 cm	53	53	41
GLP 1004	20 cm	59	57	53
	40 cm	59	58	52
	60 cm	58	54	51

LSD 5% within rows is 2.18.

CV (Irrigation) = 6.23%
CV (Cultivar) = 6.83%
CV (Depth) = 8.51%

APPENDIX 9A. ANALYSIS OF VARIANCE TABLE OF FIELD EXPERIMENT 1 (NUMBER OF PLANTS SHOWING SYMPTOMS) ANALYSED AS A SPLIT SPLIT PLOT DESIGN

Source of Variation	DF	SS	MSS	F
Sub-subplot	80	9334.47		
Subplot	26	3713.13		
Main plots	8	1766.469		
Blocks	2	412.76	206.4	
Irrigation	2	999.73	499.86	5.65^{ns}
Main plot error	4	353.98	88.49	
Variety	2	1321.32	660.66	73.82*
Irrigation x variety	4	51.75	12.94	0.27
Subplot error	12	573.59	47.79	
Depth	2	3568.58	1784.29	73.43*
Irrig x depth	4	317.6	79.4	3.27*
Var x depth	4	618.12	154.53	6.36*
Irrg x var x depth	8	194.7	24	0.99
Sub-subplot error	38	922.34	24.3	

* = Significantly different at P = 5%.

ns = Non significant, difference at P = 5%.

APPENDIX 9b. ANALYSIS OF VARIANCE TABLE OF THE FIELD EXPERIMENT 2 (NUMBER OF PLANTS SHOWING SYMPTOMS) ANALYSED AS A SPLIT-SPLIT-PLOT DESIGN.

Source of variation	DF	SS	MSS	F
Main plots	8	1512.89		
Blocks	2	14.296	7.148	
Irrigation	2	1453.56	726.78	64.56*
MPE	4	45.03	11.26	
Variety	2	244.22	122.11	9.05*
Irrg x var	4	195.26	48.82	3.62*
SPE	20	269.85	13.49	
Depth	2	337.85	168.93	8.05*
Irrig x depth	4	250.59	62.65	2.99*
Var x depth	4	74.37	18.59	0.89NS
Irrig x var x depth	8	262.82	32.85	1.57NS
SSPE	36	754.37	20.95	

** = Significant different at P = 1%.

* = Significantly different at P = 5%.

NS = Non significant, difference at P = 5%.

APPENDIX 10a. THE ANALYSIS OF VARIANCE TABLE FOR THE TOTAL ACCUMULATED DURING EXPERIMENT 2.

Source of variation	DF	SS
Subplots	26	1792.02
Main plots	8	1363.962
Blocks	2	81.84
Irrigation	2	1126.612
MPE	4	156.51
Variety	2	62.32
Var x Irr	4	147.47
SPE	12	218.27

* = Significantly differently at P = 5%.

ns = Non significant difference at P = 5%.

ABOVE GROUND DRY MATTER

MM	F
40.92	1.05^{NS}
562.81	14.38*
39.13	
31.16	1.71^{NS}
36.87	2.03^{NS}
18.18	

APPENDIX 10b. ANALYSIS OF VARIANCE OF TOTAL NUMBER OF LEAVES PER PLANT 30 DAYS POST-EMERGENCE DURING THE 1987 EXPERIMENT.

Source of variation	df	SS	MSS	F
Main plots	0	479.19		
Blocks	2	1.41	0.71	
Irrigation	2	445.85	222.93	27.94**
MPE	4	31.93	57.98	
Cultivars	2	842.74	421.37	56.2**
Irrigation x cultivar	4	212.6	53.15	7.09**
SPE	12	89.99	7.5	

** Highly significant.

APPENDIX 11. ANALYSIS OF VARIANCE OF THE YIELD (GM/M^2) EXPERIMENT 2 ANALYSED AS A SPLIT-PLOT DESIGN.

Source of variation	DF	SS	MSS	F
Sub plots	26	8755.47		
Main plots	8	3204.53		
Blocks	2	242.906	121.45	0.67
Irrigation	2	2232.943	1116.47	6.13NS
MPE	4	728.68	182.17	
Cultivar	2	2989.32	1494.66	8.08*
Irr x var	4	769.93	1.04	
SPE	12	2219.38	184.95	

*Significantly different at P = 5%.

* = Significantly different at P = 5%.

NS = Non significant difference at P = 5%.

APPENDIX 12. ANALYSIS OF VARIANCE TABLE OF THE AVERAGE NUMBER OF PODS PER PLANT OF EXPERIMENT 2 ANALYSED AS A SPLIT PLOT DESIGN.

Source variation	DF	SS	MS	F
Sub plots	26	335.63		
Main plots	8	44.96		
Blocks	2	12.52	6.26	1.47*
Irrigation	2	15.41	2.71	1.81
MPE	4	17.03	4.26	
Variety	2	193.41	96.71	2.8NS
Variety x Irrigation	4	26.81	6.71	0.19
SPE	12	70.46	35	

* = Significantly different at P = 5%.

NS = Non significant difference at P = 5%.

APPENDIX 13. ANALYSIS OF VARIANCE TABLE OF THE 100 SEEDWEIGHT (G) OF EXPERIMENT 2 ANALYSED AS A SPLIT PLOT DESIGN.

Source of Variation	DF	SS	MSS	F
Main plots	8	139.24		
Blocks	2	2.646		
Irrigation	2	135.8	67.9	342*
MPE	4	0.794	0.198	
Varieties	2	614.5	307.25	4.25*
Irrigation x variety	4	832.56	208.14	2.89*
SSPE	12	866.94	72.245	

* = Significant difference at P = 5%.

** = Highly significant.

APPENDIX 14: RAINFALL (mm) AND EVAPOTRANSPIRATION (Eto mm) DURING THE SEASON (EXPERIMENT 1).

	AUGUST		SEPTEMBER		OCTOBER		NOVEMBER	
Day	Rain	ETo	Rain	ETo	Rain	ETo	Rain	ETo
1	0	4.5	TR	3.5	0	4.0	4.8	4.8
2	0	3.0	TR	1.5	0	4.5	2.5	4.0
3	0	2.5	0	1.5	0	6.0	5.3	2.8
4	0	3.0	0.3	3.3	0	5.0	4.2	5.1
5	0	3.0	0.5	4.5	0	4.0	17.5	4.0
6	0	4.5	0	4.5	0	7.0	14.0	3.5
7	0	5.5	0	6	0	5.0	0.05	2.6
8	0	4.5	2.9	4.9	0	7.0	0	4.1
9	0	4.0	0	3	0	6.5	0.3	5.3
10	0	3.5	0	3.5	0	4.5	32.4	6.4
11	0	4.0	0	3	0	7.4	28.1	6.6
12	0	2.5	0	5.0	0.4	4.0	3.1	1.1
13	0	3.0	0.1	4	0	5.5	62	1.7
14	0	4.5	0	3	0	4.5	90	3.5
15	0	4.0	TR	2.6	0	7.0	0	2.5
16	0	0	0.1	2	0	5.0	1.2	4.2
17	1.0	2.0	0	4	0	5.5	4.9	1.9
18	0	2.5	0.4	1.0	3.3	2.3	0	2.5
19	0	2.0	0.0	4.6	0	5.0	0.5	2.5
20	0	4.5	0	3.5	0	5.0	0	4.0
21	0	2.0	0	4.9	0	5.5	20.2	3.0
22	0	4.5	0	5.0	3.8	5.3	22.0	5.2
23	0	4.0	0	5.5	10.7	5.2	2	4.0
24	0	4.0	0	6.0	5.2	2.2	33	4.0
25	0	5.5	0	6.5	0	6.0	1.3	2.3
26	0	5.5	0	5.5	5.5	3.0	7.6	4.8
27	0.3	3.3	0	6.0	0	6.0	4	2.1
28	0	3.5	0	6.0	0	4.0	2.7	1.4
29	0	4.0	0	6.0	0.3	5.3	9.9	0.7
30	0	4.5	0	6.0	11.2	4.5	0.5	0.4
31	1.0	2.5	0	6.0		1.2		4.5
	2.3	110.3	4.3	127.3	40.4	158.9	202	101.2

APPENDIX 15: RAINFALL (mm) AND EVAPOTRANSPIRATION (Eto mm) DURING THE SEASON (EXPERIMENT 2).

	JANUARY		FEBRUARY		MARCH	
Day	Rain	ETo	Rain	ETo	Rain	ETo
1	0	5.0	0	5.5	0	5.0
2	22.1	4.6	0	5.5	0	6.0
3	13.8	3.8	0	6.0	0	8.0
4	0	3.5	0	6.5	0	5.0
5	22.0	6.5	15	4.5	0	4.5
6	TR	3.5	0	3.5	0	7.5
7	0	6.0	0	6.0	0	5.5
8	0.2	3.7	0	5.0	0	6.0
9	0	4.5	0	3.0	0.1	6.1
10	0	7.5	0	5.5	0.2	4.1
11	0	2.5	0	5.5	0	6.0
12	0	5.5	0	5.5	0	7.0
13	13.7	6.0	0	6.0	0	5.0
14	0	4.2	0	6.5	0	6.5
15	0.6	6.1	0	6.0	7.6	6.3
16	0	2.6	0	6.5	0	5.5
17	0	4.0	0	6.5	0	4.5
18	0	4.5	0	5.5	0.1	4.4
19	0	5.5	80	0	1.4	3.9
20	0	4.0	0	8.3	0	5.0
21	0	4.2	0	2.5	0	4.5
22	0	6.0	0.3	4.8	0	5.5
23	0	5.0	0	6.0	0	8.0
24	0	5.0	0	6.0	0	7.0
25	0	4.5	0	5.5	0	4.0
26	0	3.5	0	6.0	0	6.0
27	0	6.5	0	6.0	0	6.0
28	0	4.5	0	6.0	0	6.1
29	0	5.0		6.5	0	5.5
30	0	3.5			0	
31	0	4.0			0	6.5
	72.4	146.5	95.5	149.6	9.4	177.9