PHYSIOLOGICAL BASIS OF YIELD DIFFERENCES IN BEAN (*Phaseolus vulgaris* L.) CULTIVARS

BY

ONYANGO, J.P. GWEYI, BSC (AGRIC)

A THESIS SUBMITTED IN PARTIAL FULFILMENT FOR THE MASTER OF SCIENCE IN AGRONOMY IN THE UNIVERSITY OF NAIROBI

1999

DECLARATION

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

ONYANGO J. P. GWEYI ....

DATE 08-03-99..................................

This thesis has been submitted for examination with my approval as the university supervisor

DR. J.O. NYABUNDI Omondi Nyabundi..................................

DATE 10/3/99..................................

DEDICATION

To my beloved mother, Mama Margaret Ombundo

ACKNOWLEDGEMENTS

My sincere gratitude goes to the German Academic Exchange Service (DAAD) for funding my studies at the university of Nairobi. I am also greatly indebted to my supervisor, Dr. J.O. Nyabundi for his close supervision, suggestions and constructive criticisms. I also dearly thank Mr. Raphael Musyoki who helped with repairs and calibration of Infrared Gas Analyser and Leaf Area Meter. Thanks are also due for Messers Mwaura of FST Lab and Karanja of plant physiology lab for the assistance they offered regarding use of various equipments and apparatus. I am also deeply indebted to Mr. Tirop and Mr. Ndambuki, both of soil science department for their assistance during analysis.

I also take this opportunity to express my heartfelt gratitude to my mother for having worked tirelessly to ensure that I got formal education. I also wish to thank all my friends, relatives and acquaintances who socially assisted me to complete this study successfully. Last but not least, I wish to express my appreciation to my good friend, Miss Lwane, who constantly encouraged me to aim higher.

DEFINITION OF ABBREVIATIONS

A.H.I	Apparent Harvest Index
C.E.R	Carbon Exchange Rate
D.A.E	Days After Emergence
H.I	Harvest Index
L.A.I	Leaf Area Index
S.L.A	Specific Leaf Area
S.L.N	Specific Leaf Nitrogen
S.L.W	Specific Leaf Weight
T.N.C	Total Non-structural Carbohydrates

TABLE OF CONTENTS

ABSTRACT

The study was conducted at the University of Nairobi Faculty of Agriculture Farm, Kabete, located on latitude 1° 5' south and longitude 36° 44' east at an altitude of about 1800 metres above sea level. The study investigated the following physiological crop parameters: leaf net photosynthetic rates, leaf nitrogen, specific leaf weight, leaf area indices and stem non-structural carbohydrate contents. Plant biomass accumulation was also determined. These parameters were taken at fortnightly intervals from 32 days after emergence (DAE) (flowering phase of growth) till maturity in ten bean (*phaseolus vulgaris L.)* cultivars namely: Pocho, GLP-92, White Haricot, GLP-1004, GLP-2, GLP-24, Ulonzo, E-1, E-3 and E-5. The study was done in two different seasons; with the first season experiment (experiment 1) running from 29th March, 1994 to 8th of July 1994. Second season experiment (experiment II) was conducted from 12th of October 1994 to 10th of January, 1995.

The results of the study revealed a variation of the above mentioned physiological parameters among cultivars. Leaf net photosynthetic rate and leaf nitrogen contents had a positive correlation at 45 DAE (pod set). There was also positive correlation between photosynthetic rates and yields. These parameters were however not the best indices for yield differences among cultivars since even higher yielding cultivars such as Pocho, E-1, E-3, and E-5 had relatively lower performance in these characters. Non-structural carbohydrate remobilization from the stem contents at pod set (about 45 DAE) seemed to be a good indicator for yield differences among bean cultivars. Specific leaf weight variation was more stable as a result of environmental changes and therefore was proposed a good index for the basis of yield differences among cultivars. Harvest index (HI), apparent harvest index (AHI) in this case, was also promising indicator of yield differences.

LIST OF APPENDICES

APPENDICES **PAGE**

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The edible bean of *phaseolus vulgaris* is an important source of protein (dry beans contain 20 - 80% protein) and calories in human diets in tropical and subtropical developing countries. This is particularly so in America which account for 47% of the World production and in eastern and southern Africa (16% of World population). Thus beans contribute to the nutritional balance of diets of millions of world population whose purchasing power does not allow consumption of proteins of animal origin.

Field bean is a typical C-3 plant which is characterised by high levels of photorespiration and this is aggravated by high temperatures which are prevalent in tropical climates. The common bean, dry bean or field bean (*phaseolus vulgaris*) is an ancient cultivated species. It belongs to the family leguminosae, sub-family papilionoideae (syn. papilionatae, faboidae, lotoidae), Hutchinson (1964). Archaeological remains of beans and pod materials dated upto 10,000 years B.C. in Peru suggest that the species was very early differentiated from wild forms through selection for cultivation (Kaplan et al; 1973) Areas of diversity and domestication occur in the highlands of meso-America and Northern South America in the 500-1200 m above sea level (Miranda, 1974; Evans 1976).

Phaseolus vulgaris is the most widely grown of four cultivated species of the phaseolus genus, all of which have their origins in Americas. It is highlypolymorphic species showing considerable variation in growth habit, vegetative characters, flower colour and size, shape and colour of both seeds and pods. Other species are *P. coccineus* (runner bean) which is grown at altitudes above 2000 m in tropical highlands of Latin America and in temperate altitudes. *P. acutifolius* (tepary bean) is adapted mainly in warm, dry subtropical climates while *P. lunatus* (Lima bean) is adapted to middle and low altitudes in the tropics. Production of *P. vulgaris* alone accounted for approximately 95% of total world phaseolus bean production of 8.3 million tonnes FAO (1979).

In Kenya, beans do not grow well below 600 metres above sea level as high temperatures and humidity cause poor fruit set (Acland, 1971). They require moderate rainfall, and excessive moisture and high temperatures predispose the plants to disease attack. As a food crop, dry bean ranks second only to maize in Kenya (Anon, 1985) and is grown mainly in intercropping systems. Land under beans have generally increased in the past few years. For instance area under beans increased from 546,390 ha in 1987 to 596,680 ha in 1988 (Anon, 1988). In 1989, there was an increase of 12.1%, rising from 596,680 ha in 1988 to 668,670 ha (Anon, 1989). In these years, the country realised additional grain increment, but this was mainly due to expanded hectarage. Yield ranging from 500 to 750 kg/ha was recorded during this period. However, Kimani *et* *al.* (1994), working with fifty one lines of beans selected for a multiple resistance to diseases, and grown at ten locations representing the main agro-ecological zones for bean growing reported mean yields of upto 1850 kg/ha in late maturity beans. Their report on the highest average mean yield at Kabete 1992, short rains, were 4683.3, 6381.6 and 5699.6 kg/ha for early, medium and late maturity groups respectively, while during the same season, they recorded mean yields of 3171.2, 3525.4 and 2535.1kg/ha respectively, for Katumani Station. Though there has been an increasing trend in bean grain production over the years, yield is still quite low compared with cereals such as maize.

Under Grain Legume Project (GLP) based at Thika, much work was done to improve yields of beans and other grain legumes. A number of bean varieties including lines of Rosecoco, Mwezi moja, Mwitemania, Haricots and Canadian Wonder were released in this effort. Follow-up physiological and agronomical research on beans has been conducted at the University of Nairobi, though with a clear concentration on GLP-2 and GLP-24 which are lines of Rosecoco and Mwezi moja respectively. Research by Ouma (1988), Tabu (1988) and D'souza and Coulson (1988), Runkulatile *et al.* (1993) have indicated that GLP-1004 outyields GLP-2 under both high and low soil water conditions even though the two cultivars have similar growth habits and duration. In addition, GLP-1004 exhibited higher photosynthetic rate and higher rate of biomass accumulation than GLP-2 (Ouma, 1988; Ogola 1991 and Ogutu 1991). GLP-1004 also had higher leaf nitrogen content than GLP-2 (Ogutu 1991). The current study attempts to investigate the photosynthetic, remobilization and partitioning of assimilates

aspect that may explain yield difference among a number of bean cultivars. The objectives being:-

(a) To ascertain cultivar differences in single leaf net photosynthetic rate per unit area of ten bean cultivars.

(b) To study the differences in a number of photosynthetic and assimilate partitioning properties namely:- leaf nitrogen content, non-structural carbohydrate contents of stems, specific leaf weights of the ten cultivars and finally;

(c) Find out differences in yields and yield components of these cultivars.

CHAPTER 2

LITERATURE REVIEW

2.1 CULTIVAR DIFFERENCES IN LEAF NET PHOTOSYNTHETIC RATE:

Phaseolus vulgaris is a C-3 plant. Maximum values of net photosynthetic rate during the ontogeny of individual leaves range from 25 to 40 mg CO_2 $dm^{-2}h^{-1}$ (1zhar and Wallace, 1967) which is comparable to most C-3 cereal crops such as rice (Tanaka *et al.*, 1966). Differences in photosynthetic rates between cultivars could be used as a selection criterion for high yielding genotypes. A number of workers (Ackerson and Herbert 1981, Hiremath et al. 1986, Ouma 1988) have shown that varieties with high net photosynthetic rates tend to have high yield values. Kuenemann *et al.* (1979) indicated that photosynthesis of field grown beans could be predictive of biological yield. However, although photosynthesis is one of the primary processes of plant growth, Evans (1975, 1983) pointed out that there is little evidence of a correlation between genetic improvement of Carbon dioxide Exchange Rate (CER) and increased yield and growth. This may be caused in part by a negative relationship between total leaf area and CER in some plants, due to compensation between them (Bhagsari and Brown 1986; Allen *et al.*, 1987). Comparisons of Carbon dioxide exchange rate for genotypes having different leaf sizes may therefore not present the inherent differences in photosynthetic potential. Peet *et al.* (1977), however concluded that the relationship between photosynthetic rate and yield appears to be a function of development stage. They found that the highest photosynthetic rate was during pod set which was positively correlated with biological seed yield. An exception was a variety with high seed yield but low photosynthetic rates which could possibly be due to efficiency of enzyme functions or biomass partitioning.

Varietal differences in net photosynthetic rate has been shown in beans (Izhar and Wallace 1970, Kuenemann et al; 1979), cotton (Ackerson and Herbert, 1981), groundnut (Hiremath *et al.*, 1986). These differences could be due to a number of factors. Peet *et al.* (1977) reported that the differences could possibly be due to efficiency of enzyme functions or biomass partitioning. Similarly Upmeyer and Koller (1973) reported that high leaf starch level impaired further synthesis of starch, leading to an increase in soluble carbohydrate levels which in turn resulted in reduction in net photosynthetic rate. Wareing *et al.* (1968), found that in normal field conditions, photosynthetic rates are not only limited by physical resistance to carbon dioxide diffusion in the leaf but also by levels of carboxylating enzymes such that the cultivars with high levels of carboxylating enzyme could have higher photosynthetic rates.

Experiments have indicated that, the great genetic variation in chlorophyll content per unit leaf area seems generally to have little impact on variation in carbon exchange rate or productivity. Work with barley (Furguson *et al.*; 1973, McCashin and Calvin, 1979) showed that even chlorophylldeficient mutants had near normal CER. Reduction in CER of soybean lines having abnormally low chlorophyll (< 35 mg cm^{-2}) (Buttery and Buzzel, 1977) was associated with low specific leaf weight in low chlorophyll genotypes (Lugg and Sinclair, 1979). Similarly there is no indication that Hill activity or photophosphorylation per unit leaf area is reflected in variation in CER (Hanson and Grier, 1973). Determination of Hill activity per unit chlorophyll can not be interpreted in relation to CER without information on chlorophyll per unit leaf area.

2.2 CULTIVAR LEAF NITROGEN CONTENT.

Approximately one-third of soils planted to beans in Latin America have very low N availability (CIAT, 1988) and the situation in Africa is probably worse. Symbiotic N fixation in beans is typically inadequate to completely compensate for soil N deficiency (CIAT, 1987). Nitrogen economy is also important in bean grown in fertile soils because seeds have a high requirement that must be balanced against the N requirements for photosynthesing leaves.

A conceptual framework for analysing N requirement and utilization in bean includes seven basic concepts: rate and duration of N acquisition (through N fixation as well as soil uptake), efficiency of N-use in vegetative growth, timing of the transition to reproductive growth (seed filling), rate and duration of N accumulation in seeds, and efficiency of N-use in seed formation. Each of these components could be influenced by physiological processes primarily genetic control. Preliminary studies suggest that genetic variability exists for some of these components in common bean germplasm grown under tropical conditions (CIAT 1988, 1989, Lynch and White, 1992).

The principal use of N in vegetative growth is in photosynthesis because the light and dark reactions of photosynthesis require large amounts of N in the form of Ribulose bisphosphate carboxylase, chlorophyll and related proteins. It has been shown that a decline in leaf nitrogen content leads to reduction in photosynthetic rate (Wittenbach *et al.*, 1980) and (Evans and Tereshima, 1987) observed that the ratio of ribulose bisphosphate carboxylase to electron transport activity increased in leaf having greater nitrogen content. Also observation in C_3 species has often been found to be correlated with carbon exchange rate (CER) as Randall *et al.* (1977) found when comparing high CER mutant fescues. Since ribulose bisphosphate carboxylase represents 30-50% of absolute proteins of the leaves, there is a risk of breeding for its activity which might be at the expense of other enzymes (Gifford and Evans, 1981). The efficiency of N-use in photosynthesis is therefore likely to be an important element of the efficiency of N-use in vegetative growth. Leaf nitrogen have been reported to be highly correlated with net photosynthetic rate in soybeans, rice, maize (Sinclair and Horie 1989), where a substantial fraction of leaf nitrogen is associated with net photosynthetic apparatus.

Tanaka and Fujita (1979) found large differences in net photosynthetic curves with time which were associated with leaf position and nitrogen content of the media and that of the leaf. A very high correlation between net photosynthetic rate and leaf nitrogen content was evident. Sinclair and Horie (1989) found that leaf nitrogen content especially when expressed per unit of leaf area, is closely related with C exchange rate. This relationship appears to result from the large fraction of leaf N associated with photosynthetic enzymes. Therefore changing levels of specific leaf N (SLN g Nm^{-2}) result in both changed amount of photosynthetic enzymes and potential CO_2 assimilation rate per unit leaf area. The Exchange rate of entire crop canopy is also dependent on the SLN of individual leaves. However, in the case of canopies, the vertical distribution of SLN among the leaves may also be important in influencing canopy C exchange rate. Field (1983) hypothesized that canopy C uptake should be maximised when leaves receiving the highest irradiance have the smallest SLN. Subsequently, Horose and Werger (1987) and Pons *et al.* (1987) calculated the non-uniform SLN distribution which resulted in substantially greater C exchange rates than those with uniform distributed SLN. Shiraiwa and Sinclair (1983) demonstrated that SLN variation with depth in soybean canopies were non-uniform. All experiments showed the highest SLN at the top of the canopy, and the SLN of the lower leaves decreased with increased cumulative LAI from the top of the canopy.

Many studies examining the uptake and redistribution of N by soybean plant have shown that the loss of N from vegetative tissues coincided with accumulation of N in the seed (Henderson and Hamprath 1970; Hanway and Weber 1971, Derman *et al*; 1978) and with plant senescence (Derman *et al*; 1978, Sesay and Shibles 1980). Several workers have estimated that between 50-60% of the N in the seed comes from redistribution of vegetative plant parts (Hanway and Weber 1971b, Egli *et al.*, 1978). Jepson *et al.* (1978) evaluated the N-harvest index of a number of soybean cultivars and concluded that there were cultivar differences in efficiency with which N was remobilized to the developing seeds. The soybean has a high N requirement because of its high protein content. This high N requirement coupled with the decline in the N assimilatory processes during seed filling suggested that N assimilatory process fail to meet the N requirement of the seed and therefore, N must be redistributed from the vegetative tissue to meet the deficit (Sinclair and de Wit 1975). The loss of N from vegetative tissue has been associated with protein degradation (Sesay and Shibles 1980) and loss in physiological activity (Wittenbach *et al*, 1980) and this may promote senescence (Sinclair and de Wit 1975).

Positive correlation between duration of seed fill and yield has led to suggestion that redistribution of N from vegetative plant parts may limit yield by restricting the duration of seed fill (Sinclair and de Wit 1975, 1976).

Several authors have concluded that grain yield is more limited by N than Carbohydrate supply during grain filling (Below *et al.*; 1981, Swank *et al.*; 1982, Reed *et al.*; 1988). They based this conclusion on the fact that vegetative reduced nitrogen remobilization to grain was greater than stem non-structural carbohydrate remobilization during grain filling period.

2.3 CULTIVAR DIFFERENCES IN NON-STRUCTURAL CARBOHYDRATE CONTENT OF VEGETATIVE PLANT PARTS.

Carbohydrates form some storage photosynthate in plants such as starch and sucrose depending on the plant. Generally during the vegetative growth phase, most plants do accumulate sugars which are utilized later during the formation of flower buds and pod filling (Jan and Reddy, 1981). It has been suggested that in beans, the photosynthates from the leaves are transported to the stems and later remobilized for pod filling (Water *et al.;* 1980, D'souza and Coulson, 1988). In beans, the level of soluble sugars have been reported to decline during the reproductive growth phase (Egli *et al.*, 1980). Whether this remobilization phenomenon can account for varietal differences in yield of these crops has not been fully evaluated, although (Adams *et al.*, 1978) reported that the bean cultivars which retained a lot of carbohydrates in stems and roots at harvest yielded lower compared to the ones which retained less. Importance of remobilization trait was further emphasized by Isquirdo and Hosfield (1987) who reported non-structural carbohydrates and nitrogen accumulation at early growth stages as the best strategy for breeding high yielding bean varieties. In work with pigeon peas, however, it has been reported that current photosynthesis, rather than storage carbohydrates, contributes the major portion of crop yield (Shibairo and Nyabundi, 1993) and Setter *et al.* (1984) found that stems and roots of pigeon peas generally contained low levels of non-structural carbohydrates both at the beginning and towards the end of pod filling.

Soluble carbohydrates including fructans and starch accumulate in stems of wheat (Judel and Mengel, 1982). Some of the carbohydrates are known to be translocated to the kernel during grain filling period (Rawson and Evans, 1971). The largest proportion of the dry matter mobilization from stem consists of non-structural carbohydrates. Analysis of seed chemical composition indicates that on a weight basis, maize requires 65 and sorghum requires 54 more carbohydrates than nitrogen for seed growth (Sinclair and de Wit, 1975). Decreases in the non-structural carbohydrate content of vegetative organs should closely parallel decrease in vegetative dry matter when stress occurs after anthesis. Using I_2-K_2 staining, Fiez *et al.*, (1991) found starch in meadoform leaves, stems and flower buds in samples taken at early flowering but not in samples taken at physiological maturity. These observations may indicate that seed yield is enhanced by the remobilization of non-structural carbohydrates (ethanol-soluble carbohydrates and starch) accumulated in other parts.

The amount of stored assimilates probably becomes critical for grain production when plant parts become dependent on such carbohydrates. Stem carbohydrate reserves have been estimated to contribute 10-20% of the final yield in wheat under normal conditions and more than 40% under drought stress or heat stress (Rawson and Evans, 1971). Stem (TNC) concentration at anthesis in wheat was shown to vary from 50 to 350 g Kg^{-1} dry mass (Judel and Mengel, 1982; Davidson and Chavelier, 1992).

At 10 to 12 days after anthesis, TNC of stems can vary from 100 to 380 g Kg^{-1} dry weight (Blacklow *et al.*, 1984). Experiments reported on cotyledonous pod producing plants such as peas and oil seed rape, indicated that towards the end of the growing period, pods and their seeds depend only little on the photosynthate currently produced by the leaves (Flinn and Pate, 1970). Work by Lucas *et al.* (1976) on beans showed that if sink capacity of the pod is inadequate as was the case 10 days after anthesis, then part of the assimilate may be used for stem growth or remobilized to the seeds. Diversion of assimilate to the stem as a result of a small sink capacity in the seed has also been reported on other varieties of *P.vulgaris*. Wein *et al.* (1973), found an increase in stem weight when flowers were removed. But removal of sink organs with a high demand for current photosynthate and a relatively low requirement for mobilized minerals such as nitrogen leads to accumulation of carbohydrates in source leaf, a depressed rate of photosynthesis, and induction of senescence (Neales and Incoll, 1968; Evans 1975).

2.4 CULTIVAR LEAF AREA AND LEAF AREA INDEX (LAI).

Leaves of higher plants have achieved a myriad of life forms but with a common function, namely interception and utilization of radiant energy. Interception is dictated by size, shape, pose and spatial distribution; utilization depends upon leaf area duration and photosynthetic effectiveness of individual organs.

Generally, extent rather than activity of photosynthetic surface is the key determinant of plant productivity, as noted by Kriedemann (1986). As numerous studies attest, generation of photosynthetic capacity is secondary. Based upon an extensive quantitative analysis of plant growth, Watson (1952) attributed productivity differences to variation in leaf area index and identified early canopy closure as crucial determinant of initial crop growth rate (CGR) in well nourished stands. The controlling influence of leaf area on productivity is still apparent despite adverse environmental conditions. Pooling data from five cultivars of sunflower (*Helianthus annus*) subjected to a range of irrigation regimes which generated wide variation in plant growth, Rawson and Turner (1982) were able to demonstrate a near-linear relationship between seed yield per plant and maximum leaf area per plant. McCree (1968) noted that during leaf expansion phase of growth if leaf area increases at a constant rate while photosynthetic rate per unit leaf area remains constant, and if a constant percentage of photosynthetic input is invested in new leaf biomass (the maintenance requirement being small relative to the growth requirement in the young plants), the biomass must increase exponentially, in accordance with the compound interest law.

In the maize plant, increasing LAI is a probable approach to increasing assimilate supply. One of the simplest ways of increasing LAI is to increase plant density (Hunter, 1977). A second approach to increasing LAI is to select genotypes with a high rate of leaf production during pre-silking stage (Hunter, 1977); Tollernaar and Doynard, 1978a). The increase in leaf area could result in selection for greater leaf number and/or greater leaves. Data from (CIAT, 1977) indicated that bean cultivar, Porrillo sentetico reached maximum LAI 40 DAE, which was less than 3.0 and the maximum dry weight accumulation was 4.5 tha^{-1}, 62 DAE. Measurement of crop growth rate of the cultivar from a number of experiments showed a curvilinear relationship to leaf area index. Experiment with light treatment increased seed yield by 48 percent near light source and LAI to a maximum of 4.0. The number of nodes on the main stem and branches increased by 45 percent as a result of the longer duration of vegetative growth, and the proportion of yield contributed by branches was greatly increased. Result showed that yield depended more on the number of pods m^{-2} than any other component. Though LAI was greater, the basic shape of the LAI curves with time was not altered by the light treatment. The efficiency of leaf area in producing yield (yield per leaf area duration) and the harvest index declined slightly as LAI and yield increased due to the prolonging of growth period by light treatment (CIAT 1977).

Several workers have observed varietal differences in leaf area in a number of crops and they have shown that leaf area is related to dry matter production and yield. Laing (1978) observed varietal differences in LAI of beans under tropical conditions. He found that the variety with maximum LAI also recorded the maximum yield and postulated that the high yield could be due to a longer leaf life. He also observed that the variety with the maximum LAI recorded the highest dry matter production indices and maximum growth of reproductive organs. Varietal differences in field grown bean has been reported by Ouma (1988), who observed that early maturing variety had higher LAI than late maturing one at both low and high water levels. The variety with the maximum LAI also had the highest yields. Work by Ogutu (1991) indicated that bean variety with higher seed yield also exhibited higher leaf area index. He pointed out that the higher leaf area provided larger photosynthetic surface that might have contributed to faster rate of biomass accumulation.

Varietal differences in leaf area and leaf area index, therefore, may provide a good selection criterion for high yielding bean cultivars.

2.5 CULTIVAR SPECIFIC LEAF WEIGHT (SLW) AND SPECIFIC LEAF AREA (SLA).

A morphological character which often but not always correlates with carbon dioxide exchange rate (CER) is specific leaf weight (SLW; leaf dry weight per unit area) or more simply leaf thickness (Charles-Edwards, 1978; Barnes 1968, Dornhoff and Shibles, 1976; Brinkman and Frey, 1978). Intergenotypic variation in SLW at a chosen ontogenic stage can show stability in ranking from season to season (Lugg and Sinclair, 1979) and is heritable (Song and Watson, 1975). Whether or not, is a good breeding strategy to select for high SLW depends on its relationship to leaf area development (Kallis and Tooming, 1974). Expansion of leaf area and thickness of leaves can be inversely related (Motto *et al.*, 1979). A second strategy might be to produce plants which expand large thin leaves early in the season and then thick leaves after the canopy intercepts all the light. Another important parameter to consider while dealing with leaf area is specific leaf area (SLA; leaf blade per unit leaf dry weight, the inverse of specific leaf weight). Mc Clendon (1962) argued that the species which achieved the highest net CO_2 exchange rate (CER) per unit leaf area from the minimum leaf material are the most efficient. This implied that high SLA, in positive correlation with CER, could be useful in screening for efficiency. However, there has been mixed success. Dornhoff and Shibles (1976), for example, found negative correlations between SLA and CER among the genotypes of soybean in one study but not in another.

Though correlations between SLA and CER (either positive or negative) have not always been achieved, the accumulated published evidence, together with a field study led Singh *et al.* (1985) to conclude that SLA was the most promising characteristic for indirect selection for grain yield in field grown soybean. Thus they inferred a link between CER and yield.

SLA is thought of in active and negative role through its link in photosynthetic volume (Charles-Edwards, (1982). Thus lower SLA equates with more layers of mesophyll (Dornhoff and Shibles, 1976) and greater light absorption per unit leaf area. This active role would apply particularly at high levels of radiation (Hunt and Cooper, 1969). A reduction in SLA, however, also equates with an increased utilization of carbon substrate in the production of leaf biomass (Rawson 1986) and the incorporation of nitrogen per unit leaf area (Khan and Tsunod, 1970). In limiting situations such as low radiation, where full light capture could be achieved by fewer layers of mesophyll, the substrate could arguably be used more efficiently to generate a larger area of thin leaves rather than a smaller area of thick leaves.

2.6 CULTIVAR BIOMASS ACCUMULATION, BIOMASS PARTITIONING AND YIELD

Total dry matter production of field grown crops results from accumulation of net CO_2 through the growing period. Because CO_2 assimilation results from solar energy (irradiance) absorption and because solar radiation, on seasonal basis, is distributed uniformly over a land surface, the primary factors affecting total dry matter yield are the solar radiation absorbed and the efficiency of utilizing that energy for CO_2

fixation. In the process, the assimilate produced by the green leaves after absorbing the radiant energy must be translocated throughout the plant for growth, development, storage and cell maintenance; partitioning of assimilate affects both productivity and survival of plants.

Work by McMichael *et al.* (1984) showed that dry matter accumulation of cotton plants was closely associated with leaf area development in all strains grown under all conditions, which may relate to the variability observed by others (Quisenberry *et al.*, 1976; Quisenberry *et al.*, 1982) in traits associated with drought tolerance for example osmotic adjustment or heat tolerance since expression of a number of these traits affects dry matter accumulation. Therefore, since the development of leaf area is a function of both leaf number and leaf size, these factors may change differently, depending on the genetic material involved and the environment in which the plants grow.

This and increased number of leaves appear to be the determinant factor contributing to increased leaf area and subsequently increase in dry matter production in exotic cotton (T25) (McMichael 1984), while increased leaf size appears to be the major factor leading to increased leaf area and dry weight accumulation in another exotic genotype (T147). The dry matter production per unit leaf area was shown to be different between the exotic cotton studied, which could account for differences in total dry matter production. Ogola (1991) reported increase in total dry matter per plant with age for all varieties of beans he worked with. Similarly, Ogutu (1991) indicated an increase in plant dry matter with time, and the cultivar with higher biomass had higher biological seed yield. As the plants grew actively, (Ogola, 1991) there was an increase in shoot biomass, and he attributed the major cause of the increased dry matter after anthesis to the development of pods and seeds. During this period, stem had no significant contribution to dry matter production; instead there was a decline in this parameter. Other workers (D,souza and Coulson 1981; Ouma 1988), have reported similar behaviour in beans.

Two useful terms used to describe partitioning of dry matter by the plant are biological yield and economic yield. The term biological yield was proposed by Nichiporovich (1960) to represent the total dry matter accumulation of plant system. Economic yield and agricultural yield have been used to refer to the volume or weight of those plant organs that constitute the product of economic or agricultural value. The proportion of biological yield represented by economic yield has been called the harvest index, the coefficient of effectiveness, or the migration coefficient. All these terms characterized the movement of dry matter to the harvested plant parts; and crop yield can be increased either by increasing the total dry matter produced in the field or by increasing the proportion of economic yield (harvest index) or both. This parameter (i.e HI) may be a bit misleading (Nyabundi, personal communication) at harvest time when most leaves have already been shed. However, apparent harvest index can alternatively be used.

Schapaugh and Wilcox (1980) found that varying environmental conditions affected the genotypic expression of soybean's actual and apparent harvest indices as well as altering the relationship between these two ratios. Nevertheless, the correlation between the actual and apparent harvest indices remained highly significant under two environmental conditions over a range of genotypes that possessed significantly different leaf area indices. Therefore, the measurements of apparent harvest index should permit a valid comparison of the relative efficiency of a group of genotypes.

CHAPTER 3

MATERIALS AND METHODS

3.1 Experimental site

The experiments were conducted at the University of Nairobi's Faculty of Agriculture Farm, Kabete, located on latitude 1° 15' South and Longitude 36° 44' East, at an altitude of about 1800 metres above sea level. The soil consists of well-drained, very deep dark reddish brown to dark red, friable clay with acid humic top soil (humic nitosols) developed from Limuru Trachyte (Michieka, 1977). The area receives an average annual rainfall of about 1000 mm with a mean monthly maximum temperature of 23 °C and a minimum of 12 °C.

There were two field experiments. The first season experiment (experiment I) was performed from 29th of March 1994 to 8th of July 1994, during the long rains. The second season experiment (experiment II) was conducted from 12th October 1994 to 10th January 1995, during the short rains. There was some supplemental irrigation during the second experiment. The site of experiment I was previously under onion (*Allium L.*) while experiment II had a previous history of Irish potatoes (*Solanum tuberosum*) crop.

3.2 Experimental layout and crop Husbandry

The experiment was designed as completely randomised block design (CRBD) with three replicates. Each block was subdivided into ten plots. Each plot measured 3.0 by 4.0 m.

Ten cultivars; Pocho, white haricot, GLP-92, GLP-1004, GLP-2, Ulonzo, GLP-24,E-1, E-3 and E-5 constituted the only treatment and they were randomised within each block.

Land was prepared to achieve a moderate tilth seed bed. Furrows were made 50 cm apart. Diammonium phosphate fertilizer (18% N; 46% P_2O_5, K_2O) was applied along the furrows at a rate of 100 kg Diannonium phosphate (D.A.P.) per hectare and thoroughly mixed with soil. Seeds of the ten cultivars were treated with aldrin 40% EC at a rate of 5 mg per kg of seed for cutworm and beanfly (*melonogomyza spp*) control. Two bean seeds were sown per hill along the furrows at an intra-row spacing of 10 cm. At second trifoliate stage (two weeks after emergence), the stand was thinned to one plant per hill.

Immediately after emergence, the seedlings were treated with Dimethoate (dimethyl-s- N-methyl carbo-methyl) phosphorolothionate) 40% Ec at a rate of 1 litre in 500 litres of water per hectare for the control of bean fly on the aerial parts of the plants. This was repeated at weekly intervals until flowering. To control bean rust (*Uromyces phaseoli*) and other fungal diseases, Benomyl [methyl N-(1-butyl carbomyl-2-benzimidazole)- carbamate] was applied at a rate of 20 gm per 20 litres of water per hectare one day after every application of Dimethoate. Manual weeding started after thinning and was repeated periodically to keep the field free of weeds. After flowering, Cypermethrin (a synthetic pyrethroid) was sprayed at a rate of 100 ml per 20 litres of water per hectare to control insect pests such as whiteflies, leaf eating caterpillars and leaf borers.

Analysis of variance (ANOVA) was done for all the parameters measured and the means were separated by Duncan multiple range test (DMRT) as laid down by steel and Torrie (1980).

3.3 Measurements and Observation

The following parameters were monitored; leaf net photosynthetic rate, leaf nitrogen content, non-structural carbohydrate contents of plant stems, leaf area and biomass accumulation, specific leaf weight, harvest index and yield and yield components were determined.

The measurements for leaf nitrogen contents, non-structural carbohydrate contents, specific leaf weights, leaf area and biomass accumulation commenced 32 DAE and was continued at fortnightly intervals, while leaf net photosynthetic rate was done 32 DAE and 45 DAE on a diurnal basis. Harvest index and yield and its components were determined at harvest.

3.3.1 Leaf Net Photosynthetic Rate

The measurements were taken on middle leaflet of the youngest fully expanded and well-exposed leaf. These were previously tagged to eliminate leaf age effects. Three readings were taken per plot in different tagged plants each time. A closed system infrared gas analyzer (Analytical development corporation Ltd; Hert, England) was used for these measurements. Measurements were taken between 8.00 hrs and 16.00 hrs (East African Standard Time) on clear sunny days of 32 DAE and 45DAE for experiment II only. These days represented flowering and grain filing phases of the experiment. The parameter was not taken during experiment I as the growth period was dominated by cloudy weather conditions.

3.3.2 Non-Structural Carbohydrate Content of Plant Stems

This was done on the same plant materials used for biomass determination in the field experiments. The bulk specific weight of plant parts were ground to pass through 0.1 mm sieve, wrapped in aluminium foil to prevent them from dampness, placed in paper bags (stems of different cultivars in separate paper bags) and re-dried at 70 °C for 24 hours before analysis (Egli *et al.*, 1980).

Analysis of starch was done by slightly modified method by Hart and Fisher (1971) as follows: 5 mg of ground sample were put into a centrifuge tube and 30 ml of hot 80% ethanol added to extract soluble sugars. The tube was vigorously shaken and then centrifuged at about 2500 rpm in a bench centrifuge (Gallen Kamp Angle-head centrifuge, Gallen Kamp, Ltd, England) for 15 minutes to separate solid fibrous particles from liquid and immiscible solvents and for resolution of emulsion that are formed during extraction. The supernatant was then decanted into some container and safely kept for determination of soluble sugars. Washing with alcohol, centrifuging and decanting was repeated three times, or until the supernatant gave no green coloration with anthrone reagent (this reagent forms a stable green colour with soluble sugars and here, it is used as an indicator for such sugars).

After the final extraction, distilled water was added to the residue to make a 10ml suspension. The suspension was cooled in an ice bath and while stirring, 13 ml of 52% $HClO_4$ (prepared by thoroughly mixing 270 ml of 71% $HClO_4$ with 100 ml of distilled water) solution was added for extraction of starch. The mixture was stirred continously for 15 minutes and thereafter occasionally for another 15 minutes while being kept cold in the ice bath. 20 ml of distilled water was added, centrifuged for 15 minutes at 2500 rpm and the suspension poured into a 100 ml volumetric flask. 5 ml of distilled water was then added to the residue in the centrifuge tube, cooled in an ice bath and 6.5 ml of 52% $HClO^4$ solution stirred in. This was solubilized as before and the contents washed into the volumetric flask. The combined extract was diluted to 100 ml with distilled water and filtered; the first few millimetres being discarded. 10 ml of the filtered solution was pipetted into 100 ml volumetric flask and distilled water added to make it to the mark. 5ml of the solution was pipetted into the test-tube, cooled in water in an ice bath and 10ml on anthrone reagent (prepared by dissolving 0.5 g anthrone in 250ml of 95% H_2S_{04} and the solution was then left to stabilize for 3-4 days at 0 °C) added - the $H_2 S_{04}$ in the reagent hydrolysed starch. The contents of the test-tube were thoroughly mixed and heated for 7½ minutes on a boiling water bath. The test-tube was then rapidly cooled to 25 °C in a water bath and the absorbance of the solution read at 630nm, with spectrophotometer, WPA S 105 (WPA ltd, Safferen, England). The amount of glucose was calculated from a standard curve and then starch content as follows:

starch = glucose x 0.9

Glucose Standard Curve:

From the solution containing 0.1 g anhydrous glucose per 100 ml, 10 ml was pipetted into a 200 ml volumetric flask and filled to the mark with distilled water, 1,2,3,4, and 5 ml of diluted solution was pipette into test-tubes and distilled water added to each test-tube to make a total volume of 5 ml. The content of each test-tube was processed as above, starting with "cooled test tube rapidly to 25 °C......" Absorbance values were then plotted against a concentration on a millimetre paper to yield a standard curve.

For determination of soluble sugars, the previously stored supernatant from alcohol extraction was heated in a crucible to evaporate alcohol. The process was stopped when the substance turned cloudy. Water was added and the mixture transferred into 100ml flask was then processed as in case of starch above;starting with "10 ml of the solution pipetted into 100 ml volumetric flask........."

3.3.3. LEAF NITROGEN DETERMINATION

3.3.3.1 Foliar N content analysis Using Kjeldahl method

The samples for determination of nitrogen were re-dried in an oven at a temperature of 72 °C for 48 hours. These samples were then finely ground using an electric micro-hammer mill and screened through 1.0 mm sieve.

3.3.3.1.1 Digestion

0.5 gm of sample was put into a digesting tube in duplicates. About one spatula end of selenium mixture (160 k_2SO_4: 10 $CuSO_4$: 3 selenium powder) and 10 ml of conc. sulphuric acid was added. These tubes were put into the digestion block inside a fume board and heated at a temperature of 300 °C for 3-4 hours until the contents cleared. It was then left to cool inside the fume board.

3.3.3.1.2 Distillation

After cooling, the digested samples were emptied into the distillation (bulb) flask. 5 drops of phenolphthalein indicator were added to each flask together with boiling marble to smoothen out the boiling. The distillation flasks were then connected to the distillation rack where receiving conical flask were placed. Each receiving flask contained 50 ml of the 0.1N HCl and about 3 drops of methyl orange indicator. 50 ml of the 40% NaOH was added into the distillation flask from the top. This was done when the tips of containers were immersed in the standard acid in the receiving flask in order to avoid escape of any ammonia which is produced immediately after addition of the 40% NaOH. Distilled water was added from the top to make volume of the distillation solution to be about 350 ml. This solution was boiled so that NH_3 escapes in gaseous form but gets condensed and collected as distillate in the receiving flask. This continued for 1-2 hours until nessler's reagent failed to react with the distillate, or until ≥ 200 ml of the distillate was got. The tips of the condenser were then removed from the distiller before putting off the heating system.

3.3.3.1.3 Titration

The distillate collected in the receiving flasks were titrated using 0.1N NaOH. The titration end point was marked when the distillate changed colour from orange to light greenish yellow. The amount of NaOH used was noted for calculation of %N as follows:

$$\% N = \frac{14.007 \times \text{titre} \times N}{\text{sample(g)} \times 1000} \times 100$$

where titre = blank titre - sample titre

N = Normality of NaoH

14.007 = Constant (atomic weight of nitrogen).

3.3.4 Specific Leaf Weight (SLW)

This was done on the youngest fully expanded leaflets. The punches using cork borer were randomly made and leaf disks pinned together on a board for drying at 40 °C for 24 hours. A total of four punches were randomly made on the leaflets on each plot. Each plot had plants previously tagged for measurement of this parameter. After drying, the weights were taken together and average of the four taken. Sampling was done early in the morning when leaf starch content was presumed lowest. SLW was then expressed as follows:

$$\frac{\text{g(average weight of four leaf disks)}}{\text{cm}^2\text{ (area of single leaf disk)}} = \text{g/cm}^2$$

3.3.5 Biomass and leaf area determination

Sampling for these measurements was started about four weeks after emergence and continued at two weeks intervals up to maturity. These measurements were taken in both field experiments. Ten plants per plot were sampled from 0.5 m^2 central area of each row. Sampling was not done on the outer rows to eliminate boundary effects. The subsequent sampling were done on alternate row basis and was stratified to avoid creation of random gaps within the field.

The leaves were separated from the stems and roots. The leaves were used for the treatment of leaf area (LA) using a leaf area metre, Li-cor automatic LA integrator (model Li-300, Li-cor inc. Lincon, Nebraska). The stems and leaves and pods (i.e. after pod set) were separated and put in different paper bags and placed in the oven at 70 °C for 48 hours and the dry weight taken by use of weighing balance. The leaves used for leaf are determination were used for leaf biomass determination.

3.3.6 Yield and Yield Components

The sampling area consisted of 2.0 m^2 per plot. This was done on the middle central rows. A total of 40 plants were sampled per plot. Of the sampled plants, 10 were used to determine the mean number of pods per plant and 100 seed weight. The seeds were then mixed with the ones from rest of the plants and used for the calculation of final seed yield. Oven drying was done for 48 hours at 40 °C.

3.3.7Harvest Index

This was taken at maturity by dividing (economic) yield by final above ground (biological) yield and then multiplied by 100.

$$HI = \frac{Y - econ}{Y - biol.} \times 100$$

CHAPTER 4

RESULTS

4.1 Leaf net photosynthetic rate

There was significant difference in leaf net photosynthetic rates among cultivars in experiment II (appendix 5a and 5b). GLP-92 exhibited the highest diurnal leaf net photosynthetic rate, followed by White Haricot at 32 DAE, while Ulonzo and Pocho had consistently lower leaf net photosynthetic rates during this phase of development. At 45 DAE, Pocho had superior performance in this character, followed by White Haricot, while GLP-2 registered the lowest leaf net photosynthetic rate. Pocho's rate of decline in this parameter was however faster than White Haricot after reaching peak photosynthetic rate. Other cultivars, which exhibited rapid decline in this parameter, were E-1 and E-5. In both experiments, the peak leaf net photosynthetic rate was reached at 12.00 hr by all cultivars, while the lowest was observed at 8.00 hr. There was also an observed similarity in trend exhibited by all cultivars, though at 45 DAE, the curves were closer than at 32 DAE.

4.2 Leaf Nitrogen Content

GLP-24 had the highest leaf nitrogen content during flowering period (Ca: 32 DAE), while Pocho and E-3 had the lower mean leaf nitrogen content. However, pocho's leaf nitrogen content was relatively higher at 45 DAE when compared to the other cultivars (Appendix 6a; and also fig 2, experiment 1). Though GLP-24 had the highest leaf nitrogen at 32 DAE, it

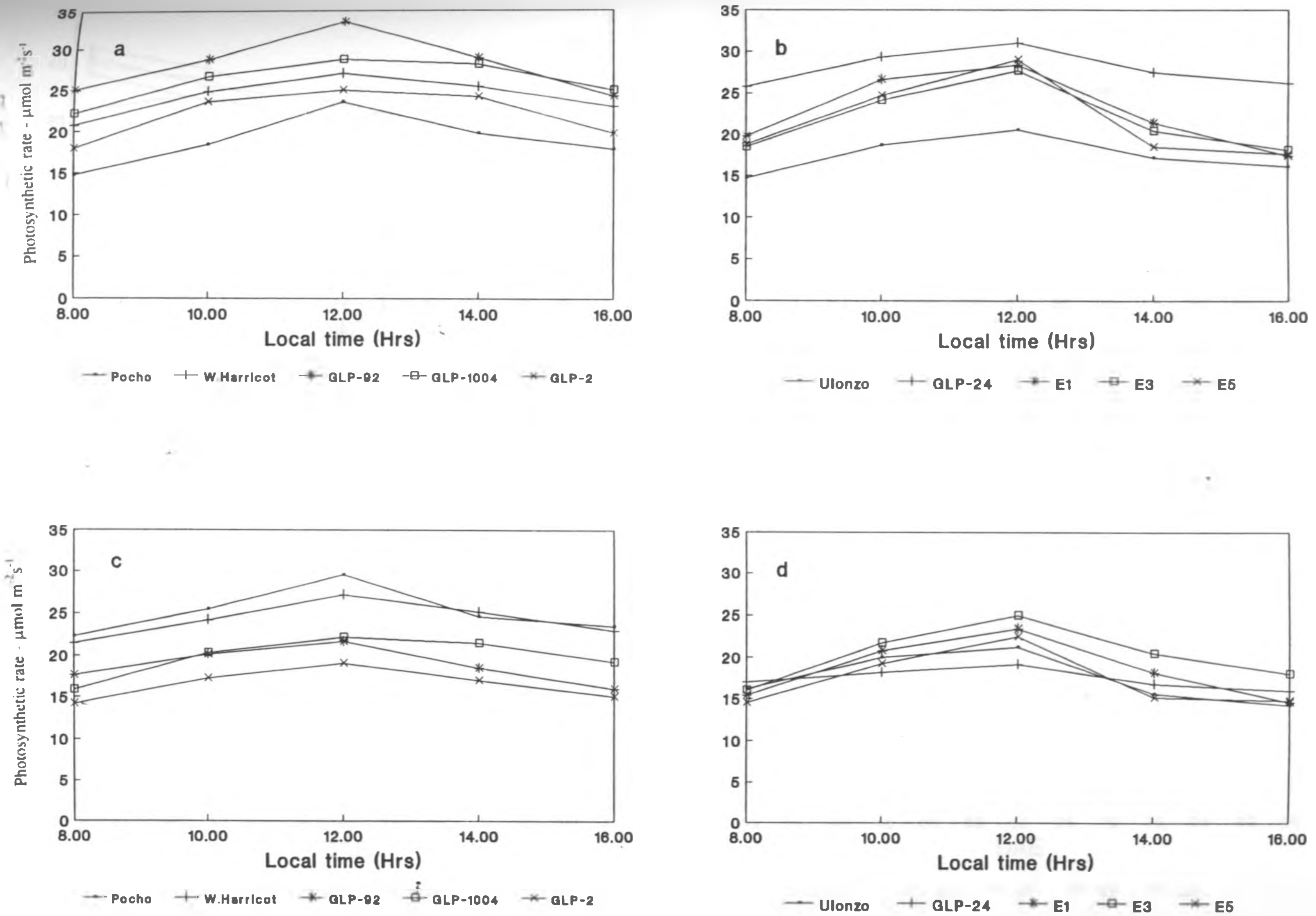


Fig. 1.0 Cultivar variation in leaf net photosynthesis during short rains 32DAE(a&b); 45DAE(c&d).

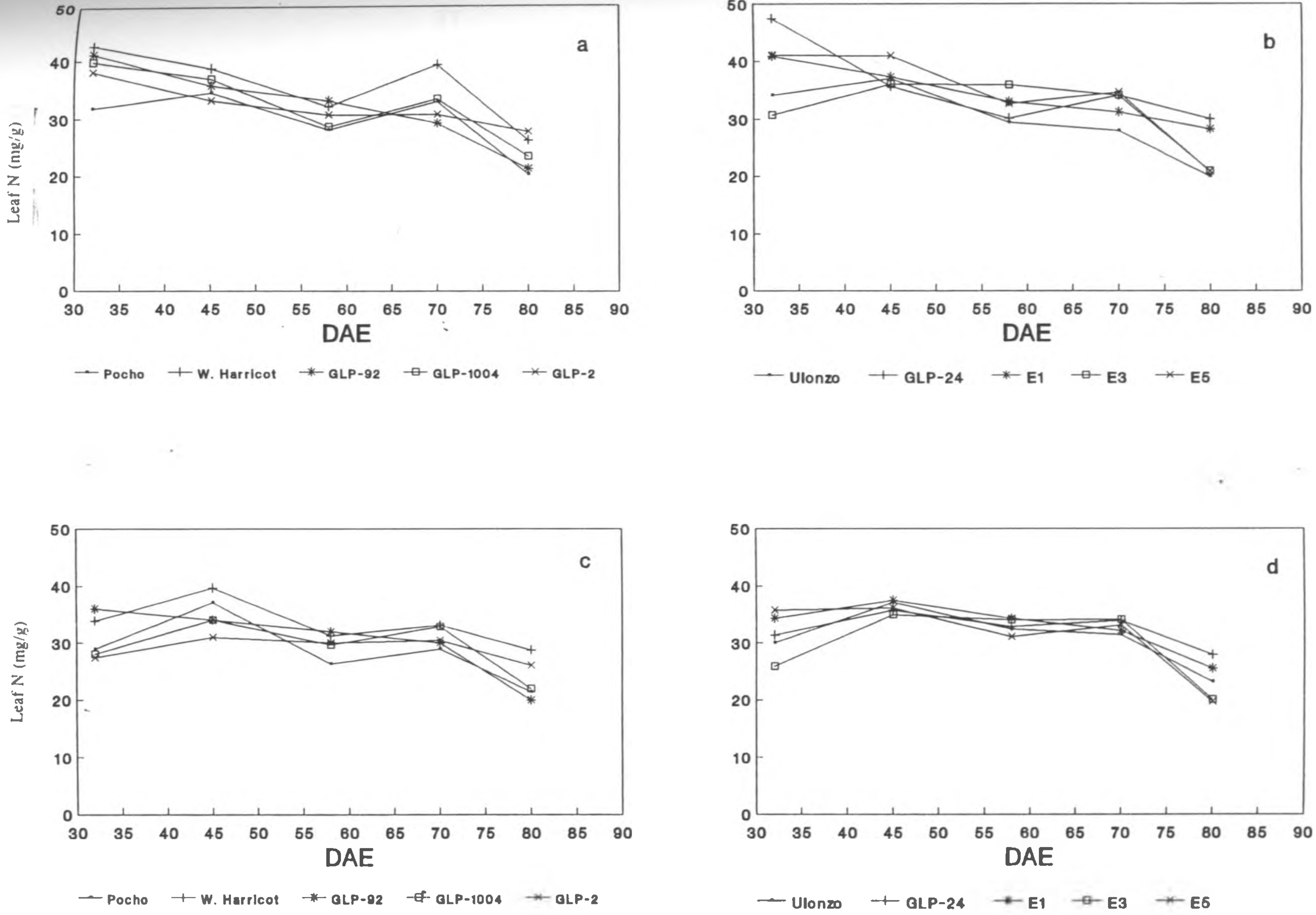


Fig. 2.0 Cultivar variation in leaf nitrogen content during long rains (expt.I); a&b; and short rains (expt. II); c&d.

Fig. 2b: Cultivar variation in leaf nitrogen content during short rains (experiment II) also exhibited more rapid decline in this parameter from this period to about 58 DAE. All cultivars exhibited a general increase in leaf nitrogen contents after 58 DAE, reaching a peak at 70 DAE. Thereafter, all of them had a decline in this parameter upto harvest time. GLP-92, White Haricot, E-1 and Pocho had higher leaf nitrogen contents during peak period (45 DAE), while GLP-2 had the lowest. Contrary to the results of experiment 1, there was an observable increase in leaf nitrogen content after 32 DAE in almost all cultivars in experiment 11 (Appendix 6b) reaching a peak at 45 DAE. GLP-2 and E-5 however, had their peak nitrogen contents at 32 DAE and thereafter leaf N decline steadily till harvest time. The decline from the peak to the lowest point was however more rapid than in experiment 1 (fig 2.0), in all cultivars.

4.3 Non-Structural Carbohydrate Contents of Plant Parts

There were variations in stem soluble sugars and starch contents among cultivars throughout the growing periods (fig 3.1 and 3.2). There were significant differences in both stem soluble sugars and starch contents in the two experiments (Appendix 7a, 7b, 7c, and 7d). Pocho, GLP-24 and GLP-2 had consistently higher stem non-structural carbohydrate contents than any other cultivars, while Ulonzo and GLP-92 were among the cultivars which exhibited lower stem non-structural carbohydrate contents during growth period of experiment 1. The cultivars which had lower contents of stem non-structural carbohydrates contents in experiment 11 (season 2) were GLP-92, White Haricot and E-1. In both experiments there was a drop in stem soluble

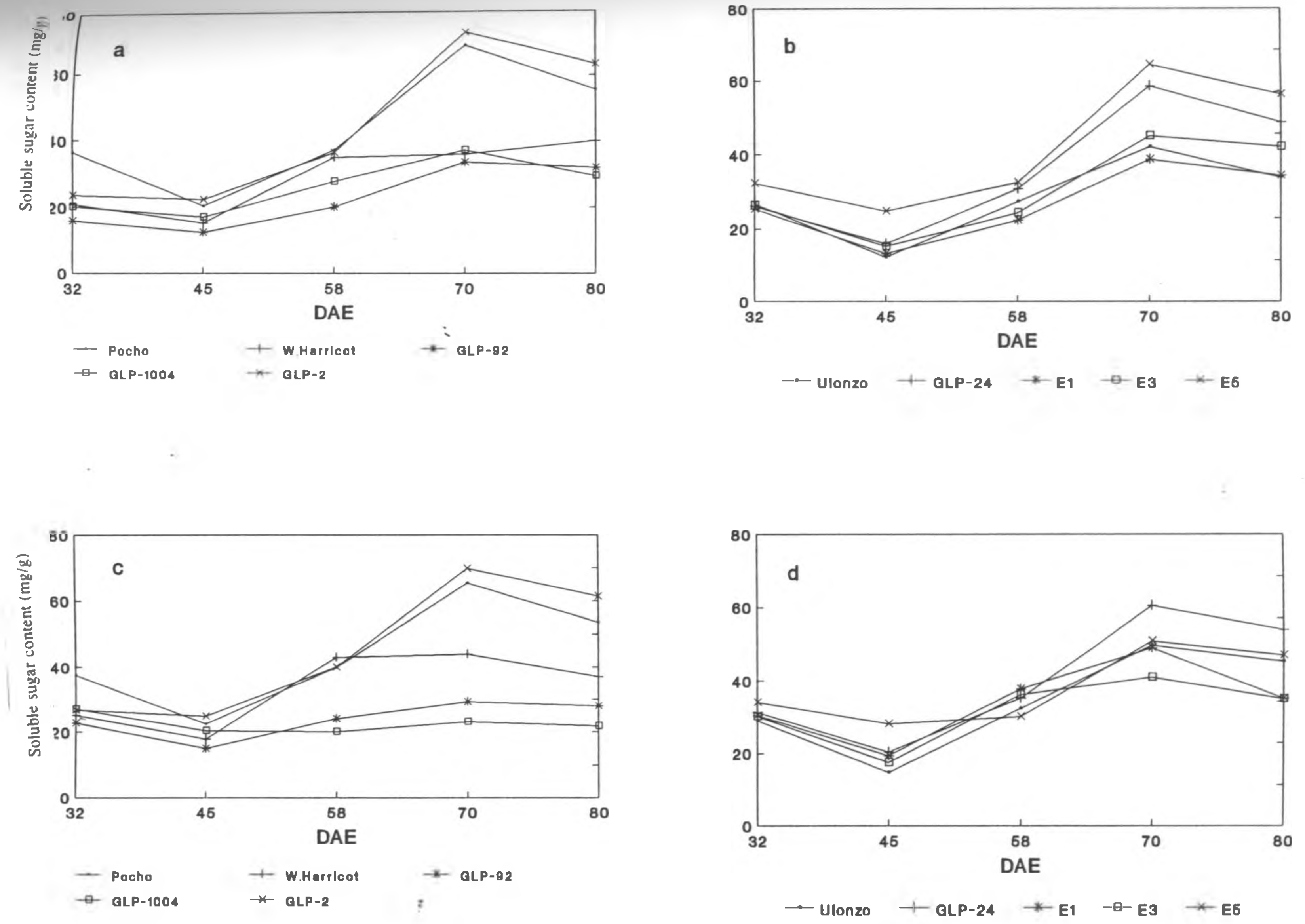


Fig. 3.1 Cultivar variation in stem soluble sugar content during long rains (expt I); a&b; and short rains (expt. II) c&d)

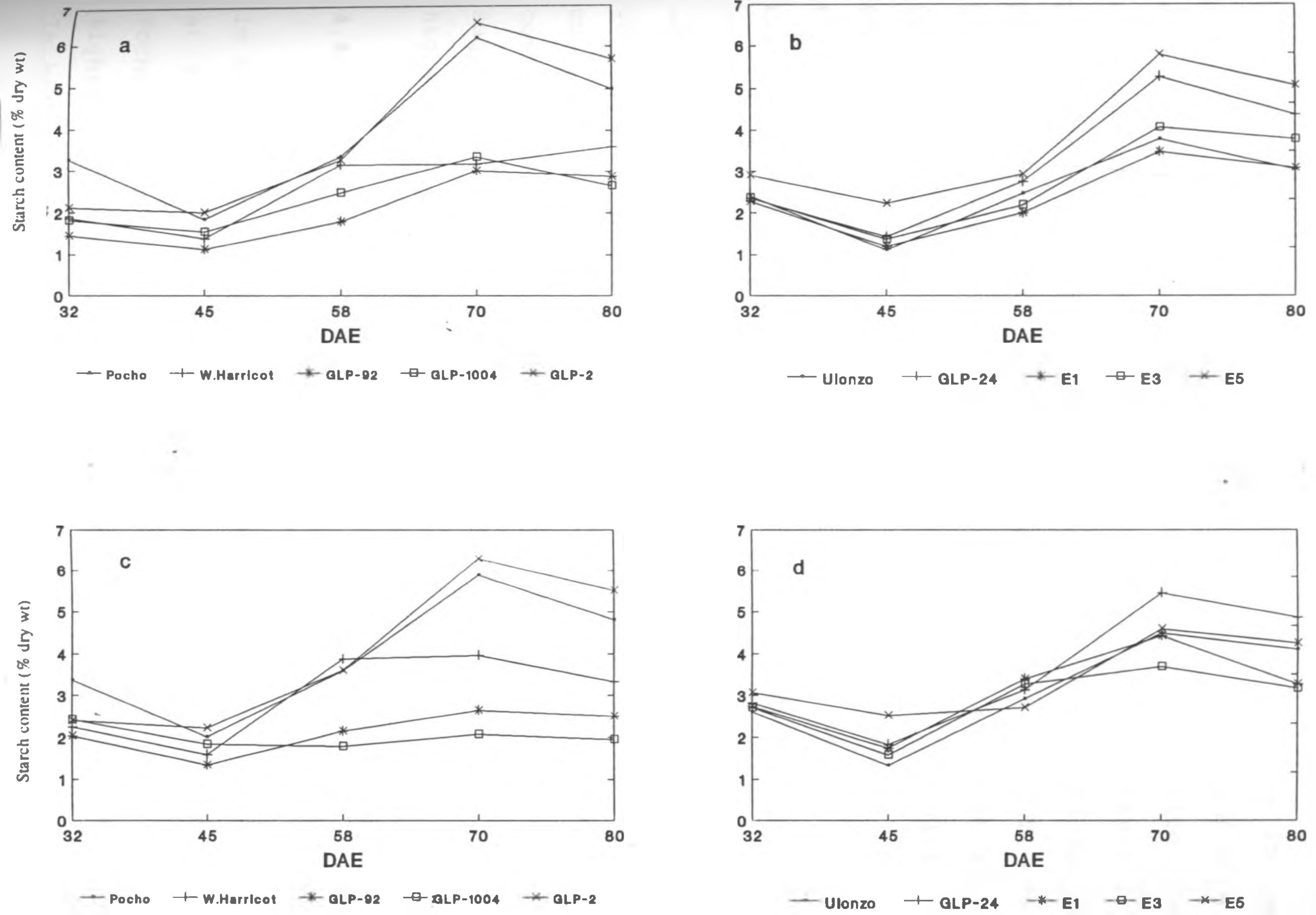


Fig. 3.2 Cultivar variation in stem starch content during long rains (expt. I); a&b and short rains (expt II) c&d.

sugars and starch at 32 DAE, with minimum values around 45 DAE. After this period there was an appreciable increase in these parameters in all cultivars. However, the increments were at varying proportions. GLP-24, Pocho and GLP-2, despite having higher amounts of the non-structural carbohydrate contents, the percentage reduction in stem soluble sugars was higher for GLP-24 and Pocho than GLP-2, for instance, between 32 DAE and 45 DAE, with GLP-24 and Pocho having reductions of 34.9% and 40% respectively, while GLP-2 being 7.1%. In all cultivars, peak stem soluble sugar contents were reached at around 70 DAE and then started declining till harvest time. Unlike other cultivars, White Haricot, however, had its peak around 58 DAE in both experiments and its rate of decline in this parameter was also more steady upto harvest time. A pronounced reduction in stem non-structural carbohydrate contents occurred in all cultivars between 32 DAE and 45 DAE in experiment 11 as compared with experiment 1. Generally the mean stem soluble sugars and starch contents of experiment 11 were slightly higher than for experiment 1.

4.4 Cultivar leaf area indices.

The highest leaf area index was observed on White Haricot in experiment 1 (Appendix 8a and also fig 4.0). This occurred at around 58 DAE, while the lowest at this phase was GLP-2. Pocho, White Haricot and E-3 were among the cultivars with higher performance in this parameter between 32 DAE and 45 DAE. In both experiments there was a highly significant difference in leaf area indices throughout the growing periods (Appendix

8a, and 8b).There was a general increase in leaf area indices for all cultivars, reaching peak at around 58 DAE. Thereafter, there was a general decline in LAI. However, the rate of decline was not the same in all cultivars. White Haricot for instance, had a gradual decline and its LAI was consistently higher compared to GLP-2 and Ulonzo. GLP-24 and Pocho also exhibited very gradual decline in LAI after 58 DAE (peak point) and were among the cultivars with higher LAI at maturity (beyond 70 DAE). Mean LAI for experiment 11 were evidently lower than those for experiment 1 (appendix 8a, and 8b). White Haricot, however, had generally higher LAI during the growth periods in both experiments, while GLP-2 exhibited the lowest LAI during these periods.

4.5 Cultivar biomass accumulation.

Total plant biomass was not significantly different at 32 DAE in experiment 1 (Appendix 9a) for most of the cultivars. But thereafter, there was a significant difference in total plant dry weight. There was no clear distinction on cultivars that performed better than the rest in biomass accumulation during the course of growth. This was also observable in experiment 11 (Appendix 9b). In both experiments there was a general increase in biomass, reaching a peak at around 70 DAE and then followed by a plateau in most cultivars, while in some cases there were slight increments in total plant biomass after 70 DAE (Fig. 5.1). E-3 however reached its peak biomass production at around 58 DAE in experiment 11. The rates of total biomass accumulation were however different among cultivars in both experiments. GLP-2 and Pocho had a gradual rate of plant biomass

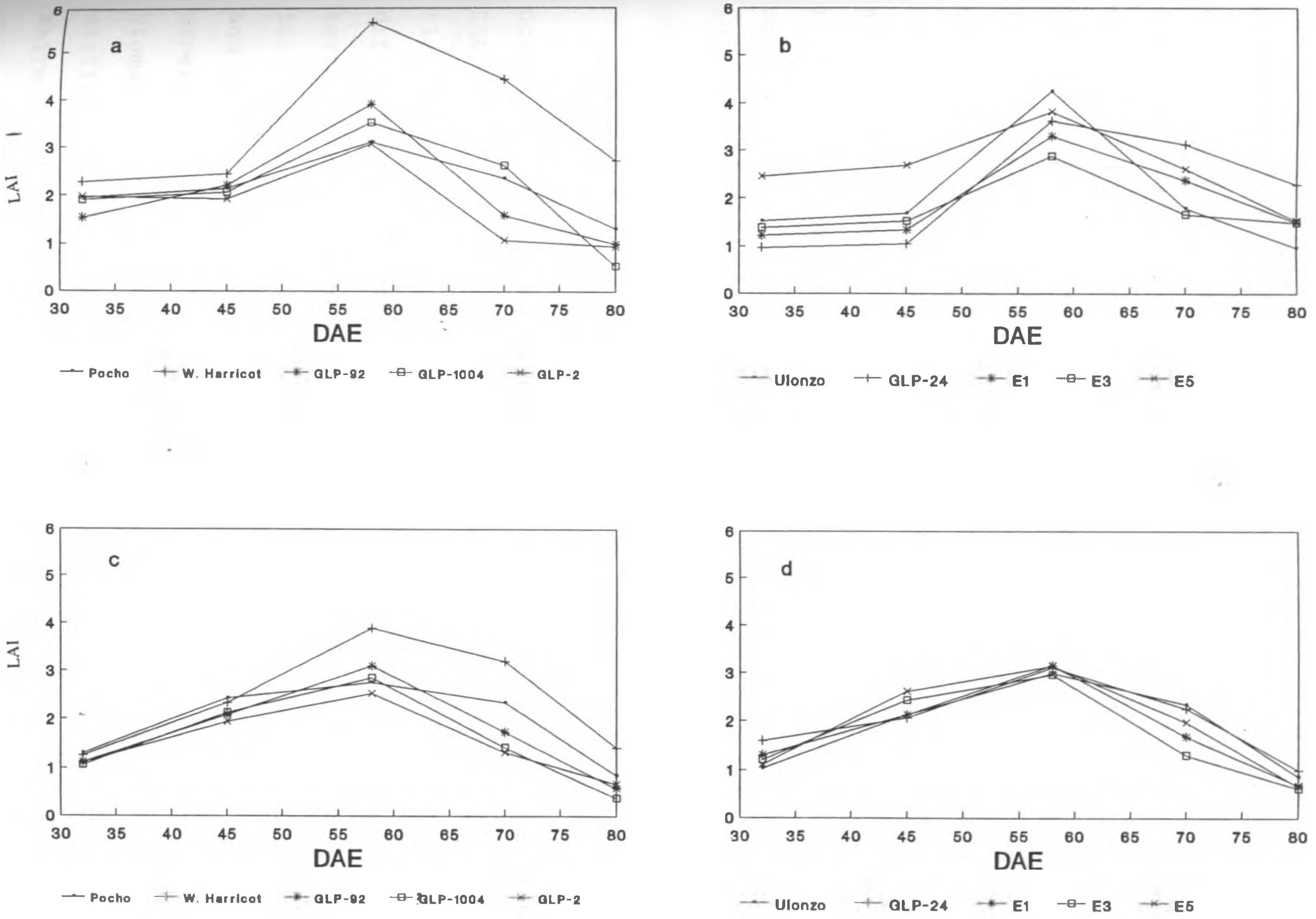


Fig. 4.0 Cultivar variation in leaf area indices during long rains (expt. I); a&b) and Short rains (expt.II) c&d.

accumulation upto 58 DAE (experiment 1), then they started exhibiting more rapid increments in this parameter. Despite sharp increase in plant biomass in both cultivars, GLP-2 had generally lower total biomass than Pocho. In fact, at maturity Pocho was among the cultivars with higher total plant biomass. Other cultivars had a more rapid biomass accumulation between 45 and 58 DAE, and thereafter the increase was gradual upto 70 DAE. In experiment 11, the rate of total plant biomass accumulation was quite similar in most cultivars upto 58 DAE. After this period, Pocho, Ulonzo and GLP-24 maintained steady rates of biomass accumulation till 70 DAE when there was an observable decline; while on the other hand, E-5, E-1 and GLP-1004 exhibited very low rates of plant biomass accumulation after 58 DAE.

Stem dry weight production at 32 DAE (experiment 1) were not statistically significant (Appendix 9c) and 32 DAE and 45 DAE, the significance was not highly different in experiment 11. After 45 DAE, stem dry weight production was significantly different among cultivars (Appendix 9c), with White Haricot having the most rapid rate of stem biomass accumulation until 58 DAE, after which the exhibited a decline in this parameter and the rate of decline was accelerated after 70 DAE (fig 5.2, experiment 1). GLP-1004, E-5 and E-3 also had rapid stem biomass accumulation after 32 DAE but E-5 reached its peak earlier (58 DAE) and started dropping gradually till maturity. White Haricot also had a peak at 58 DAE, but its decline in this parameter was more rapid and steady. However, E-3 showed a noticeably rapid rates of stem biomass decline after 70 DAE. On the contrary, GLP-2 maintained a lower rate of stem biomass accumulation throughout the growing period in experiment 1 and had no noticeable drop in this parameter at any point of growth.

In experiment 11 the cultivars exhibited similar trends in stem biomass accumulation as in experiment 1 (fig 5.2). However, their mean stem dry matter remained lower than in experiment 1. E-3 had a very sharp decline after 70 DAE (peak point). Pocho was among the cultivars which accumulated low stem biomass accumulation in experiment 1 but was among the superior performers in this character in experiment 1. The decline in stem dry weight after the peak point was easily evident.

There was no significant difference in leaf dry weight at 32 DAE in both experiments. After 32 DAE, there was an appreciable increase in leaf biomass accumulation, reaching peak at 58 DAE (fig 5.3). After this point there followed a drop in leaf dry matter. GLP-92 and Ulonzo had out-performed the other cultivars in leaf dry matter production at 58 DAE of experiment 1. They also exhibited a very rapid decline in this parameter after 58 DAE (peak point) during experiment 1.

The cultivars showed highly significant differences in pod dry matter production, with White Haricot having the lowest pod dry matter at 58 DAE. E-3, E-5, GLP-2 and Pocho had almost the same init also had the highest pod dry weight at maturity (experiment 1, Appendix 9g). Though E-3 had lower initial pod dry matter, its rate of pod biomass accumulation was very rapid. This was also

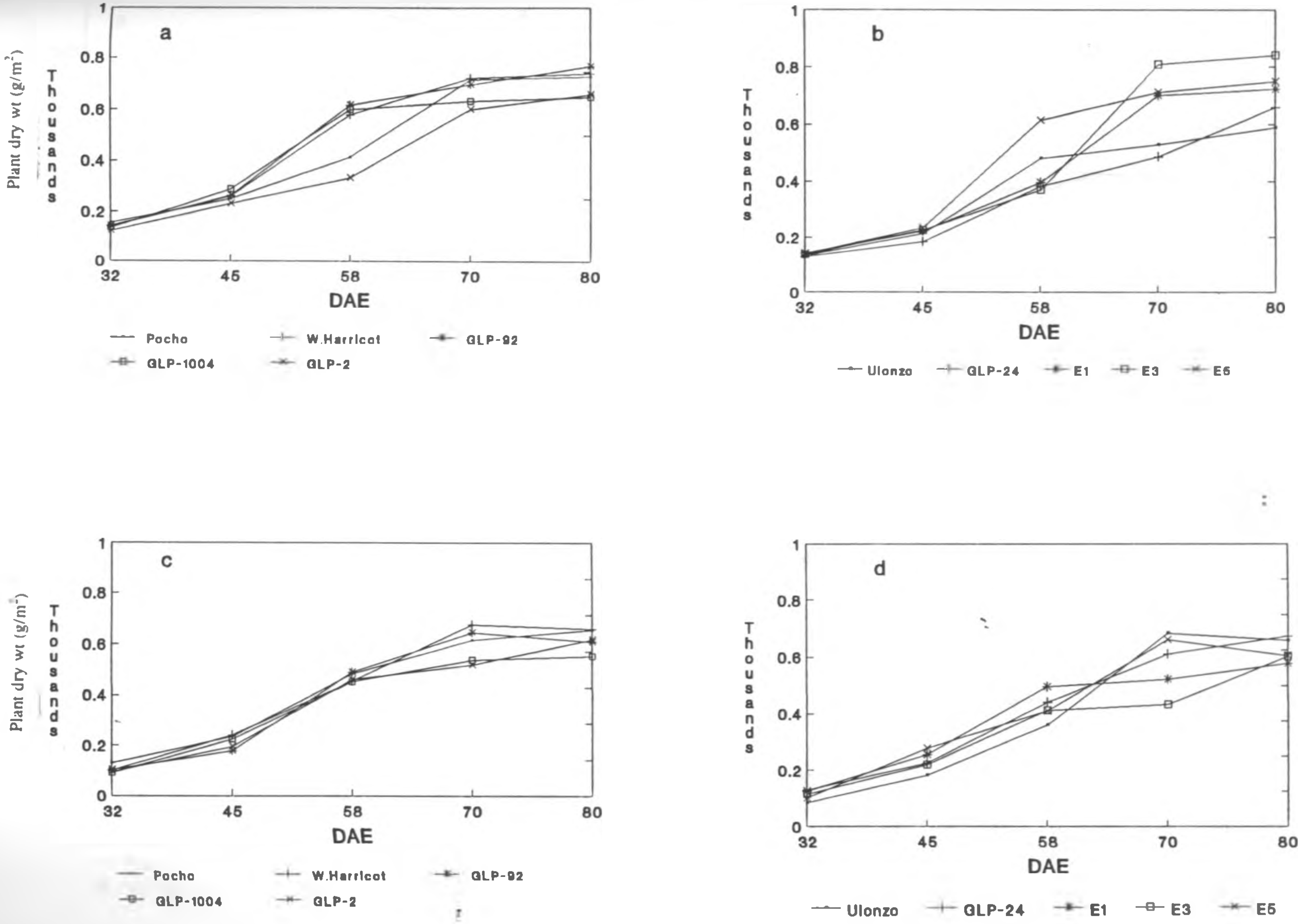


Fig. 5.1 Cultivar variation in total plant biomass accumulation during long rains (expts I) a&b and short rains (expt. II) c & d.

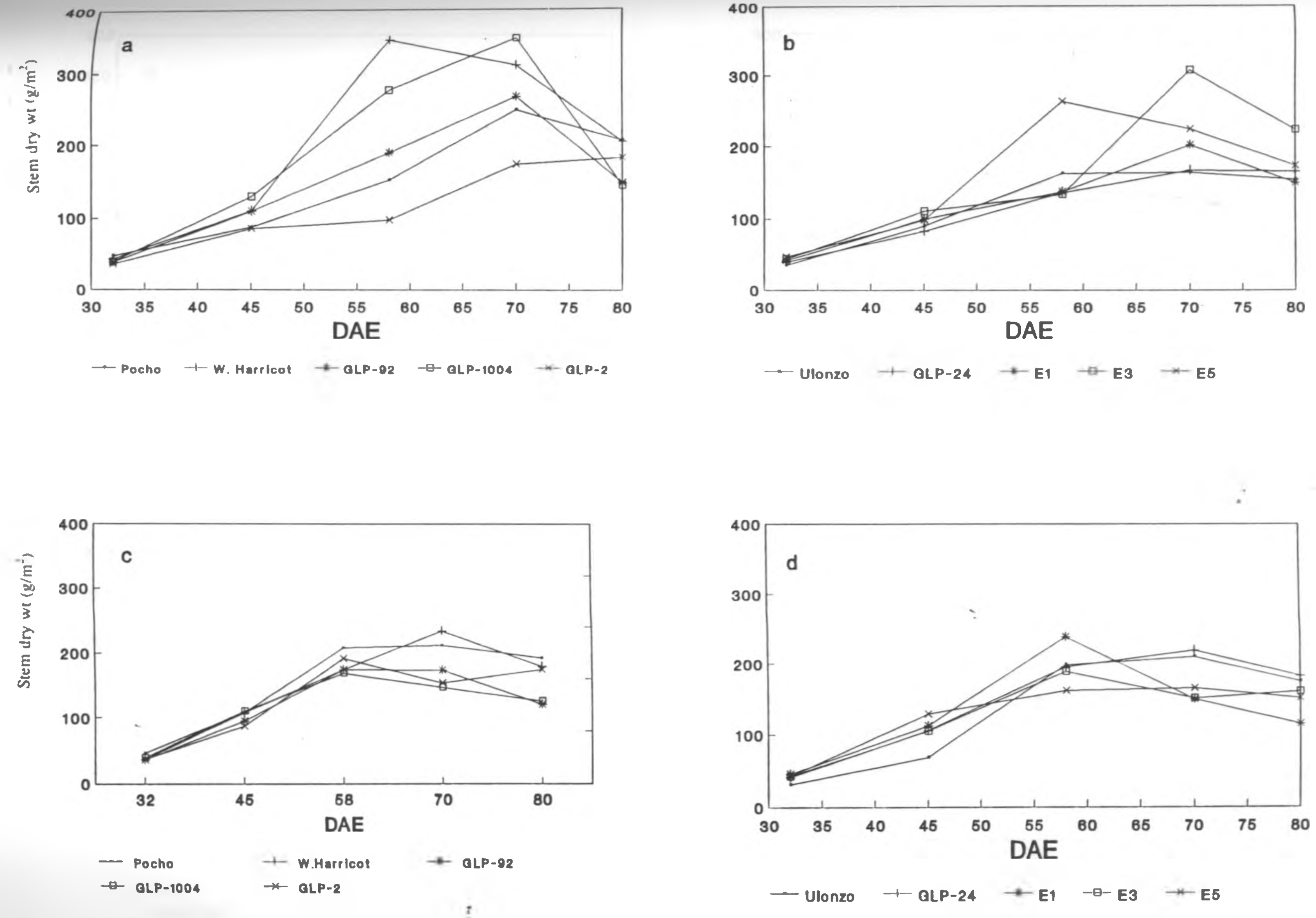


Fig. 5.2 Cultivar variation in stem dry weight accumulation during long rains (expt I) a&b and short rains (expt. II) c&d.

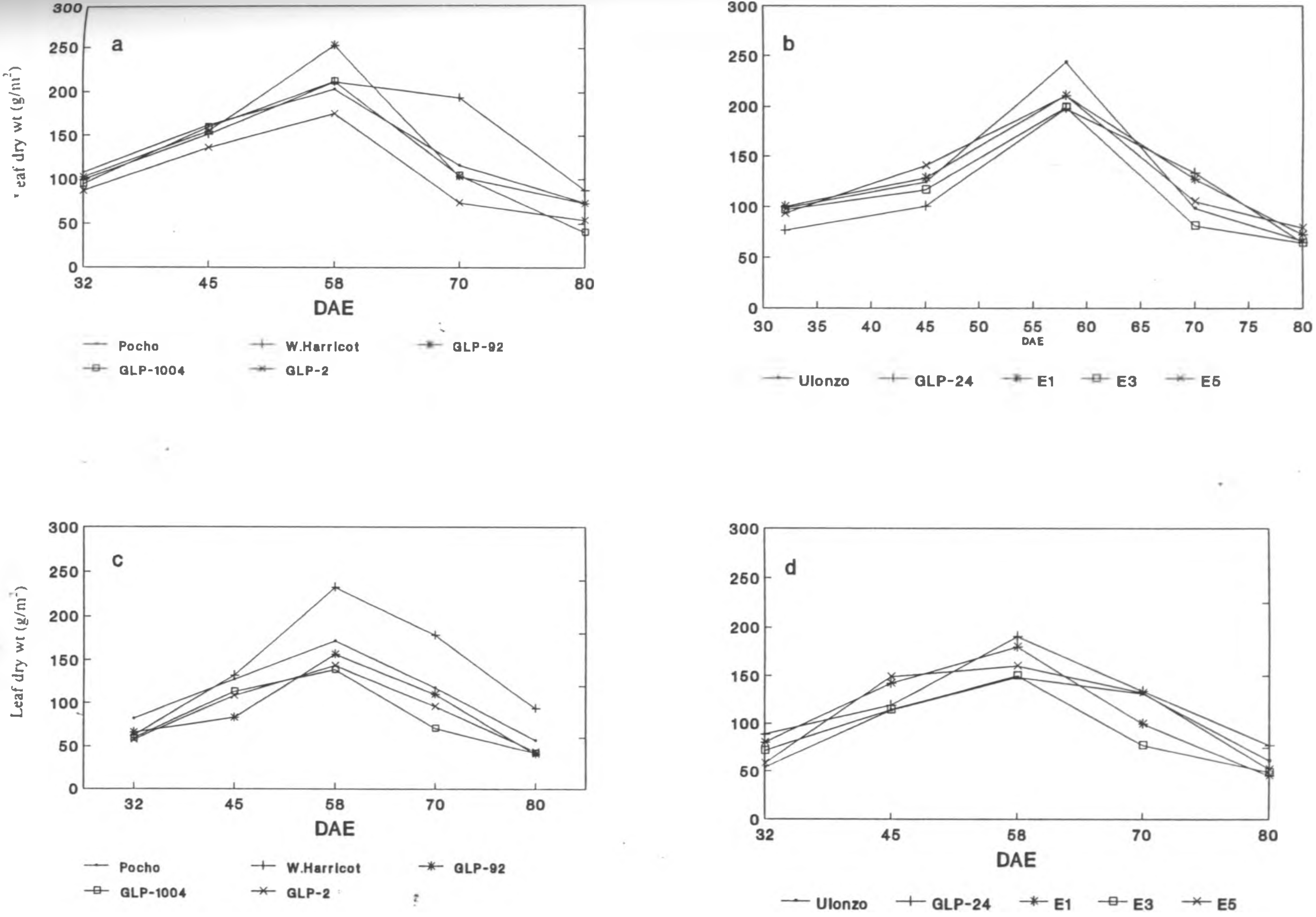


Fig. 5.3. Cultivar variation in leaf dry weight accumulation during long rains (expt I) a&b and short rains (expt II) c&d.

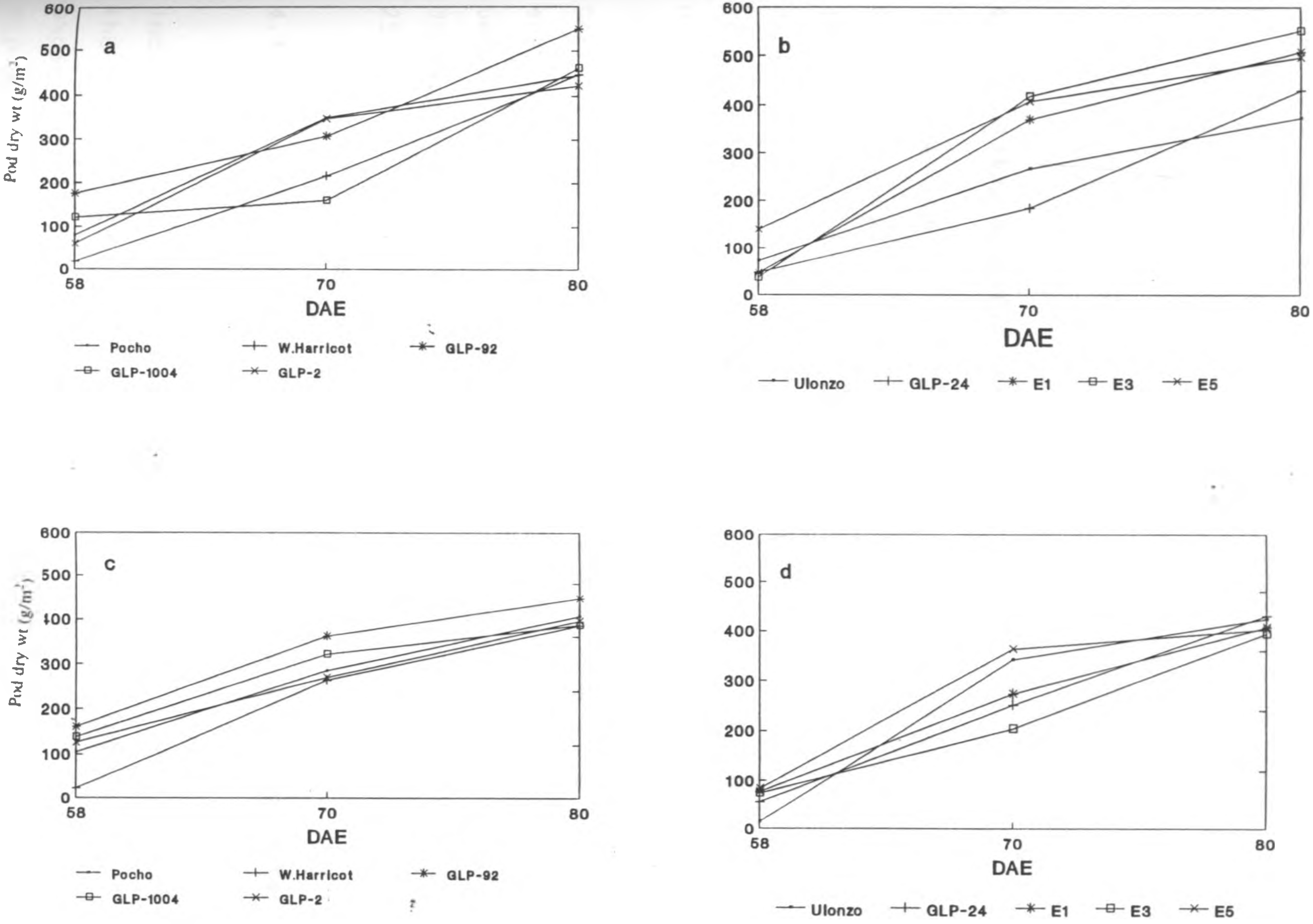


Fig. 5.4 Cultivar variation in pod dry weight accumulation during long rains (expt I) a&b and short rains (expt II) c&d.

observable in E-1. During experiment 11, GLP-92 and GLP-1004 registered higher initial pod biomass production (fig. 5.4) E-3, GLP-24 and White Haricot were among cultivars with lower initial pod biomass production (at 58 DAE). Need abit more highlight of final pod dry matter i.e at 80 DAE.

4.6 Cultivar Specific Leaf Weights

There was a significant difference in specific leaf weights throughout the growing periods in both experiments (Appendix 10a and 10b). In both experiments, White Haricot had consistently lower specific leaf weights during growth periods (fig 6.0). GLP-92 and E-3 had higher SLWS during experiment 1. Ulonzo had lower SLW from 32 DAE to 45 DAE after which it rapidly increased to peak at 58 DAE (experiment 1). After 58 DAE, all the cultivars had a decline in SLW between the two seasons. There were however difference in this character between the two seasons; for instance, at 32 DAE, the differences in mean SLW between the two growth periods was 25.3%.

4.7 Cultivar Harvest Indices, Yields and Yields Components

There was a significant difference in cultivar harvest indices in both experiments (Appendix 11a and 11b) GLP-24 had the highest HI in experiment 1, followed by Pocho. In experiment 11, E-1 had the highest HI, followed by E-3, while GLP-2 had the lowest HI in both experiments.

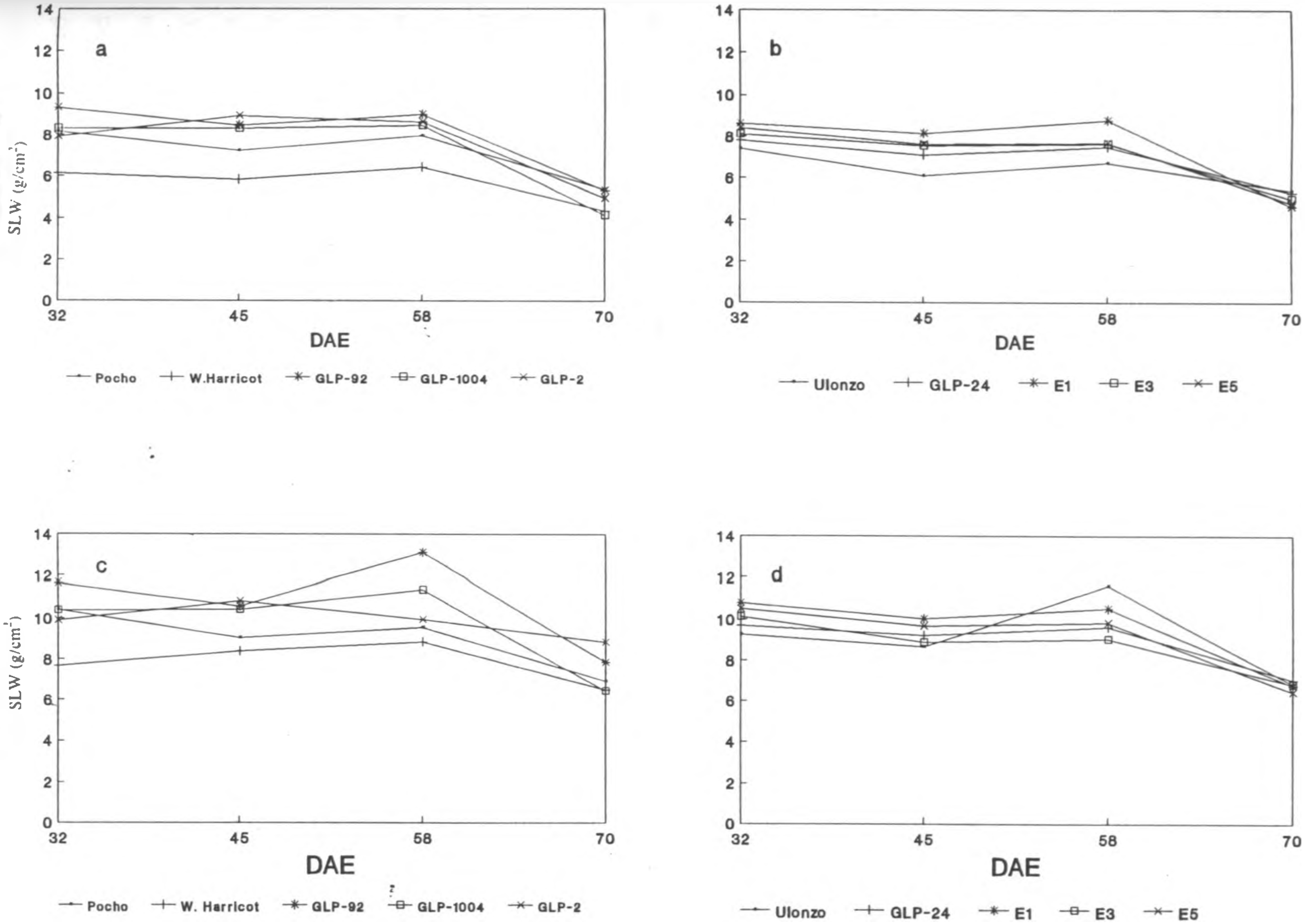


Fig. 6.0 Cultivar variation in specific leaf weight during long rains (expt. I) a&b; and short rains (expt II) c&d.

There was significant difference in cultivar grain yield. Pocho, GLP-24 and E-3 were the cultivars with higher yields in experiment 1 (Appendix 11a), while GLP-2 and Ulonzo had lower grain yields. In experiment 11, E-1, E-5 and Pocho were higher yielding cultivars; with GLP-2 and Ulonzo still remaining poorer performers (Appendix 11b). Pocho, E-1, E-3 and E-5 had higher 100 seed weights in experiment 1; while Ulonzo and White Haricot had lower 100 seed weights. In experiment 11, E-1, E-3 and E-5 remained the cultivars with higher 100 seed weights just as in experiment 1. Mean pod numbers per plant was however greater in White Haricot, Ulonzo, GLP-92 and GLP-24.

4.8 Relationships between different Plant Parameters

At 32 DAE (Appendix 12), flowering stage for most cultivars, there was a weak positive correlation between leaf nitrogen and photosynthesis, leaf area index and specific leaf weights. The relationship between LAI and specific leaf weight was however negative. These relationships were not statistically significant. At 45 DAE (Appendix 13) leaf nitrogen content had a strong negative correlation with specific leaf weight. The correlation was however not statistically significant. The relationship between specific leaf weights and rates of photosynthesis was a significant negative correlation, while there was a highly significant positive correlation between leaf nitrogen and leaf net photosynthetic rates at this period. The relationship between LAI and other traits were not statistically significant. At 58 DAE (Appendix 14), pod biomass was negatively correlated with LAI. It was also negatively correlated with leaf nitrogen content. The correlation was not statistically significant though. Non-structural carbohydrates had significant negative correlations with specific leaf weights and leaf nitrogen contents. There was a weak negative correlation between stem biomass and pod dry weight at this phase of growth. This was not statistically significant. There was no significant correlation between yield and non-structural carbohydrates at 70 DAE (peak point). Both pod number and pod weight had a weak negative relationship with stem non-structural carbohydrates. Stem biomass was positively correlated with pod number but negatively correlated with pod weights. The relationship between stem biomass and pod weights was insignificant. Rate of decline of stem biomass happened to be negatively correlated with pod dry weight accumulation rates between 58 and 80 DAE (Appendix 17a and b). The relationship was however statistically insignificant. Rate of decline in stem dry weight was negatively correlated to yield while rate of pod biomass accumulation was positively correlated to yield (Appendix 17a). At harvest time (Appendix 16) stem biomass was highly positively correlated with non-structural carbohydrates and non-structural carbohydrates contents had a weak negative correlation with yield.

CHAPTER 5
DISCUSSION

There was cultivar differences in leaf net photosynthetic rates in both experiments (fig 1.0 and Appendix 5a and 5b). This varietal differences in net photosynthetic rates has been shown in beans (Izhar and Wallace, 1970; Kueneman *et al*; 1979; Ouma 1988; Ogutu 1991) cotton (Ackerson and Herbert 1981) and groundnuts (Hiremath *et al*; 1986). These differences in photosynthetic rates between cultivars could be due to a number of factors. Peet *et al* (1977) reported that the differences could possibly be due to efficiency of enzyme functions or biomass partitioning. Similarly Upmeyer and Koller (1973) reported that high leaf starch level impaired further synthesis of starch, leading to an increase in soluble carbohydrate levels which in turn resulted in reduction in net photosynthetic rates.

In experiment 11, (fig 1.0) GLP-2 and Ulonzo had lower leaf net photosynthetic rates at 45 DAE. It was also observed that these cultivars had lower grain yields. GLP-2 also exhibited higher stem starch and soluble sugars contents. Stem is one of the sinks of current assimilates and it is thought that failure of the sinks to accommodate extra assimilates may cause feedback inhibition, resulting in reduced photosynthesis as pointed out by Upmeyer and Koller (1973). Mondal *et al* (1978) reported that if sinks were unable to utilize the increased production there would be a steady build up of sugars in the system, causing a feedback inhibition resulting in reduced photosynthesis. So, for leaf photosynthesis to be at maximum potential rates, sinks must be able to utilize all the assimilates produced. Under these circumstances partitioning would be controlled by sink strength, that is, sink availability and the rate at which available sinks can utilise assimilates (Gifford and Evans, 1981).

GLP-24 had a higher diurnal leaf net photosynthetic rate, followed by GLP-92 at 32 DAE, while GLP-2 had consistently lower net photosynthetic rate and Ulonzo the least. GLP-92, despite having higher leaf net photosynthetic rate at 32 DAE, was among the lower yielding cultivars. This could be due to enzyme functions or partitioning of biomass as indicated by Peet *et al* (1977). Evans (1975) found no correlation between single leaf net photosynthetic rate and total dry matter in several plants. This could be explained by observations that a negative correlation generally exists between leaf net photosynthesis and leaf area per leaf (Bhagsari and Brown, 1966; Allen *et al*; 1987). Comparisons of carbon dioxide exchange rates for genotypes having different leaf sizes may therefore not present the inherent difference in photosynthetic potential. Peet *et al* (1977), however concluded that the relationship between photosynthesis and yield appears to be a function of developmental stage. This could offer an explanation to the behaviour in performance of leaf net photosynthetic rates at 32 and 45 DAE; and also variation in ranking in performance in this parameter during these periods (fig 1.0). Peet *et al*, (1977) found that the highest photosynthetic rate during pod set was positively correlated with biological seed yield. This agreed with the results of experiment 11 (Appendix 13) where a significant positive correlation between yield at harvest and single leaf net photosynthetic rate (Corr. Coeff. of 0.516) was observed. This period represented pod set phase for most cultivars.

Cultivars also showed significant differences in leaf nitrogen contents (Appendix 6a and 6b; also fig. 2.0). Similar observations had earlier been reported by Ogutu (1991). There was a general decline in leaf nitrogen contents from 32 DAE to 58 DAE in most cultivars in experiment 1 followed by a general increase. However, some cultivars like GLP-2 did not realize any increase at any point of growth phase, but declined progressively till maturity. Pocho on the other hand, had two maxima, one at 45 DAE; and the other at 70 DAE (around maturity), after which there was further decline. This loss could be due to remobilization of N from the leaves to the seeds. In fact many workers examining the uptake and redistribution of N by soybeans have shown that the loss of N from vegetative tissues coincides with accumulation of N in the seed (Henderson and Kamparath 1970; Hannay and Weber 1971 b; Derman *et al* 1978) and with plant senscence (Derman *et al* 1978, Sesay and Shible 1980). It is not therefore imperative to speculate that GLP-2's and Ulonzo's consistently lower leaf N could be attributed to redistribution with consequent degradation of proteins which finally led to lower photosynthetic rate as observed in experiment 1. This in part, could explain their lower yields compared with other cultivars.

In experiment 11, there was a significant positive correlation between leaf N and yield at 45 DAE (pod set). At this point there was also a significant positive correlation between yield and net photosynthetic rate. It was observed that GLP-2 and Ulonzo which had lower leaf N also were lower yielding cultivars. This relationship between N and leaf net photosynthetic rate seems to provide a link between yield and leaf N content. GLP-92, E-1, E-3 and GLP-24 had higher leaf N content (Appendix 6a and 6b), while GLP-2 and Ulonzo had lower leaf N. They also happened to have lower single leaf net photosynthetic rates and lower yields compared to other cultivars. It has been reported in other plants that the varieties with high nitrogen content tend to have higher net photosynthetic rates than those with low leaf nitrogen (Herridge and Pate 1976; Servarite *et al* 1986; Tsunoda and Fukoshima 1986; Tanaka and Fujita 1979). Caemmerer and Farquhar (1981) and Ouma (1991) have reported similar observations in beans. Ribulose- bisphosphate carboxylase, the carboxylasing enzyme in C-3 plants comprises a high proportion of leaf protein (Aceveado and Andreeva 1973; Creswell *et al* 1974). It has been shown that a decline in leaf nitrogen content leads to reduction in photosynthetic rate (Wittenbach *et al*, 1986). Evans and Terashima (1987) observed that the ratio of ribulose bisphosphate carboxylase (Rubisco) to electron transport activity increased in leaves having greater nitrogen content. The observations that E-3, E-5 and E-1 had higher leaf nitrogen content, while GLP-2 and Ulonzo had lower; may therefore provide at least partial explanation to net photosynthetic rates and consequently yield variations among the cultivars. Because of its association with the carboxylation process, leaf nitrogen influences photosynthesis.

The relationship between varietal differences in photosynthesis and yield in not clearly understood. Single leaf photosynthesis has been found to be uncorrelated with growth rate and total dry matter production in a number of plants (Evans 1975). Differences in crop architecture would dictate that dry matter production rate be more related with total canopy photosynthesis canopy duration and carbon partitioning. This could possibly be the reason GLP-92 and White Haricot, despite having relatively higher leaf nitrogen content and higher leaf net photosynthetic rates had poorer grain yield. Most of the lower leaves in these varieties were shaded (high LAI) and hence their assimilate contribution to the seeds may not have been positive at the time measurements were made. Therefore canopy carbon exchange rates for these cultivars were possibly lower due to the lower bulk of older leaves that had lower N-use efficiency.

Pocho, despite having lower leaf N and lower leaf net photosynthetic rate, was among the highest yielding cultivars. Its superiority in yield could not therefore be explained by leaf N and net photosynthetic rates. It is possible that other factors other than the preceding ones may be behind cultivar difference in yield. Apart from leaf architecture, Pocho's high yield may be attributed to efficiency of assimilate partitioning. Carbon and nitrogen metabolism efficiency in this cultivar may be another phenomenon. In fact Pocho and GLP-2, the cultivars which showed lower leaf N contents also registered very high non-structural carbohydrate contents of the stems. However, due to sink limitation in GLP-2, its yield was significantly lower.

There was negative correlation between specific leaf weight (SLW) and leaf N and between SLW and leaf net photosynthetic rates (Appendices 12, 13, 14 and 15). McClendon (1962) argued that the species which achieved the highest net CO_2 exchange rate per unit leaf area (CER) from minimum leaf material was most efficient. The results of experiment 11 showed that higher yielding cultivars like E-1 and Pocho recorded lower specific leaf weights as compared with GLP-92 for instance. The SLW values of season 1, (a period dominated by cloudy weather conditions) were lower than those of experiment 2 (unfavourable period). In limiting situations such as low radiations, where full light capture would be achieved by fewer layers of mesophyll, the substrate could arguably be used more efficiently to generate a larger area of thin leaves rather than a smaller area of thick leaves (Khan and Tsunoda, 1970).

It is a general observation that during the vegetative growth phase, most plants do accumulate sugars which are utilized later during the formation of flower buds and pod filling (Jan and Reddy 1981). This was observed between 32 DAE and 45 DAE (flowering and pod filling phases respectively) of both experiments where there was a general decline in stem soluble sugars and starch contents (fig 3.1 and 3.2). It has also been suggested that in beans, the photosynthates from the leaves are transported to the stem and roots and later mobilized for pod filling (Waters *et al* 1980; D'souza and Coulson 1988). High stem soluble sugars and starch contents during pod growth in GLP2 could imply low remobilization capacity with only 7.1% reduction between 32 and 45 DAE (Appendix &a, b, c, and d). Pocho, another superior cultivar in stem soluble sugars but higher yielding, had a reduction of 40% in this parameter between 32 and 45 DAE. In soybeans, the level of soluble sugars has been reported to decline during reproductive phase (Egli *et al*; 1980). Whether this remobilization phenomenon can account for varietal differences in yield of the crops has not been fully evaluated. Adams *et al*. (1978) reported that the bean cultivars, which retained a lot of carbohydrates in stems and roots at harvest, yielded less. GLP-2, the lowest yielding cultivar had the highest stem soluble sugars and starch contents. Pocho, E-5 and GLP-24 retained higher non-structural carbohydrate contents in their stems at harvest, but were however among higher yielding cultivars. Pocho, E-1 and E-5 had also higher stem soluble sugars at 32 DAE, but their percentage reduction in this parameter at 32 DAE and 45 DAE (flowering and pod filling phases) were comparatively higher than other cultivars (fig 3.1 and 3.2).

Isquirdo and Hosfield (1987) emphasized importance of remobilization trait and reported that non-structural carbohydrates and nitrogen accumulation in early stages as best strategy for breeding high yielding bean cultivars. This may offer an explanation of high seed yield in Pocho, E-1 and E-5 which had high contents of soluble sugars and starch in stems at 32 DAE, despite retaining higher contents at harvest. It is not high content *per se* that matters, but ability to remobilize these higher contents at early stages of reproductive phase. Little information is available in the distribution of assimilates produced by the leaves and pods of *Phaseolus vulgaris* during reproductive phase. Work on beans by Lucas *et al.* (1976) on beans showed that if sink capacity of the pod is inadequate at anthesis, then part of the assimilate from the leaves may be translocated to the stem. GLP2 had the lowest number of pods/plant (Appendix 11a & b) implying a sink limitation. Diversion of assimilates to the stem as a result of sink capacity (flower removal) have been reported in the other varieties of *P. vulgaris* (Wein *et al.*, 1973). This might explain the differences in stem non-structural carbohydrate contents between the two seasons. During the second season (unfavourable growth period) crops showed a relatively higher stem non-structural carbohydrates as compared to experiment 1 (long rains). This could be due to poor seed development as a result of higher proportion of flower abortion and consequently empty pods.

Based upon an extensive quantitative analysis of plant growth, Watson (1952) attributed productivity differences in leaf area index and identified early canopy closure as a crucial determinant in initial crop growth rate in well nourished stand. Results of experiment 1 (Appendix 8a and fig 4a) showed that E-5, GLP-1004, Pocho and GLP-2 were superior in this parameter at 32 DAE. In experiment 11, E-5, Pocho and GLP-24 out-performed the other cultivars in LAI during initial stages of growth (32 DAE). These cultivars also happened to be higher yielding. There was also a significant positive correlation between yield and LAI at 32 DAE but a weak negative relationship at 45 DAE. The same was observed at 58 DAE (Appendices 12, 13 and 14). The positive correlation between LAI and yield during initial growth stages that leaves capture more incident radiant energy and also make efficient use of other environmental resources consequently have higher initial crop growth rate (Watson, 1952). On the other hand, a negative correlation later in the season implies that the bulk of the aged leaves, especially at the bottom of the canopy synthesize very little assimilates just for their own maintenance, and most probably tend to be net importers. These same leaves tend to reallocate their nitrogen to the young expanding leaves and hence their N use efficiency becomes very low.

The plant gets rid off these (abscission) negative correlation between LAI and specific leaf weight at later stages of development (Appendices 12, 13, 14 and 15) might dictate production of plants which expand thin leaves early in the season and then thick leaves after canopy intercepts all light (Motto *et al.*, 1979). This could explain high yields in E-1 and Pocho. On the contrary, White Haricot had high LAI and low SLW during most periods of growth, and probably could not intercept a lot of light, especially during the cloudy weather conditions of experiment 1. It is true that leaves are the photosynthetic surfaces and generation of this area is important in crop productivity. However, although photosynthesis is one of the primary process of plant growth, Evans (1983) pointed out that there is little evidence of a correlation between LAI and CER and increased yield. This was observed in the results of this study (Appendix 12).

Sharaiwa and Sinclair (1993) demonstrated a non-uniform specific leaf nitrogen (SLN) variation with depth in soybean canopies. All their experiments showed the highest SLN at the top of the canopy and the SLN of the leaves decreased with increased cumulative LAI from the top of the canopy. This may explain the reason as to why White Haricot and GLP-92, despite having high LAI could not therefore take this advantage to produce high grain yields. This may be due to poor N use efficiency of the leaves lower in the canopy.

Leaf number and leaf area development can help to elucidate plant dry matter production (Farah, 1981); El-Sharkawy *et al.*, 1965). Since the development of leaf area is a function of leaf numbers and leaf size, these factors may change differently depending on genetic materials and the environment in which the plants grow (Quisenbery *et al.*, 1976; Quisenbery *et al.*, 1982). This observation offers an explanation to the differences in leaf biomass observed between the two growth seasons (season 1 and season 2 fig 5.2). The major contributor to plant dry matter increase after anthesis was pods and seeds. This was also associated with decrease in stem dry weights in some cultivars in both experiments (fig 5.3). The decline in stem dry matter corresponded with reproductive phase (pod filling) of growth hence re-allocation of stored assimilates to the developing pods and seeds (Boyer, 1976). Similar observations were noted by Ouma (1988) and Ogutu (1991). It appears that beans accumulate some non-structural assimilates in the stem which are later remobilized for pod development. Laing *et al* (1983) reported a decline in carbohydrate contents of the main stem as grain development proceeded in beans. Stem dry weights were much lower in experiment 11 compared to experiment 1 (favourable period), but their reductions in this character after peak period were more pronounced (fig 5.3). Despite higher stem dry weights during experiment 1, there was no appreciable differences in 100-seed weights between the two experiments. Partition coefficients (stem wt: TDM) did not change between the two seasons and non-structural CHO was higher in season II than one!

It was also noted that high yielding cultivars had high harvest indices (Appendix 11a and 11b). There was a positive correlation between yield and harvest index at 45 DAE in experiment 11, while in experiment 1, it was not significant. Under low levels of productivity, there may be a positive relationship between harvest index and biological seed yield (Mc Vetty and Evans, 1980). Under high levels of productivity, this may be even reversed. This may explain the positive relationship between this parameter and yield observed in experiment 11, while none was noted in experiment 1 (favourable growth period).

CONCLUSION

The study revealed existence of cultivar differences in the parameters investigated. Lower yielding cultivars like Ulonzo and GLP-2 exhibited lower leaf net photosynthetic rates. GLP-24 and GLP-92 had highest leaf net photosynthetic rates. Pocho, E-1 and E-5; though high yielding cultivars, did not exhibit the highest mean leaf net photosynthetic rates. Leaf net photosynthetic rate, could not therefore offer explanation to cultivar differences in yields. It is likely that higher yielding cultivars were more efficient in partitioning of the assimilates to the grain as indicated by high harvest indices (HI) in these cultivars, or the variation may have resulted from contribution of other photosynthetic structures other than leaves (e.g. pods) that might have been more significant in the high yielding cultivars.

There was a significant positive correlation between leaf nitrogen and net photosynthetic rate at 45 DAE. Cultivars with higher mean leaf net photosynthetic rates also had higher leaf nitrogen. Cultivars with higher leaf nitrogen contents were however not the most superior ones in terms of yields. Remobilization of leaf N did not explain cultivar yield differences observed in the study. This may be due to the fact that N accumulated in the leaf tissue may served to buffer photosynthesis against effects of N remobilization to developing seeds. Therefore the cultivars with more remobilization capacity of leaf N reduced leaf longevity and consequently photosynthesis at later stages of growth. N-use efficiency must have definitely dropped faster in the cultivars with higher remobilization capacities.

There was an observable cultivar differences in stem non-structural carbohydrates. It was evident that even high yielding cultivars retained higher amounts of these carbohydrates at harvest time. The cultivars with higher stem non-structural carbohydrate contents at early stages of growth, but less of these after onset of pod filling were found to be superior in grain yield. There were also cultivar differences in LAI during growth periods. The variations in LAI throughout the growing periods and between the two seasons proved that it could not offer any basis to yield differences. Its correlations with yield also varied greatly with stages of growth. SLW, though varied with seasons, was more stable and seemed to be a suitable index to consider as regards yield differences among cultivars.

RECOMMENDATIONS

1. (a) Further research should be done to confirm whether remobilization of leaf N is inherent or environmentally induced. Soil nitrogen levels should be varied and the relationship with leaf N and also remobilization rates during course of growth examined. If the leaf remobilization is a result of environment, then a certain rate would reveal no remobilization.
   (b) Investigate rate of change in soil N planted to different cultivars and the subsequent leaf N and leaf nitrogen remobilization rates.
   (c) It would be important to find out if the amount of soil N affects carbohydrate metabolism differently among cultivars. Different forms of nitrogen should be applied (NO^-_3 and NH_4^+).
2. To test for remobilization of non-structural carbohydrates, there should be an imposed water stress to the crops; especially immediately after pod set. This should involve a number of watering regimes and find out if the most stressed treatments remobilized more; or if there is an accompanied drop in yield (mainly 100-seed weight).
3. Investigation of pod photosynthesis should be determined and compared with leaf net photosynthetic rates of different cultivars. If pod photosynthesis

proves significant, it is likely that it will be negatively correlated to leaf net photosynthesis.

REFERENCES

Ackerson, R.C. and R.R. Herbert (1981). Osmoregulation in relation to water stress. Plant physiol. 67: 484-488.

Acland J.D. (1971). East African Crops, FAO (1971) Longmans. London pp. 24-25.

Adams, M.W; J.Y. Wiersman and J. Salazaar (1978). Difference in starch accumulation among dry bean cultivars. Crop Sci. 18: 155-157.

Allen, S.G; F.S. Nakayama; D.A. Dierig and B.A. Basmick (1987). Plant water relations, photosynthesis and rubber content of young gayule plant during water stress. Agron. J. 79: 1030-1035.

Allen, L.H. Jr; J.C.V. Vu, R.R. Vale, K.J. Boote and P.H. Jones (1988). Non-strutural carbohydrates and nitrogen of soybean grown under carbon diox enrichment. Crop Sci. 28:84-94.

Anonymous (1985a). Development plan for the period 1984-1988. Fifth development plant. Govt. printers Nairobi.

Anon (1988) Ministry of Agriculture. Director's Annual report. Government Printers Nairobi.

Anon (1989) Ministry of Agriculture. Director's Annual report. Government Printers Nairobi.

Barnes, D.K; Pearce, R.B., Carlson, G.E., Hart, R.H; Hanson, C.H. 1969. Specific leaf weight defferences in alfalfa associated with variety and plant age.

Below, F.E; L.E. Christensen, A.J. Deed, and R.H. Hageman (1981). Availability of reduced N and carboxydrate for ear development of maize. Plant physiol. 68:1186-1190.

Bhagsari, A.S and R.H. Brown (1986). Leaf photosynthesis and its correlations with leaf area. Crop Sci. 26:127-132.

Blacklow, W.M; B. Darbyshire, and P. Pheloung (1984) Fructans polymerised and depolymerised in the internodes of winter wheat as grain filling progressed. Plant. Sci. Lett. 36: 213-218.

Brinkman, M.A and Frey, K.J (1978). Flag leaf physiology analysis of oat isolines that differ in grain yield from their recurrent parents. Crop Sci. 18: 67-73.

Buttery, R.R., Buzzell, R.I (1977). The relationship between chlorophyll content and rate of photosynthesis in soybean Can. J. Pl. Sci. 57: 1-5.

Caemmerer S. Von and G. D. Farguhar (1981). Some relationships between the bochemistry of photosynthesis and the gas exchange of leaves. Planta. 153: 376-387.

Charles - Edwards, D.A. (1978). An analysis of the photosynthesis and productivity of vegetative crops in UK. Ann. Bot. 42: 717-32. In: Ann. Rev of plant physiol. 1981; 32: 485-509

CIAT (1977) Bean program annual report. Centro internacional de agricultura Tropical, Cali Colombia.

CIAT (1987). Bean program annual report. Centro internacional de agricultura, Tropical, Cali, Colombia.

CIAT (1988). Bean program annual report. Centro internacional de agricultura tropical, cali, Colombia.

CIAT 1989 Bean program annual report. Centro international de agricultura tropical, cali, Colombia.

Davidson, D.J., and P.M. Chevalier (1992) storage and remobilization of water-soluble carbohydrates in stems of spring wheat. Crop Sci. 32: 186-190.

Derman, B.D; Rupp, and L.D. Nooden' (1978) Mineral distribution in relation to fruit development and monocarpic senescence in Anoka soybeans. Amr. J.Bot. 65: 205-213.

Dornhorff, G.M; Shibbles, R.M. (1976). Leaf morphology and anatomy in relation to carbon dioxide exchange rate of soybean leaves. Crop Sci. 16: 377-81.

D'souza, H.A. and C.L. Coulson (1988). Dry matter production and partitioning in two cultivars of *Phaseolus vulgaris L.* under differnt watering regimes. Trop Agric. Tricidad 65 (2) 179-181.

Egli D.B, E. leggett, and W.G. Duncan 1978. Influence of N stress on leaf senescence and N redistribution in soybeans. Agron. J. 70: 43-47.

Egli, D.B., J.E. Leggett and A.Cheniae (1980)., Carbohydrate levels in soybean leaves during reproductive growth. Crop Sci. 20: 468-473.

Evans A. (1976). Beans (phaseolus spp). In evolution of crop plants (Ed. N.W. Simnond, Longmans, London).

Evans, J.R. and I Tereshima. (1987). Effects of nitrogen nutrition on electron transport components and photosynthesis in Spinach. Aust. J. Plant. physiol. 14: 59-68.

Evans, L.T. 1975. The physiological basis of crop yield. P. 327-355 in L.T. Evans (ed) crop physiology cambridge Univ. press, carbridge.

Evans, L.T. 1983. Raising the yield potential by selection or design. Pages 371 - 389 in T. Kosuge, C.P. Maredith and A. Hollaender, eds. Genetic Engineering of Plants; an agricultural perspective; Plenum Press, New York and London.

FAO (1979) FAO production year book. Vl 33 p 120 FAO Rome 1980.

Flinn, A.M. and J.S. Pate (1970). A quantitative study of carbon transfer from pod and subtending leaf to the ripening seeds of field pea (*pisum arvense*

L) Journal of expt. Bot. 21: 71-82.

Field, C. (1983). Allocating leaf nitrogen for the maximization of carbon gain: Leaf age as a control on the allocation programm. Oecologia 56:341-347.

Fiez T.E; O.S. Norberg, and G.D. Jullif (1991) Dry matter production and carbohydrate accumulation in three meadowfoam lines. Crop Sci. 31: 1008-1014.

Furguson, H. Estlick, R.F. Aase, J.K. (1973). Canopy temperatures of barley as influenced by morphological characteristics, Agron. J. 65: 425-428.

Gifford, R.M. and L.T. Evans (1981). Photosynthesis, carbon partitioning and yield. Ann. Rev. Pl. physiol. 32: 485-509.

Hanson, W.D, R.E. Grier (1973) photosynthesis, carbon partitioning and yield. Ann. Rev. Pl. Physiol. 32: 485-509.

Hanway J.J, & C.R. Weber (1971) N, percentages in soybean plant parts. Agron. J. 63: 286-290.

Hart F.L. and H.J. Fisher. (1971) Modern Food Analysis. Springer Verlaf, Berlin, Heidelberg, N.Y.

Henderson, J.B. and E.J. Kamprath (1970) Nutrient and dry matter accumulation by soybeans. North carolina Agric. Exp. Stn. Tech. Bull 197.

Herridge D.F. and J.S. Pate (1977). Utilization of net photosynthesis for nitrogen fixation production in annual legumes. Plant physiol. 60: 759-764.

Hirose, T; and M.J.A. Weger 1987. Maximising daily canopy photosynthesis with respect to the leaf nitrogen allocation pattern in the canopy. Oecologia 72: 520-526.

Hiremath, S.M. Farnadhan, A.F. Habib; Y.C. Ranehal (1986). Varietal dfferences in leaf photsynthetic rate and its relation with certain leaf characters and yield in groundnuts (*Arclis hyprogea L.)* Crop physiol. bst. (1986). Vol. 12. No.8: 326.

Hutchinson, J. (1964). The genera of flowering plants. Vol. 1 Oxford University Press.

Hunter, R.B. (1977). Growing corn and Sorghum in short season areas P. 58-71 in Proc. Thirty-second annu. corn and sorghum Res. conf. Ann. seed Trade Assoc. Washington D.c.

Izhar, S and Wallace, D.H. (1967). Studies of physiological basis for yield difference. II Genetic variation in photosynthjetic efficiency of *phaseolus vulgaris L.* crop Sci. 7: 457-460.

Isquirdo J.A. and G.L. Hosfield (1987). Flower, pod and Leaf abscission of dry beans (*P. vulgaris L.)* Agrociencia 3 (2): 105-115.

Jain T.C. and G.R. Reddy (1981). performance of different crops with residue moisture in vertisols. Indian J. Agric. Sci. 51: 181-184.

Jeppson, R.G. R.R. Hohnson, and H.H. Hadley (1978). Variation in mobilization of plant nitrogen to the grain in nodulating and non-nodulating soybean genotypes crop Sci. 18: 1058-1062.

Judel, G.K. and K. Mengel (1982). Effect of shading on non-structural carbohydrates and their turnover in culms and leaves during the grain filling period of spring wheat. Crop Sci. 22: 958-962.

Kallis, A; Tooming, H (1974). Estimation of the influence of leaf photosynthetic parameters, specific leaf weight and growth functions on yield. *Photosynthetica* 8: 91-103.

Kaplan L; Lynch T.C. and Smith C.E. (1973). Early cultivated beans (*phaseolus vulgaris)* from an intermontane peruvian valley; Sci. 175: 76-77.

Kimani, P.M., A.W. Mwangombe, J.W. Kimenju and E.N. Njambere, (1994). Performance of bean lime tested for Multiplerestrace across environment in Kenya. A Paper presented at plant Breeders Workshop in Kampala, Uganda.

Kriedemann P.E. (1986). Stomatal and photosynthetic limitations to leaf growth. Aust. J. Pl. physiol. 13: 15-31.

Kueneman E.A; D.H. Wallace, P.M. Ludford (1979). Phytosynthetic measurements of field grown dry beans and their relation to selection for yield. J. Amer, Soc. Hort. Sci. 104(4) 480-482.

Lucas, E.O. and Milbourn, G.M. (1976). Effect of density on the growth of two *phaseolus vulgaris* varieties in England. J. agric. Sci. Camb. 87: 89-99.

Lugg, D.G. and Sinclair, T.R. (1979). A survey of soybean cultivars for variability in specific leaf weight. Crop Sci. 19: 887-892.

Lynch, J and J.W. White (1992). Shoot nitrogen dynamics in tropical common bean. Crop Sci. 32: 392-397.

McCashin B.G. Canvin D.T. (1979). Photosynthetic and photorespiratory characteristics of mutant *Hordeum vulgare L.* plant physiol. 64: 354-360.

McCree, K.J. (1986) Whole plant carbon balance during osmotic adjustment to drought and salinity stress. Aust.J. Pl. physiol. 13: 33-43.

Mibourn, G.M; and R.C. Hardwick (1968). The growth of vining peas. I. The effect of time of sowing. J. Agric. Sci. Cambridge 70: 393-402.

Michieka D.O. (1977). Soils of the valley bottom of Kabete Veterinary Laboratories, Nairobi site Evaluation report. Kenya soil survey.

Miranda C.S. (1974). Evolutionary genetics of wild and cultivated phaseolus vulgaris and P coccineus Ph.D. Thesis, University of cambrdidge England. In physiology of tropical field crops (1984). (Ed P.R Goldsworthy and N.M Fisher; John Wiley and sons Ltd).

Mondal, M.H. W.A. Brun and M.L. Brenner 1978. Plant physiol. 61; 394-397.

Motto, M; Soress, G.P; Salamini, F (1979). GRowth analysis in a reduced leaf mutant of common bean (*Phaseolus vulgaris*). *Euphytica* 28: 593-600.

Neales, J.F; and L.D. Incoll (1968). The control of leaf photosynthetic rate by level of assimilate concentration in the leaf: A review of the hypothesis. Bot. Rev. 34: 107-125.

Ogola, J.B.O (1991). Varietal differences in photosynthesis, growth and yield responses of beans (*Phaseolus vulgaris L*) MSc thesis, University of Nairobi.

Ogutu (1991). Physiological baris of yield differences between two bean (*phaseolus vulgaris L.)* varieites. M.Sc thesis University of Nairobi.

Ouma J.P. (1988) The effect of soil moisture deficit on photosynthesis and leaf water potential of field grown beans (*P. vulgaris L.)* M.Sc. thesis, University of Nairobi.

Peet, M.M.; A. Bravo, D.H. Wallace, J.L. Ozbun (1977) photosynthesis, stomatal resistance and enzyme activities in relation to yield of field grown dry bean varieties. Crop Sci. 17: 287-293.

Pons, T L; F. Shieving, T. Hirose, and M.J.A. Werger 1989. Optimization of leaf nitrogen allocation for canopy photsyntheis in Lysimachia vulgaris P.

175-186. In H. Lambers et al (ed) causes and consequences of variation in growth rate and productivity of higher plants. plants. SPB Academic publishing, the Hague

Rawson, H.M.; and L.T. Evans (1971) The contribution of stem reserves to grain development in a range of wheat and oats grown in semi arid environment. Crop Sci. 22: 321-331.

Randall, D.D; Nelson, C.J; Asay, K.H. (1977), Ribulose bisphosphate carboxylase. Altered genetic expression in tall fescue. Plant physiol. 59: 8-41. In Annual review of plant physiol. 1981. 32:349-383.

Rawson, H.M. and Turner N.C. (1982). Recovery from water stress in five sunflower (*Herlianthis annus L.*). cultivars. I. Effects of timing of water application on leaf area and seed production. Aust. J. pl. physiol. 9: 437-448.

Reed, A.J. G.W, Singletary, J.R. Schussler, D.R. Williamson and A.L. Christy. (1988). Shading effects on dry matter and nitrogen partitioning, Kernel number and yield of maize crop Sci. 28: 819-825.

Runkulatile H.H.E, J.O. Nyabundi, P.O. Ayiecho (1993). Relationship between leaf water status and varietal adaptation of beans to'wet and dry agricultural zones of Kenya. E.Afri. agric, For. J. 58(3) 95-104.

Setter, T.L., C.R. McDonald and F.B. Loper (1984). photosynthate partitioning in pigeon pea in response of defoliation and shading. Crop Sci. 24(2): 221-224.

Sesay, A. and R. Shibles. (1980). Mineral deplotion and leaf senscence in soybean as influenced by foliar nutrient application during seed filling. Ann. Bot 45: 47-55.

Shibairo, S.I., J.O. Nyabundi (1993). Effect of deflowering and defoliation during reproductive phase on flower and pod abscission and yield of pigeon peas. Discovery and invovation 5(4): 377-380.

Sharaiwa T; and T.R. Sinclair (1993). Distribution of nitrogen among leaves in soybean canopies. Crop Sci. 33: 804-808.

Sinclair, R.R. and T. Horrie (1989). Leaf nitrogen photosynthesis and crop radiation use efficiency. A review crop Sci. 29 (1) 90 - 98.

Sinclair, T.R. and C.T. de Wit 1975. Comparative analysis of photsynthesis and nitrogen requirements on the production of seeds by various crops. Science 189: 565-567.

Sinclair, T.R. and C.T. de Wit 1976. Analysis of the carbon and nitorgen limitations to soybean yield Agron. J. 68: 319-324.

Appendix 7c: Cultivar stem starch content during short rains (experiment II)

Stem starch content (% dry wt)

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	3.70^{a}	2.02^{c}	3.59^{b}	5.88^{b}	4.81^{b}	4.00
White Haricot	2.26^{f}	1.60^{e}	3.87^{a}	3.96^{e}	3.33^{e}	3.00
GLP-92	2.04^{g}	1.35^{f}	2.16^{c}	2.64^{g}	2.50^{g}	2.14
GLP-1004	2.43^{e}	1.84^{d}	1.80^{h}	2.08^{h}	1.96^{h}	2.02
GLP-2	2.40^{ef}	2.23^{b}	3.60^{a}	6.28^{a}	5.51^{a}	4.00
Ulonzo	2.60^{d}	1.33^{f}	2.91^{e}	4.48^{d}	4.10^{d}	3.08
GLP-24	2.81^{c}	1.83^{d}	3.13^{d}	5.45^{c}	4.86^{b}	3.62
E1	2.73^{cd}	1.74^{d}	3.39^{c}	4.43^{d}	3.26^{ef}	3.11
E3	2.71^{cd}	1.58^{e}	2.26^{cd}	3.69^{f}	3.16^{f}	2.88
E5	3.06^{b}	2.52^{a}	2.71^{f}	4.59^{d}	4.25^{c}	3.43
Mean	2.64	1.80	3.04	4.35	3.77	
SE	0.31	0.03	0.03	0.03	0.03	
CV	3.47%	4.29%	3.24%	2.08%	2.08%	
	**	**	**	**	**	

**Significant different at $P<0.05$, ns not significant at $P<0.05$. Values followed by the same letter superscript are not significantly different from each other.

Appendix 7d: Cultivar stem starch content during short rains (experiment II)

Stem starch content (% dry wt)

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	3.27^{a}	1.84^{c}	3.35^{a}	6.19^{b}	5.00^{b}	3.93
White Haricot	1.87^{f}	1.38^{e}	3.15^{b}	3.18^{hi}	3.60^{e}	2.64
GLP-92	1.44^{g}	1.12^{f}	1.80^{g}	3.02^{i}	2.88^{g}	2.05
GLP-1004	1.82^{f}	1.54^{d}	2.48^{d}	3.35^{gh}	2.65^{h}	2.37
GLP-2	2.12^{e}	2.01^{b}	3.27^{ab}	6.57^{a}	5.70^{a}	3.93
Ulonzo	2.40^{c}	1.12^{f}	2.47^{d}	3.79^{f}	3.05^{f}	2.57
GLP-24	2.35^{cd}	1.43^{de}	2.76^{c}	5.29^{d}	4.39^{c}	3.24
E1	2.28^{d}	1.20^{f}	2.10^{f}	3.48^{g}	3.09^{f}	2.41
E3	2.37^{cd}	1.37^{e}	2.19^{e}	4.07^{e}	3.79^{d}	2.76
E5	2.90^{b}	2.23^{a}	2.93^{c}	5.80^{c}	5.08^{b}	3.79
Mean	2.28	1.52	2.64	4.47	3.92	
SE	0.02	0.03	0.03	0.03	0.03	
CV	2.74%	5.81%	3.83%	2.21%	1.98%	
	**	**	**	**	**	

**Significant different at $P<0.05$, ns not significant at $P<0.05$. Values followed by the same letter superscript are not significantly different from each other.

Wareing, P.F. , N.M. Khalifa and J.K. Treharne (1968).Rate limiting process in photosythesis at saturating light intensities . Nature. 220: 453 - 457.

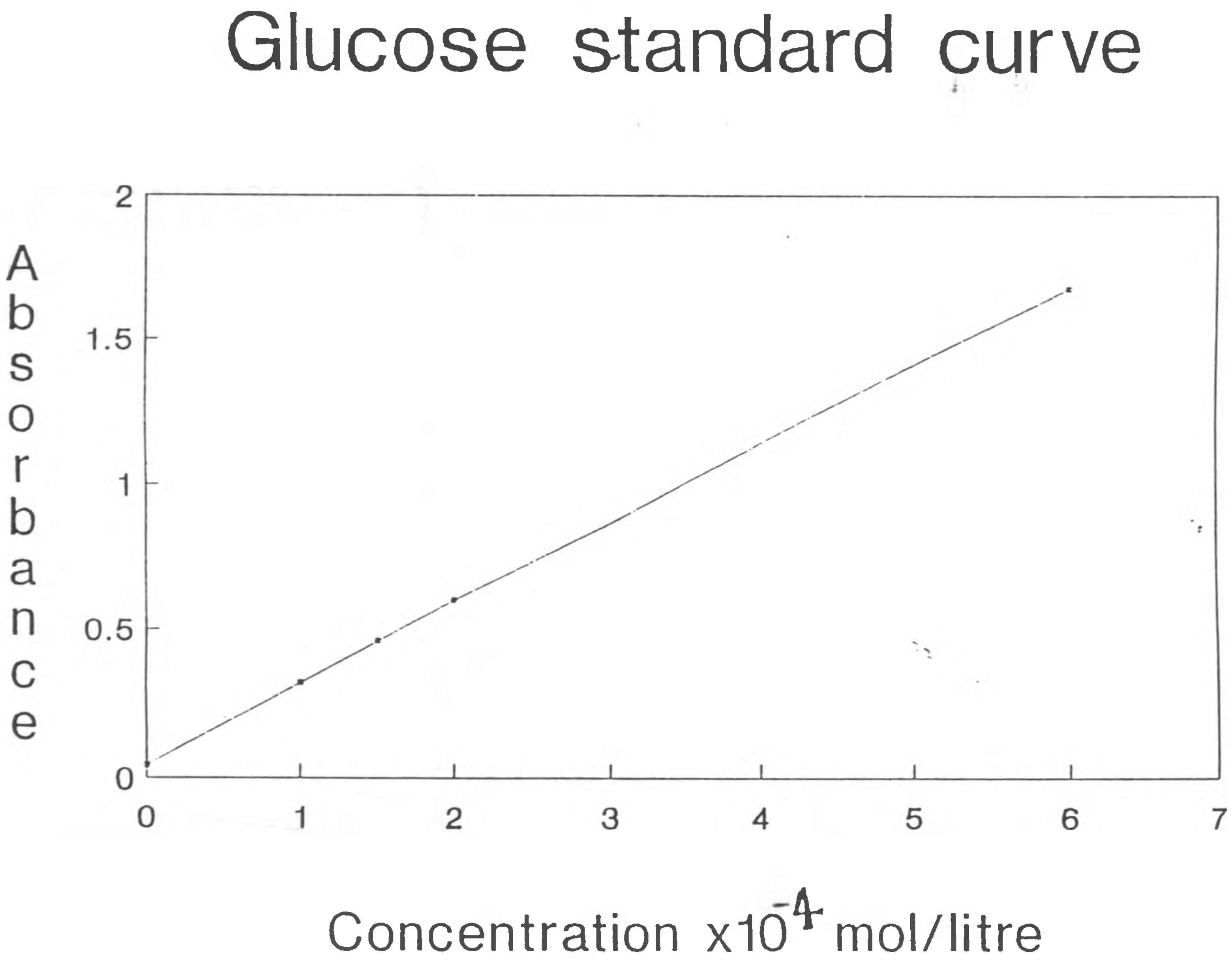
Waters. L. Jr. P.J. Breen, P.H. Graham and H.J. Mack (1980). Translocation of C-photosynthate carbohydrate content and nitrogen fixation in *phaseolus vulgaris L.* during reproductive development. J. Amer. Soc. Hort. Sci. 105 (3) 424-427.

Watson, D.J. (1952). The physiological basis for variation in yield. Adv. Agron. 4, 101-145.

Wein, H.C. Standsted, R.F. and Wallace, D.H. (1973. The influence of phaseolus vulgaris L.J. Ameri. Soc. Hort. Sci. 98: 45-49.

Wittenbach, V.A. R.C. Ackerson, R.T. Giagqinta and R.R. Herbert. (1980). Changes in photosynthesis, ribulose bisphosphate carboxylase, proteolytic activity, and ultrastructure of soybean leaves during senscence. Crop Sci. 20: 225 - 231.

APPENDIX 1. SPECTROPHOTOMETRIC READINGS OF GLUCOSE AT 630 nm



Appendix 2 Weather data during experimental period

Year	Month	Mean Rainfall	Temperature (°C)	
			Max	Min
1994	March	56.3	35.9	14.4
1994	April	237.2	23.8	14.6
1994	May	92.2	22.2	13.8
1994	June	44.4	21.7	11.9
1994	July	18.8	20.5	11.8
1994	August	33.9	20.5	12.2
1994	September	1.3	23.1	12.1
1994	October	87.8	24.1	13.8
1994	November	301.4	22.3	14.0
1994	December	64.7	23.3	13.3
1995	January	8.6	24.0	13.2
1995	February	139.7	23.8	13.3

Appendix 3 Some soil chemical properties experimental site (season I)

Soil depth	Soil pH	H_2O	%N	%C	K	Na	Ca	Mg	P	C:N
0-15	5.80	6.5	0.30	3.01	1.04	0.52	6.00	2.14	20.5	10.05
15-30	5.78	6.4	0.25	2.51	0.66	0.44	5.80	2.01	14.1	10.04
30-60	5.92	6.5	0.18	1.75	0.53	0.44	4.50	2.11	20.8	9.72

Appendix 4 Some soil chemical properties experimental site (season II)

Soil depth	Soil pH	H_2O	%N	%C	K	Na	Ca	Mg	P	C:N
0-15	5.58	6.2	0.31	2.98	1.04	0.79	10.0	2.80	20.4	9.60
15-30	5.48	6.2	0.24	2.51	0.77	0.52	7.81	2.43	19.8	10.56
30-60	5.45	6.2	0.20	2.01	0.65	0.41	5.54	2.54	20.5	10.05

Appendix 5a: **Cultivar differences in leaf net photosynthetic rate during second season (Experiment II) 32 at DAE**

Leaf net photosynthetic rate in μ mol m^{-2} s^{-1}

	8.00Hr	10.00hr	12.00hr	14.00hr	16.00hr	Mean
Pocho	14.76^{h}	18.46^{h}	23.76^{h}	19.96^{g}	18.09^{g}	19.01
White Haricot	20.75^{d}	24.90^{e}	27.16^{f}	25.60^{d}	23.28^{d}	23.34
GLP-92	25.05^{b}	28.81^{b}	33.53^{a}	29.11^{a}	24.55^{c}	28.21
GLP-1004	22.20^{c}	26.71^{c}	28.86^{cd}	28.33^{b}	25.27^{b}	26.27
GLP-2	17.93^{g}	24.67^{g}	25.15^{g}	22.42^{g}	20.00^{e}	22.03
Ulonzo	14.73^{h}	18.71^{h}	20.72^{i}	17.22^{i}	16.14^{h}	17.50
GLP-24	25.79^{a}	29.34^{a}	31.04^{b}	27.55^{c}	26.21^{a}	27.99
E1	19.74^{e}	25.67^{d}	28.43^{d}	21.46^{f}	17.43^{g}	22.55
E3	18.45^{f}	24.16^{f}	27.75^{e}	20.42^{g}	18.14^{f}	21.78
E5	18.76^{f}	24.76^{e}	29.07^{c}	18.50^{h}	17.61^{g}	21.74
Mean	19.82	24.42	27.62	23.06	20.67	
SE	0.07	0.08	0.11	0.10	0.08	
CV	1.06%	0.97%	1.17%	1.31%	1.13%	
	**	**	**	**	**	

**Significant different at $P<0.05$, ns not significant at $P<0.05$. Values followed by the same letter superscript are not significantly different from each other.

Appendix 5b: **Cultivar differences in leaf net photosynthetic rate during second season (Experiment II) at 45 DAE**

Leaf net photosynthetic rate in μ mol m^{-2} s^{-1}

	8.00Hr	10.00hr	12.00hr	14.00hr	16.00hr	Mean
Pocho	22.32^{a}	25.46^{a}	29.51^{a}	24.64^{b}	23.51^{a}	25.08
White Haricot	21.59^{b}	24.90^{e}	27.20^{b}	25.20^{a}	23.00^{b}	24.21
GLP-92	17.62^{c}	20.11^{e}	21.71^{f}	18.53^{e}	16.01^{e}	19.00
GLP-1004	15.78^{ef}	20.33^{de}	22.19^{e}	21.50^{c}	19.25^{c}	19.81
GLP-2	14.20^{g}	17.24^{h}	19.06^{h}	17.04^{f}	15.09^{f}	16.53
Ulonzo	16.19^{e}	20.01^{e}	21.25^{g}	15.67^{g}	14.29^{h}	17.48
GLP-24	17.01^{d}	18.22^{g}	19.19^{h}	16.83^{f}	16.01^{e}	17.45
E1	15.40^{f}	20.82^{d}	23.48^{d}	18.17^{e}	14.63^{gh}	18.50
E3	16.00^{ef}	21.75^{c}	25.01^{c}	20.47^{d}	18.05^{d}	20.26
E5	14.54^{g}	19.23^{f}	22.52^{e}	15.18^{h}	14.82^{fg}	17.26
Mean	17.06	20.73	23.11	19.32	17.47	
SE	0.119	0.116	0.079	0.085	0.07	
CV	2.09%	1.68%	1.02%	1.31%	1.21%	
	**	**	**	**	**	

**Significant different at $P<0.05$, ns not significant at $P<0.05$. Values followed by the same letter superscript are not significantly different from each other.

Appendix 6a: Cultivar leaf Nitrogen content during long rains (experiment I)

Leaf Nitrogen content (mg/g)

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	31.8 ^{d}	34.6 ^{bc}	28.2 ^{e}	33.1 ^{b}	20.4 ^{d}	29.6
White Haricot	42.6 ^{ab}	38.8 ^{ab}	32.3 ^{bcd}	39.5 ^{a}	26.4 ^{b}	35.9
GLP-92	41.2 ^{b}	35.8 ^{bc}	33.3 ^{b}	29.4 ^{dc}	21.4 ^{cd}	32.2
GLP-1004	39.8 ^{bc}	37.0 ^{abc}	28.8 ^{e}	33.6 ^{b}	23.6 ^{c}	32.6
GLP-2	38.1 ^{bc}	33.1 ^{c}	30.8 ^{bcde}	30.9 ^{cd}	27.9 ^{ab}	32.2
Ulonzo	34.2 ^{cd}	37.1 ^{c}	29.6 ^{de}	28.0 ^{e}	20.8 ^{cd}	29.9
GLP-24	47.4 ^{a}	35.7 ^{bc}	30.2 ^{bcde}	34.2 ^{b}	30.1 ^{a}	35.5
E1	40.9 ^{b}	37.4 ^{abc}	33.1 ^{b}	31.3 ^{c}	28.2 ^{ab}	34.2
E3	30.7 ^{d}	36.1 ^{abc}	36.0 ^{a}	34.2 ^{b}	21.0 ^{bc}	31.6
E5	41.1 ^{b}	41.0 ^{a}	32.7 ^{bc}	34.7 ^{b}	20.9 ^{cd}	34.1
Mean	38.78	36.66	31.50	32.89	24.07	
SE	1.09	0.87	0.51	0.32	0.53	
CV	8.46%	7.14%	4.90%	2.92%	6.64%	
	**	**	**	**	**	

**Significant different at P<0.05, ns not significant at P<0.05. Values followed by the same letter superscript are not significantly different from each other.

Appendix 6b: Cultivar leaf Nitrogen content during long rains (experiment II)

Leaf Nitrogen content (mg/g)

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	28.9 ^{dc}	37.2 ^{b}	26.3 ^{e}	28.9 ^{f}	21.4 ^{def}	28.5
White Haricot	33.9 ^{b}	39.7 ^{a}	31.3 ^{bcd}	33.2 ^{abc}	28.8 ^{a}	33.4
GLP-92	36.1 ^{a}	34.1 ^{c}	32.0 ^{bc}	30.0 ^{ef}	20.0 ^{ef}	30.4
GLP-1004	28.0 ^{de}	34.1 ^{c}	29.9 ^{d}	32.9 ^{abc}	22.0 ^{de}	29.3
GLP-2	27.4 ^{ef}	31.0 ^{d}	30.0 ^{d}	30.5 ^{def}	32.1 ^{d}	29.0
Ulonzo	30.4 ^{cd}	37.2 ^{b}	32.5 ^{bc}	31.5 ^{cde}	23.1 ^{d}	30.9
GLP-24	31.4 ^{c}	35.8 ^{bc}	32.9 ^{ab}	34.0 ^{ab}	27.9 ^{ab}	32.4
E1	34.4 ^{ab}	37.5 ^{ab}	34.4 ^{a}	32.2 ^{bcd}	25.9 ^{ab}	32.9
E3	25.9 ^{f}	35.0 ^{bc}	34.1 ^{a}	34.2 ^{a}	20.1 ^{ef}	29.9
E5	35.8 ^{a}	36.2 ^{bc}	31.1 ^{cd}	34.0 ^{ab}	19.7 ^{f}	31.4
Mean	31.18	35.78	32.90	32.14	23.45	
SE	0.39	0.43	0.29	0.33	0.40	
CV	3.70%	3.71%	2.68%	3.06%	5.07%	

**Significant different at P<0.05, ns not significant at P<0.05. Values followed by the same letter superscript are not significantly different from each other.

Appendix 7a: Cultivar stem soluble sugars during long rains (experiment I)

Stem soluble sugar content (mg/g)

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	37.5 ^{a}	22.4 ^{h}	39.9 ^{b}	65.3 ^{b}	53.4 ^{b}	43.7
White Haricot	25.1 ^{f}	17.8 ^{e}	43.0 ^{e}	44.0 ^{e}	37.0 ^{e}	33.4
GLP-92	22.7 ^{g}	15.0 ^{f}	24.0 ^{g}	29.3 ^{g}	28.0 ^{g}	23.8
GLP-1004	27.0 ^{e}	20.4 ^{d}	20.0 ^{b}	23.1 ^{h}	21.8 ^{b}	22.5
GLP-2	26.7 ^{ef}	24.8 ^{b}	40.0 ^{b}	69.8 ^{a}	61.4 ^{a}	44.5
Ulonzo	28.9 ^{d}	14.8	32.3 ^{e}	29.8 ^{d}	45.5 ^{d}	30.3
GLP-24	31.2 ^{c}	20.3 ^{d}	35.2 ^{d}	60.6 ^{c}	54.0 ^{b}	40.3
E1	30.3 ^{cd}	19.3 ^{d}	37.7 ^{c}	49.2 ^{d}	36.2 ^{ef}	34.5
E3	30.1 ^{cd}	17.5 ^{e}	36.2 ^{cd}	40.1 ^{f}	35.1 ^{f}	37.3
E5	34.0 ^{b}	28.0 ^{a}	30.1 ^{f}	51.0 ^{d}	47.2 ^{c}	38.1
Mean	29.4	20.0	33.8	48.5	42.0	
SE	0.34	0.29	0.35	0.34	0.29	
CV	3.44%	4.27%	3.08%	2.10%	2.06%	
	**	**	**	**	**	

**Significant different at P<0.05, ns not significant at P<0.05. Values followed by the same letter superscript are not significantly different from each other.

Appendix 7b: Cultivar stem soluble sugars during long rains (experiment II)

Stem soluble sugar content (mg/g)

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	36.3 ^{a}	20.4 ^{c}	37.2 ^{a}	68.8 ^{b}	55.5 ^{b}	43.6
White Haricot	20.8 ^{f}	15.3 ^{e}	35.0 ^{b}	35.9 ^{h}	40.0 ^{e}	29.4
GLP-92	16.0 ^{g}	12.4 ^{f}	27.6 ^{c}	33.6 ^{i}	32.0 ^{g}	24.3
GLP-1004	20.2 ^{f}	17.1 ^{d}	20.0 ^{g}	37.2 ^{gh}	29.4 ^{h}	24.8
GLP-2	23.6 ^{e}	22.3 ^{b}	36.4 ^{ab}	73.0 ^{a}	63.3 ^{a}	43.7
Ulonzo	26.7 ^{c}	12.3 ^{f}	27.4 ^{d}	42.1 ^{f}	33.8 ^{f}	28.5
GLP-24	26.1 ^{cd}	15.9 ^{cd}	30.7 ^{c}	58.7 ^{d}	48.8	36.0
E1	25.3 ^{c}	13.3 ^{f}	22.3 ^{f}	38.7 ^{g}	34.3 ^{e}	26.8
E3	26.3 ^{cd}	15.2 ^{e}	24.3 ^{e}	45.2 ^{e}	42.1 ^{d}	30.6
E5	32.2 ^{b}	24.8 ^{a}	32.5	64.5 ^{c}	56.4 ^{b}	42.1
Mean	25.4	16.9	29.3	49.8	43.6	
SE	0.23	0.32	0.38	0.34	0.28	
CV	2.73%	5.75%	3.85%	2.03%	1.95%	
	**	**	**	**	**	

**Significant different at P<0.05, ns not significant at P<0.05. Values followed by the same letter superscript are not significantly different from each other.

Appendix 7c: Cultivar stem starch content during short rains (experiment II)

Stem starch content (% dry wt)

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	3.70 ^{a}	2.02 ^{c}	3.59 ^{b}	5.88 ^{b}	4.81 ^{b}	4.00
White Haricot	2.26 ^{f}	1.60 ^{e}	3.87 ^{a}	3.96 ^{e}	3.33 ^{e}	3.00
GLP-92	2.04 ^{g}	1.35 ^{f}	2.16 ^{c}	2.64 ^{g}	2.50 ^{g}	2.14
GLP-1004	2.43 ^{e}	1.84 ^{d}	1.80 ^{h}	2.08 ^{h}	1.96 ^{h}	2.02
GLP-2	2.40 ^{ef}	2.23 ^{b}	3.60 ^{a}	6.28 ^{a}	5.51 ^{a}	4.00
Ulonzo	2.60 ^{d}	1.33 ^{f}	2.91 ^{e}	4.48 ^{d}	4.10 ^{d}	3.08
GLP-24	2.81 ^{c}	1.83 ^{d}	3.13 ^{d}	5.45 ^{c}	4.86 ^{b}	3.62
E1	2.73 ^{cd}	1.74 ^{d}	3.39 ^{c}	4.43 ^{d}	3.26 ^{ef}	3.11
E3	2.71 ^{cd}	1.58 ^{e}	2.26 ^{cd}	3.69 ^{f}	3.16 ^{f}	2.88
E5	3.06 ^{b}	2.52 ^{a}	2.71 ^{f}	4.59 ^{d}	4.25 ^{c}	3.43
Mean	2.64	1.80	3.04	4.35	3.77	
SE	0.31	0.03	0.03	0.03	0.03	
CV	3.47%	4.29%	3.24%	2.08%	2.08%	
	**	**	**	**	**	

**Significant different at $P<0.05$, ns not significant at $P<0.05$. Values followed by the same letter superscript are not significantly different from each other.

Appendix 7d: Cultivar stem starch content during short rains (experiment II)

Stem starch content (% dry wt)

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	3.27 ^{a}	1.84 ^{c}	3.35 ^{a}	6.19 ^{b}	5.00 ^{b}	3.93
White Haricot	1.87 ^{f}	1.38 ^{e}	3.15 ^{b}	3.18 ^{hi}	3.60 ^{e}	2.64
GLP-92	1.44 ^{g}	1.12 ^{f}	1.80 ^{g}	3.02 ^{i}	2.88 ^{g}	2.05
GLP-1004	1.82 ^{f}	1.54 ^{d}	2.48 ^{d}	3.35 ^{gh}	2.65 ^{h}	2.37
GLP-2	2.12 ^{e}	2.01 ^{b}	3.27 ^{ab}	6.57 ^{a}	5.70 ^{a}	3.93
Ulonzo	2.40 ^{c}	1.12 ^{f}	2.47 ^{d}	3.79 ^{f}	3.05 ^{f}	2.57
GLP-24	2.35 ^{cd}	1.43 ^{de}	2.76 ^{c}	5.29 ^{d}	4.39 ^{c}	3.24
E1	2.28 ^{d}	1.20 ^{f}	2.10 ^{f}	3.48 ^{g}	3.09 ^{f}	2.41
E3	2.37 ^{cd}	1.37 ^{e}	2.19 ^{e}	4.07 ^{e}	3.79 ^{d}	2.76
E5	2.90 ^{b}	2.23 ^{a}	2.93 ^{c}	5.80 ^{c}	5.08 ^{b}	3.79
Mean	2.28	1.52	2.64	4.47	3.92	
SE	0.02	0.03	0.03	0.03	0.03	
CV	2.74%	5.81%	3.83%	2.21%	1.98%	
	**	**	**	**	**	

**Significant different at $P<0.05$, ns not significant at $P<0.05$. Values followed by the same letter superscript are not significantly different from each other.

Appendix 8a: Cultivar leaf area indices during long rains (experiment I)

Leaf area index

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	1.95^{b}	2.15^{bc}	3.13^{de}	2.05^{de}	1.40^{bc}	2.14
White Haricot	2.28^{a}	2.45^{ab}	6.68^{a}	4.47^{a}	3.10^{a}	3.78
GLP-92	1.54^{c}	2.29^{abc}	3.94^{bc}	1.60^{e}	1.11^{cd}	2.10
GLP-1004	1.91^{b}	2.07^{bc}	3.51^{cde}	2.49^{cd}	0.54^{e}	2.10
GLP-2	1.93^{b}	1.97^{bcd}	3.09^{e}	1.08^{f}	0.89^{d}	1.79
Ulonzo	1.53^{c}	1.60^{bcd}	4.29^{b}	1.70^{e}	0.97^{d}	2.04
GLP-24	0.96^{e}	1.05^{f}	3.57^{cde}	3.69^{b}	3.29^{a}	2.51
E1	1.22^{e}	1.38^{ef}	3.31^{e}	2.30^{cd}	1.61^{b}	1.96
E3	1.39^{cd}	1.53^{def}	2.99^{e}	1.67^{e}	1.42^{bc}	1.80
E5	2.45^{a}	2.69^{a}	3.76^{bdc}	2.61^{c}	1.54^{b}	2.61
Mean	1.72	1.92	3.83	2.37	1.58	
SE	0.06	0.09	0.11	0.11	0.07	
CV	9.78%	14.64%	8.70%	13.34%	12.50%	
	**	**	**	**	**	

**Significant different at $P<0.05$, ns not significant at $P<0.05$. Values followed by the same letter superscript are not significantly different from each other.

Appendix 8b: Cultivar leaf area indices during long rains (experiment II)

Leaf area index

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	1.30^{b}	2.43^{ab}	2.75^{d}	2.34^{b}	0.85^{bc}	1.93
White Haricot	1.26^{bc}	2.33^{bc}	3.90^{a}	3.20^{a}	1.42^{a}	2.42
GLP-92	1.11^{cd}	2.08^{cd}	3.10^{b}	1.73^{cd}	0.40^{ef}	1.68
GLP-	1.06^{d}	2.12^{cd}	2.85^{cd}	1.42^{e}	0.38^{e}	1.57
GLP-2	1.12^{cd}	1.94^{d}	2.53^{e}	1.32^{e}	0.67^{d}	1.52
Ulonzo	1.03^{d}	2.12^{cd}	2.99^{bc}	2.34^{b}	0.86^{b}	1.87
GLP-	1.59^{a}	2.06^{d}	3.11^{b}	2.25^{b}	1.00^{b}	2.00
E1	1.30^{b}	2.13^{cd}	3.16^{b}	1.68^{d}	0.68^{cd}	1.79
E3	1.20^{bcd}	2.43^{ab}	2.96^{bc}	1.30^{e}	0.61^{d}	1.70
E5	1.10^{a}	2.61^{a}	3.14^{b}	1.97^{c}	0.66^{d}	1.90
Mean	1.21	2.23	3.05	1.96	0.75	
SE	0.03	0.04	0.04	0.05	0.03	
CV	7.54%	5.95%	3.52%	7.41%	12.80%	
	**	**	**	**	**	

**Significant different at $P<0.05$, ns not significant at $P<0.05$. Values followed by the same letter superscript are not significantly different from each other.

Appendix 9a: Cultivar Total plant biomass accumalation during long rains (Experiment I)

Total plant dry weight (g/m^2)

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	154.67 ^{a}	250.04 ^{bdc}	343.87 ^{b}	718.00 ^{b}	730.00 ^{b}	456.92
White Haricot	142.33 ^{ab}	262.33 ^{abc}	580.00 ^{a}	725.33 ^{a}	742.67 ^{b}	490.53
GLP-92	140.67 ^{ab}	264.47 ^{ab}	616.67 ^{a}	700.00 ^{bc}	771.33 ^{b}	498.63
GLP-1004	134.00 ^{ab}	289.13 ^{a}	600.00 ^{a}	634.00 ^{cd}	650.00 ^{c}	461.43
GLP-2	121.73 ^{b}	231.07 ^{cde}	333.33 ^{e}	602.00 ^{d}	660.67 ^{c}	389.76
Ulonzo	133.67 ^{a}	214.33 ^{e}	479.33 ^{b}	529.33 ^{e}	588.67 ^{d}	389.07
GLP-24	128.93 ^{b}	182.93 ^{f}	381.33 ^{cde}	486.00 ^{e}	359.33 ^{c}	307.70
E1	141.60 ^{ab}	227.73 ^{de}	395.33 ^{cd}	701.00 ^{b}	724.00 ^{b}	438.00
E3	135.93 ^{ab}	227.27 ^{de}	370.00 ^{de}	808.67 ^{a}	839.33 ^{a}	476.24
E5	140.33 ^{ab}	234.20 ^{bcde}	614.67 ^{a}	712.60 ^{b}	750.06 ^{b}	490.25
Mean	137.41	238.35	480.25	661.17	711.60	
SE	3.60	5.77	10.80	13.43	9.46	
CV	7.85%	7.26%	6.74%	6.10%	4.00%	
	*	**	*	**	*	

* Significant different at P<0.05, ns not significant at P<0.05 values followed by the same letter superscript are not significantly different from each other.

Appendix 9b: Cultivar Total plant biomass accumalation during short rains (Experiment II)

Total plant dry weight (g/m^2)

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	128.47 ^{a}	234.87 ^{b}	484.47 ^{a}	615.00 ^{b}	655.67 ^{ab}	423.70
White Haricot	99.27 ^{bc}	240.13 ^{b}	453.40 ^{ab}	676.30 ^{a}	659.27 ^{ab}	425.67
GLP-92	101.60 ^{bc}	178.00 ^{d}	490.00 ^{a}	645.30 ^{ab}	608.60 ^{bcd}	404.70
GLP-1004	189.00 ^{c}	223.20 ^{bc}	451.00 ^{ab}	638.40 ^{c}	553.27 ^{d}	410.97
GLP-2	94.00 ^{bc}	194.80 ^{cd}	460.80 ^{ab}	518.20 ^{e}	616.67 ^{abc}	376.89
Ulonzo	84.73 ^{c}	182.27 ^{d}	359.47 ^{c}	683.20 ^{a}	659.27 ^{ab}	393.79
GLP-24	129.87 ^{a}	224.27 ^{bc}	440.67 ^{ab}	610.10 ^{b}	675.33 ^{a}	416.05
E1	125.40 ^{a}	253.93 ^{ab}	411.67 ^{bc}	522.10 ^{bc}	578.93 ^{cd}	378.41
E3	114.07 ^{ab}	218.87 ^{ac}	495.80 ^{a}	432.00 ^{d}	603.00 ^{bcd}	372.75
E5	100.75 ^{bc}	277.60 ^{a}	405.00 ^{bc}	660.93 ^{b}	605.34 ^{bcd}	409.92
Mean	106.86	222.79	445.23	600.15	621.53	
SE	3.92	6.49	11.74	10.76	10.85	
CV	11.00%	8.74%	7.91%	5.38%	8.24%	
	**	**	**	**	**	

* Significant different at P<0.05, ns not significant at P<0.05 values followed by the same letter superscript are not significantly different from each other.

Appendix 9c: Cultivar stem biomass accumalation during long rains (Experiment I)
Stem dry weight (g/m^2)

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	94.80 ^{a}	88.13 ^{dc}	153.13 ^{d}	252.33 ^{c}	210.07 ^{a}	159.69
White Haricot	43.29 ^{abcd}	110.87 ^{b}	350.93 ^{a}	315.33 ^{b}	208.27 ^{a}	205.74
GLP-92	38.87 ^{cde}	109.87 ^{b}	191.27 ^{c}	217.93 ^{c}	150.40 ^{de}	141.67
GLP-1004	39.73 ^{bcde}	124.80 ^{a}	270.33 ^{b}	354.47 ^{a}	143.20 ^{e}	186.51
GLP-2	35.67 ^{de}	85.60 ^{d}	98.33 ^{e}	175.60 ^{e}	185.13 ^{b}	116.07
Ulonzo	35.07 ^{e}	90.13 ^{cd}	162.60 ^{d}	164.47 ^{e}	153.87 ^{de}	121.23
GLP-24	39.53 ^{bcde}	82.93	135.53 ^{d}	167.00 ^{e}	165.87 ^{cd}	118.17
E1	41.60 ^{abcde}	99.33 ^{bc}	137.67 ^{d}	202.60 ^{d}	149.27 ^{de}	126.09
E3	43.67 ^{abc}	110.53 ^{b}	134.00 ^{d}	308.33 ^{b}	224.00 ^{a}	164.11
E5	46.93 ^{ab}	98.47 ^{c}	263.93	224.93 ^{d}	173.67 ^{b}	161.59
Mean	45.91	100.57	190.65	243.70	176.38	
SE	1.37	2.28	5.06	5.16	3.27	
CV	5.44%	6.81%	7.97%	6.60%	5.57%	
	ns	**	**	**	*	

* Significant different at $P<0.05$, ns not significant at $P<0.05$ values followed by the same letter superscript are not significantly different from each other.

Appendix 9d: Cultivar stem biomass accumalation during long rains (Experiment II)
Stem dry weight (g/m^2)

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	46.67 ^{a}	107.13 ^{abc}	207.93 ^{ab}	212.00 ^{a}	191.80 ^{a}	153.11
White Haricot	36.80 ^{bc}	197,80 ^{abc}	198.87 ^{abc}	234.23 ^{a}	180.20 ^{abc}	151.58
GLP-92	35.87 ^{bc}	94.93 ^{bc}	173.80 ^{bc}	173.13 ^{b}	120.47 ^{e}	119.64
GLP-1004	39.13 ^{abc}	109.73 ^{bc}	168.13 ^{bc}	146.26 ^{b}	124.80 ^{de}	117.61
GLP-2	37.20 ^{abc}	86.53 ^{cd}	191.73 ^{bc}	150.00 ^{b}	173.60 ^{abc}	128.41
Ulonzo	30.80 ^{c}	68.60 ^{d}	197.93 ^{bc}	209.53 ^{a}	174.00 ^{abc}	136.17
GLP-24	41.27 ^{ab}	105.40 ^{abc}	195.20 ^{bc}	218.87 ^{b}	182.07 ^{ab}	148.56
E1	45.07 ^{ab}	119.93 ^{ab}	239.01 ^{a}	149.00 ^{b}	114.47 ^{e}	133.50
E3	42.73 ^{ab}	104.53 ^{bc}	188.60 ^{bc}	150.00 ^{b}	160.13 ^{bc}	129.20
E5	42.40 ^{ab}	128.73 ^{a}	161.26 ^{bc}	164.93 ^{b}	150.00 ^{cd}	129.46
Mean	39.79	102.53	192.25	181.40	157.12	
SE	1.69	4.09	7.46	6.66	5.34	
CV	12.72%	11.97%	11.64%	11.01%	10.10%	
	*	*	**	*	**	

* Significant different at $P<0.05$, ns not significant at $P<0.05$ values followed by the same letter superscript are not significantly different from each other.

Appendix 9e: Cultivar leaf biomass accumalation during long rains (Experiment I)
Leaf plant dry weight (g/m^2)

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	107.33^{a}	161.87^{a}	204.27^{bc}	116.47^{bcd}	73.60^{abc}	132.71
White Haricot	99.27^{ab}	151.47^{ab}	211.53^{abc}	194.13^{a}	87.60^{a}	148.80
GLP-92	100.00^{ab}	154.60^{ab}	252.53^{a}	102.87^{cde}	73.13^{abc}	136.63
GLP-1004	94.26^{abc}	159.33^{a}	212.20^{abc}	104.53^{cde}	40.13^{e}	122.09
GLP-2	86.73^{bc}	135.53^{cd}	175.80^{c}	73.33^{f}	53.67^{cd}	105.01
Ulonzo	98.60^{ab}	124.20^{de}	244.00^{ab}	98.80^{def}	66.53^{abc}	126.43
GLP-24	76.87^{c}	100.60^{f}	198.53^{bc}	133.67^{b}	64.87^{abc}	114.91
E1	101.80^{ab}	128.40^{cde}	211.27^{abc}	127.33^{bc}	72.87	128.33
E3	92.27^{abc}	116.73^{e}	199.53^{d}	81.53^{ef}	64.27^{bc}	110.87
E5	93.40^{abc}	141.13^{bc}	211.13^{abc}	105.20^{cde}	79.53^{ab}	126.08
Mean	95.05	137.39	212.08	113.79	67.20	
SE	3.26	2.93	8.09	4.79	3.40	
CV	10.27%	6.39%	11.44%	12.63%	17.72%	
	ns	**	*	*	*	

* Significant different at $P<0.05$, ns not significant at $P<0.05$ values followed by the same letter superscript are not significantly different from each other.

Appendix 9f: Cultivar leaf biomass accumalation during long rains (Experiment II)
Leaf plant dry weight (g/m^2)

Cultivar	32 DAE	45DAE	58DAE	70DAE	80DAE	Mean
Pocho	80.80^{ab}	127.73^{bc}	172.27^{bcd}	117.87^{bc}	57.07^{cd}	111.35
White Haricot	62.47^{cde}	132.33^{bc}	232.53^{a}	178.83^{a}	93.47^{a}	139.93
GLP-92	65.80^{cd}	83.07^{d}	190.00^{b}	110.00^{bc}	40.67^{f}	97.91
GLP-1004	49.87^{e}	113.47^{bcd}	138.93^{d}	70.47^{e}	42.27^{ef}	83.00
GLP-2	57.60^{cde}	108.27^{cd}	143.53^{cd}	96.07^{cde}	47.07^{ef}	90.51
Ulonzo	53.93^{de}	113.67^{bcd}	148.53^{cd}	131.47^{b}	61.47^{c}	101.81
GLP-24	88.60^{a}	118.87^{bcd}	190.47^{b}	133.87^{b}	77.67^{b}	121.90
E1	80.33^{ab}	175.33^{a}	180.07^{bc}	100.00^{cd}	45.60^{ef}	116.27
E3	71.33^{bc}	114.33^{bcd}	149.87^{cd}	77.20^{de}	49.07^{def}	92.36
E5	58.33^{cde}	149.20^{ab}	160.20^{cd}	132.47^{b}	52.13^{cde}	110.47
Mean	7.01	123.63	170.64	114.78	56.60	
SE	2.51	6.96	6.42	6.66	1.98	
CV	11.25%	16.89%	11.29%	17.40%	10.52%	
	ns	*	**	**	**	

* Significant different at $P<0.05$, ns not significant at $P<0.05$ values followed by the same letter superscript are not significantly different from each other.

Appendix 9g: **Cultivar pod dry matter accumalation during long rains (Experiment I)**

Pod dry matter weight (g/m^2)

Cultivar	58DAE	70DAE	80DAE	Mean
Pocho	79.67^{c}	350.33^{c}	446.33^{abc}	292.11
White Haricot	17.53^{f}	215.87^{e}	446.80^{abc}	226.73
GLP-92	175.89^{a}	306.67^{c}	547.80^{a}	343.45
GLP-1004	120.60^{b}	160.60^{f}	461.13^{abc}	247.44
GLP-2	59.20^{cde}	347.40^{b}	421.87^{bc}	276.16
Ulonzo	72.73^{cd}	268.33^{d}	374.93^{c}	238.66
GLP-24	47.60^{de}	185.40^{ef}	431.00^{bc}	221.33
E1	46.40^{de}	371.40^{b}	508.53^{ab}	308.78
E3	36.73^{b}	418.60^{a}	551.07^{a}	335.47
E5	139.73^{b}	408.27^{a}	396.80^{bc}	314.93
Mean	79.63	303.29	458.63	
SE	4.81	6.21	20.25	
CV	18.12%	6.14%	13.25%	
	**	**	*	

* Significant different at P<0.05, ns not significant at P<0.05 values followed by the same letter superscript are not significantly different from each other.

Appendix 9h: **Cultivar pod dry matter accumalation during long rains (Experiment II)**

Pod dry matter weight (g/m^2)

Cultivar	58DAE	70DAE	80DAE	Mean
Pocho	104.27^{d}	285.13^{bc}	406.80^{ab}	224.05
White Haricot	22.00^{g}	263.73^{c}	385.60^{b}	223.78
GLP-92	159.53^{a}	362.20^{a}	447.40^{a}	323.04
GLP-1004	137.60^{b}	321.67^{ab}	386.20^{b}	281.82
GLP-2	125.53^{c}	269.13^{bc}	396.00^{ab}	256. 55
Ulonzo	76.67^{e}	342.20^{a}	423.80^{ab}	280.89
GLP-24	55.00^{f}	250.73^{cc}	431.00^{bc}	245.58
E1	13.73^{g}	273.01^{bc}	407.13^{ab}	231.29
E3	73.20^{e}	204.40^{d}	393.80^{ab}	223.80
E5	83.60^{e}	363.53^{a}	403.20^{ab}	283.44
Mean	85.11	293.57	408.09	
SE	1.93	9.84	9.83	
CV	6.81%	10.06%	7.22%	
	**	**	*	

* Significant different at P<0.05, ns not significant at P<0.05 values followed by the same letter superscript are not significantly different from each other.

Appendix 10a **Cultivar specific leaf weight during short rains (Experiment II)**

Specific leaf weight (g/m^2)

Cultivar	32 DAE	45DAE	58DAE	70DAE	Mean
Pocho	8.13^{cde}	7.24^{c}	7.96^{d}	5.38^{a}	7.18
White Haricot	6.13^{a}	5.83^{g}	6.40^{g}	4.35^{d}	5.68
GLP-92	9.31^{a}	8.44^{b}	9.01^{a}	5.34^{a}	8.03
GLP-1004	8.31^{bcd}	8.31^{bc}	8.46^{c}	4.15^{e}	7.31
GLP-2	7.90^{de}	8.93^{a}	8.63^{bc}	4.95^{b}	7.60
Ulonzo	7.40^{f}	6.10^{f}	6.74^{f}	5.40^{a}	6.41
GLP-24	7.81^{e}	7.11^{e}	7.50^{e}	5.30^{a}	6.93
E1	8.63^{b}	8.14^{c}	8.80^{ab}	4.65^{c}	7.56
E3	8.10^{cde}	7.55^{d}	7.66^{e}	5.00^{b}	7.08
E5	8.41^{bc}	7.63^{d}	7.70^{e}	4.82^{bc}	7.14
Mean	8.01	7.53	7.89	4.93	
SE	0.08	0.05	0.05	0.04	
CV	2.86%	2.04%	1.82%	2.32%	

** ** ** **

* Significant different at P<0.05, ns not significant at P<0.05 values followed by the same letter superscript are not significantly different from each other.

Appendix 10b: **Cultivar specific leaf weight during short rains (Experiment II)**

Specific leaf weight (g/m^2)

Cultivar	32 DAE	45DAE	58DAE	70DAE	Mean
Pocho	10.42^{bc}	9.04^{bc}	9.54^{cd}	6.90^{cd}	8.98
White Haricot	7.66^{f}	8.37^{c}	8.84^{d}	6.47^{c}	7.84
GLP-92	11.64^{a}	10.56^{a}	13.09^{a}	7.84^{b}	10.78
GLP-1004	10.39^{cde}	10.42^{a}	11.35^{b}	6.42^{c}	9.65
GLP-2	9.89^{cde}	10.81^{a}	9.92^{cd}	8.84^{a}	9.87
Ulonzo	9.28^{c}	8.65^{c}	11.59^{b}	6.84^{a}	9.09
GLP-24	9.70^{de}	9.23^{bc}	9.63^{cd}	7.04^{bc}	8.90
E1	10.79^{b}	10.02^{ab}	10.51^{bc}	6.76^{c}	9.52
E3	10.12^{bcd}	8.89^{c}	9.04^{d}	6.81^{c}	8.72
E5	10.51^{bc}	10.51^{a}	9.83^{cd}	6.42^{c}	9.32
Mean	10.04	9.69	10.33	7.03	
SE	0.12	0.18	0.08	0.17	
CV	3.61%	5.65%	2.23%	7.31%	

** ** ** **

* Significant different at P<0.05, ns not significant at P<0.05 values followed by the same letter superscript are not significantly different from each other.

Appendix 11a: **Cultivar harvest indices; yield and yield components (Experiment I)**

Cultivar	grain yld g/m ^{2}	100 seed wt (grams)	mean pod no/plant	grain yld ton/ha	H.I
Pocho	322.1 ^{a}	69.4 ^{a}	14.3 ^{d}	3.22 ^{a}	44.2 ^{cd}
White Haricot	270.7 ^{cd}	27.4 ^{f}	20.0 ^{a}	2.71 ^{cd}	36.4 ^{d}
GLP-92	256.0 ^{de}	40.6 ^{e}	17.7 ^{b}	2.56 ^{de}	33.2 ^{d}
GLP-1004	274.7 ^{cd}	55.9 ^{c}	12.0 ^{d}	2.74 ^{cd}	40.9 ^{bc}
GLP-2	225.4 ^{f}	54.8 ^{c}	8.7 ^{e}	2.26 ^{f}	34.5 ^{d}
Ulonzo	248.4 ^{e}	22.1 ^{g}	19.7 ^{a}	2.48 ^{e}	42.4 ^{bc}
GLP-24	306.5 ^{ab}	45.9 ^{d}	17.0 ^{b}	3.07 ^{ab}	46.5 ^{a}
E1	270.4 ^{bc}	68.9 ^{a}	9.7 ^{e}	2.90 ^{bc}	40.2 ^{c}
E3	276.1 ^{cd}	62.7 ^{b}	10.0 ^{e}	2.76 ^{cd}	33.0 ^{d}
E5	268.3 ^{de}	63.2 ^{b}	9.7 ^{e}	2.69 ^{de}	35.8 ^{d}
Mean	271.86	51.09	13.90	2.74	38.71
SE	3.74	0.58	0.33	0.04	0.66
CV	4.12%	3.42%	7.18%	4.08%	5.08%

** ** ** ** **

* Significant different at $P<0.05$, ns not significant at $P<0.05$ values followed by the same letter superscript are not significantly different from each other.

Appendix 11b: **Cultivar harvest indices; yield and yield components (Experiment II)**

Cultivar	grain yld g/m ^{2}	100 seed wt (grams)	mean pod no/plant	grain yld ton/ha	H.I
Pocho	258.4 ^{bc}	61.1 ^{d}	12.8 ^{b}	2.58 ^{bc}	39.4 ^{cd}
White Haricot	238.8 ^{e}	28.5 ^{h}	15.9 ^{a}	2.38 ^{e}	36.4 ^{cd}
GLP-92	225.5 ^{f}	40.2 ^{g}	16.2 ^{a}	2.25 ^{f}	37.1 ^{de}
GLP-1004	228.3 ^{f}	55.4 ^{e}	8.4 ^{d}	2.28 ^{f}	41.3 ^{bc}
GLP-2	205.4 ^{g}	54.3 ^{e}	6.0 ^{e}	2.05 ^{g}	33.4 ^{g}
Ulonzo	222.8 ^{f}	25.9 ^{i}	16.5 ^{a}	2.23 ^{f}	33.8 ^{fg}
GLP-24	248.1 ^{d}	52.5 ^{f}	10.8 ^{c}	2.48 ^{d}	36.8 ^{de}
E1	281.6 ^{a}	68.3 ^{a}	6.7 ^{e}	2.81 ^{a}	47.7 ^{a}
E3	264.8 ^{b}	63.3 ^{c}	7.1 ^{e}	2.65 ^{b}	43.1 ^{b}
E5	252.8 ^{cd}	65.7 ^{b}	6.9 ^{e}	2.53 ^{cd}	41.8 ^{bc}
Mean	242.65	51.52	10.73	2.42	39.1
SE	1.49	0.32	0.17	0.02	0.51
CV	1.85%	1.90%	4.81%	1.82%	3.93%

** ** ** ** **

* Significant different at $P<0.05$, ns not significant at $P<0.05$ values followed by the same letter superscript are not significantly different from each other.

Appendix 12: Correlation coefficients between some plant parameters at 32 DAE and grain yield at harvest (experiment 2) short rains

	SLW	LAI	LEAF N	PHOTOSYNTHETIC RATE	GRAIN YIELD	POD NUMBER	100 SEED WEIGHT	HI
SLW	1.000							
LAI	-0.180	1.000						
Leaf N	-0.149	0.070	1.000					
Photosynthetic rate	0.172	0.341	0.370	1.000				
Grain Yield	0.154	0.427*	0.171	-0.061	1.000			
Pod N	-.289	-0.027	0.287	0.046	-0.290	1.000		
100 seed weight	0.535	0.189	-0.149	-0.042	0.568*	-0.843**	1.000	
HI	0.416	0.102	0.171	0.026	0.179**	-0.522*	0.686**	1.000

* Significant at 0.01 ** Significant at 0.001.

Appendix 13: Correlation coefficients between some plant traits at 45 DAE and grain yield at harvest (experiment 2) short rains.

	SLW	LAI	LEAF N	PHYS RATE	GRAIN YIELD	POD NO.	100SEED WT	HI
SLW	1.000							
LAI	0.075	1.000						
Leaf N	-0.422	0.173	1.000					
Phys. Rate	-0.478*	0.213	0.771**	1.000				
Grain Yield	-0.253	-0.174	0.424*	0.516*	1.000			
Pod No.	-0.444*	0.064	0.489*	0.290	0.083	1.000		
100seed Wt	0.301	-0.052	-0.139	0.066	0.393**	-0.823**	1.000	
HI	-0.199	-0.353	0.178	0.103	0.613**	0.263	-0.025	1.000

* significant at 0.01 ** significant at 0.001

Appendix 14: Correlation coefficient between some plant traits at 58 DAE (experimental 2) short rains

	SLW	Leaf N	LAI	Stem sol. Sugars	T Biom.	S Biom.	L Biom.	Pod Biom.	Starch	Pod No.	100 seed wt.	Grain Yield	HI
SLW	1.000												
L. Nitrogen	-0.155	1.000											
LAI	-0.365	-0.053	1.000										
Stem Soluble Sugars	-0.517*	-0.567**	0.128	1.000									
Total Biomass	-0.156	0.212	-0.092	-0.063	1.000								
Stem Biomass	-0.257	0.063	0.034	-0.071	0.539*	1.000							
Leaf Biomass	-0.232	0.135	0.589**	0.057	0.341	0.203	1.000						
Pod Biomass	0.419	-0.324	-0.495*	-0.182	0.521*	-0.249	-0.273	1.000					
Starch	-0.518*	-0.567**	0.129	0.990*	-0.061	-0.072	-0.056	-0.184	1.000				
Pod Number	0.189	-0.238	0.658**	-0.009	-0.156	-0.010	0.521*	-0.426*	-0.010	1.000			
100 Seed Wt.	-0.251	0.254	-0.661**	0.030	0.356	0.102	-0.326	0.471*	0.031	-0.825**	1.000		
Grain Yield	-0.298	-0.180	-0.132	-0.069	0.231	0.270	0.231	-0.120	0.069	0.083	0.393	1.000	
HI	-0.015	-0.410	-0.178	0.242	-0.048	0.186	0.070	-0.285	0.244	0.263	-0.100	0.087	1.000

* significant at 0.01   ** significant at 0.001

Appendix 15: Correlation coefficient between some plant traits at 70 DAE (experimental 2) short rains

	SLW	Leaf N	LAI	Stem Soluble Sugars	Total Biom.	S Biom.	L Biom.	Pod Biom.	Pod No.	100 seed wt	Grain Yield	Starch	HI
SLW	1.000												
L. Nitrogen	0.269	1.000											
LAI	-0.303	0.009	1.000										
Stem Soluble Sugars	0.333	-0.760	0.173	1.000									
Total Biomass	-0.204	-0.194	0.730**	0.035	1.000								
Stem Biomass	-0.212	-0.041	0.817**	0.284	0.646**	1.000							
Leaf Biomass	-0.113	0.088	0.856**	0.253	0.733**	0.664**	1.000						
Pod Biomass	-0.102	-0.335	0.060	-0.296	0.656**	-0.081	0.087	1.000					
Pod Number	-0.085	-0.292	0.676**	-0.191	0.699**	0.682**	0.530*	0.298	1.000				
100 Seed wt	-0.056	0.112	-0.580**	0.187	-0.593**	-0.556	-0.527*	0.225	-0.843**	1.000			
Grain Yield	-0.494*	0.274	0.050	-0.033	-0.247	-0.060	-0.042	-0.317	-0.290	0.586**	1.00		
Starch	0.332	-0.177	0.173	0.594**	0.035	0.288	0.253	-0.288	-0.191	0.187	0.034	1.000	
HI	-0.377	0.335	-0.321	-0.271	-0.428*	-0.436*	-0.340	-0.154	-0.522	0.700**	0.791	-0.436*	1.000

* significant at 0.01 ** significant at 0.001

Appendix 16: Correlation coefficient between some plant traits at 80 DAE (experimental 2) short rains

	Leaf N	LAI	Stem Soluble Sugars	T Biom.	S Biom.	L Biom.	Pod Biom	Starch	Pod No.	100 seed wt.	Grain Yield	HI
Leaf N	1.000											
LAI	0.680**	1.000										
Stem Soluble Sugars	0.309	0.326	1.000									
Total Biomass	0.237	0.629**	0.472*	1.000								
Stem Biomass	0.295	0.577**	0.655**	0.719	1.000							
Leaf Biomass	0.630**	0.908**	0.257	0.629**	0.591**	1.000						
Pod Biomass	-0.194	-0.030	0.998**	0.583**	-0.026	-0.063	1.000					
Starch	0.310	0.328	0.019	0.475*	0.657**	0.266	0.020	1.000				
Pod Number	0.034	0.514*	-0.150	0.477*	0.237	0.440*	0.306	0.020	1.000			
100 Seed Wt.	-0.310	-0.534*	0.102	-0.394	-0.246	-0.496*	-0.138	-0.138	-0.843**	1.000		
Grain Yeild	-0.086	0.044	-0.125**	-0.054	-0.106	0.021	-0.024	-0.024	0.290	0.586**	1.000	
HI	-0.230	-0.366	-0.230	-0.316	-0.533*	-0.367	-0.338	-0.409	-0.522*	0.696**	0.791**	1.000

-----* significant at 0.01   ** significant at 0.001

Appendix 17a: Correlation coefficient between some plant parameters between 58 and 80 DAE (Season 1) long rains

	Change in Pod dry wt.	Change in stem dry wt.	Yield
Change in pod dry wt.	1.000		
Change in Stem dry Wt.	-0.290	1.000	
Yield	0.190	-0.415	1.000

Appendix 17b: Correlation coefficient between some plant parameters between 58 and 80 DAE (Season 2) Short rains

	Change in Pod dry wt.	Change in stem dry wt.	Yield
Change in pod dry wt.	1.000		
Change in Stem dry Wt.	-0.403	1.000	
Yield	0.523	0.153	1.000