AN EVALUATION OF SOURCE-SINK RELATIONSHIPS

IN THREE DRY BEAN (*PHASEOLUS VULGARIS* L.) CULTIVARS

by

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Submitted

in partial fulfilment of

the requirements for

the degree of

DOCTOR OF PHILOSOPHY

in the Department of Crop Science

University of Natal

Pietermaritzburg

November 1989

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DECLARATION

I certify that the research work reported in this dissertation is the result of my own original investigation, except where acknowledged herein.

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ACKNOWLEDGEMENTS

ABSTRACT

The effect of intensities and times of source or sink related stresses on the growth and development of a determinant (Teebus) and two indeterminant (NEP 2, Bonus) dry bean (*Phaseolus vulgaris* L.) cultivars was measured in a series of field experiments at Potchefstroom Research Station. Variation in stress levels was attained by defoliation, thinning, light intensity manipulation (shades and reflectors) and removal of reproductive organs.

No permanent detrimental effect on vegetative or reproductive organs was observed when source was reduced or increased during the vegetative period (V1-V6f). Flower initiation (V6f-R1) was identified as the period most sensitive to defoliation as expressed in vegetative growth and economic yield. The negative effect of shading on vegetative development was reduced by an extended growing period. Thinning during flower initiation increased the vegetative and reproductive sink. A source stress (defoliation and shading) during the flowering period (R1-R5) restricted partitioning to the reproductive organs reducing seed yield and harvest index values. Reduced interplant competition during flowering favoured partitioning to the reproductive organs. Source size had a direct relationship with economic yield during flowering. This was confirmed by the absence of a yield response to partial depodding.

A lack of response to defoliation (NEP 2) and shading (Bonus) may indicate a limited sink size in these two cultivars. During seed filling (R5-R9) Bonus was very sensitive to defoliation while NEP 2 was insensitive. Bonus was less sensitive to shading than Teebus. Thus in certain cultivars the level of current photosynthesis had a significant effect on seed yield throughout seed filling. The lack of a yield response to thinning in all cultivars during this period indicated that the potential sink size was set before R5.

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The results provided strong evidence supporting the concepts of yield component compensation in dry beans. Pod number was most seriously affected by defoliation during flower initiation and flowering. The potential sink size was determined mainly through the number of pods per plant which was in balance with the source unless some stress factor was present. The number of seeds per pod responded to current photosynthesis as well as the previously set pod number. Seed size was the least responsive yield component and it had a consistent negative relationship with the number of pods per plant.

CHAPTER 1

INTRODUCTION

It is generally accepted that modern crops differ much from their wild ancestors due to man's selection for higher yields of economically impor- tant organs and hence a large sink capacity. Very little, if any, progress has been made in improving yield by exploiting the variation in photosyn- thetic rate per unit leaf area which exists within species of crops such as cotton (Muramoto, Hesketh & El-Sharkawy, 1965), beans (*Phaseolus vulgaris* L.) (Izhar & Wallace, 1967) and sugarcane (*Saccharum officinarum* L.) (Irvine, 1967).

There is evidence that the yield increases attained in modern cultivars of many crops are the result of the partitioning of a higher proportion of their photosynthate to the storage organs than was the case in their parent cultivars (Donald, 1962; Gifford & Evans, 1981). Thus crop yield can be limited by an insufficient supply of photosynthate due to stress factors limiting photosynthesis. On the other hand a limited sink can set a ceiling to the potential yields (Evans, 1975).

The dry bean has been under domestication for at least 7 000 years in Central and South America (Evans, 1978), and is an essential source of plant protein and carbohydrates in the diets of people in the Americas and in Africa. Selection by man has transformed the crop from one with a viny growth habit with small seeds which shatter easily to one with a more upright growth habit, larger seeds and non-shattering pods (Vieira, 1973).

Dry bean production has not increased to the same extent as a result of breeding as is the case with cereals such as maize (*Zea maize* L.), wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.). The main improvements have been in the field of disease resistance or favourable maturity adjustments (Adams, 1973). Even with the best technology and improved cultivars, dry beans are considered a high risk crop especially in the

tropics due to susceptibility to stresses associated with disease, pest and climatic influences (Hernandez-Bravo, 1973).

In the past dry bean yields in South Africa have been limited mainly by source related stress factors such as leaf diseases particularly bean rust (*Uromyces phaseoli* (Ruben) Wint.), common blight (*Xanthomonas phaseoli* (E.F.Sm.) Dows.) and halo blight (*Pseudomonas phaseolicola* (Burk.) Dows.). With the introduction of disease free seed, improved cultivation practices and better cultivars, the yield potential has been raised and the risk involved in growing the crop has been lowered resulting in a general increase in farm yields.

In the quest for still higher yields, a better knowledge of the yield physiology of the crop is becoming more and more important. The crop is often grown under one or more of the following stress conditions: variable rainfall, low soil fertility, temperature extremes, or weed competition, and is often damaged by hail, insect pests or diseases which all influence plant population and light interception. These stresses vary in intensity and duration as well as the development stage during which they take place. A better understanding of the principles governing the influence of stress on the plant would help agronomists to explain and predict crop behaviour and breeders in selecting breeding material with a higher yield potential or better stress resistance.

On the basis of a review of the relevant literature (see Chapter 2), a hypothesis regarding the effects of stress on source-sink relationships in dry beans was developed, as outlined below:

(i) The effect of stress on the sink (vegetative as well as reproductive) is in proportion to the intensity of the stress.

(ii) Organs having preference to partitioned carbohydrates at a particular development stage will be more harmed by stress or benefit most from relief of stress. This will have the following consequences:

(a) The effect of stress on source or sink organs will vary depending on the development stage at which it is applied.

(b) Stress during the vegetative stage will determine the size of the source organs. This in turn will have an indirect depressing influence on the size of the later formed reproductive sinks.

(c) Stress during the reproductive stage will restrict the size of the reproductive sink.

(d) There are critical development stages which are more important than others in determining the size of the source or sink organs. There is therefore, no direct relationship between the length of the stress period and its effect on plant growth and development.

(e) When stress is relieved, the opposite mechanisms of those operating under stress will come into action.

(iii) Non-structural carbohydrate reserves can be mobilized when source becomes the limiting factor.

(iv) Yield component compensation takes place during the reproductive stage with the number of pods per plant as the first formed and most important yield component followed, in time and importance, by the number of seeds per pod and seed size.

(v) Source and sink sizes tend to be in balance by means of yield component compensation.

(vi) Cultivar differences which are observed can be explained in terms of source-sink relationships.

(vii) The influence of any stress on the plant, independent of the nature
       of the stress, takes place through the source of carbohydrates for-
       med in photosynthesis and therefore, there is a similarity between
       the effects of the different types of stress.

The main objective of the present study was to test this hypothesis in a
series of field experiments at Potchefstroom Research Station
(27° 05'E;26° 44'S;1345 m above sea level) which is situated in the Trans-
vaal highveld. The dry bean crop is grown during the frost free months of
the summer rainy season which extends from mid-October to mid-April. The
soil at the experiment sites consists of the Shorrocks series (Hutton
form) varying in depth between 600 mm and 900 mm. The treatments consis-
ted of levels and times of defoliation, thinning, removal of reproductive
organs and light intensity modification using shades and reflectors. A
cultivar variable was included in some of the experiments. Water stress
was not incorporated as a treatment and the experiments were irrigated to
provide a favourable soil moisture environment throughout the growing
season. Similarly fertilizer was applied to maintain optimum conditions of
soil fertility.   Disease free certified seed was planted each year to
prevent yield losses or uneven disease contamination. As an additional
precaution different sites were used each season to avoid carry over of
soil-borne diseases.

Meteorological data and details of irrigation, soil analyses and fertili-
zer application for seasons (1979/80, 1980/81, 1981/82 and 1985/86) in
which the experiments were conducted, are given in Appendices 1 (meteoro-
logical data) and 2 (soil analysis and fertilizer).

CHAPTER 2

LITERATURE REVIEW

2.1   General considerations

2.1.1   Synthesis of carbohydrates

The relationship between photosynthesis, carbohydrate assimilation and crop yield is very complex, largely as a result of the dependence of crop yield on the net assimilation value, which in turn is determined by photosynthetic rate, as well as leaf surface size, leaf area duration (LAD), canopy structure, dark and light respiration, translocation and partitioning of assimilates (Nasyrov, 1978).

Economic yield in the agronomic sense is in most cases not equivalent to total dry matter production but only to a certain fraction thereof. This fraction is not constant for a particular crop and may change both with the environment and the genotype. An increase in economic yield can be achieved by applying suitable methods of plant husbandry as well as breeding (Stoy, 1969).

Since leaves are the plant organs where most of the photosynthesis takes place, leaf area (LA) is a major physiological component of whole plant yield. The immediate components of LA are leaf number and leaf size. Normally in a plant community photosynthetic production rises with increasing LA per unit ground area, that is the leaf area index (LAI). This rise is, however, limited by mutual shading of the leaves whereby the mean rate of photosynthetic production per unit leaf (net assimilation rate (NAR)) is decreased. The LAI required for 95% light interception ranges from 3,1 to 4,5 for soybeans depending on the planting density and spatial arrangement (Shibles, Anderson & Gibson, 1976). The equivalent LAI for dry beans is about 4,0 (Aguilar, Fischer & Kohashi, 1977). In these two crops, there is no evidence of an optimum LAI or that the crop growth rate (CGR) falls

markedly above an LAI of 4,0 which represents the maximum LAI for optimum growth (Shibles & Weber, 1966; Aguilar *et al.*, 1977). Light interception in a crop canopy can be improved if the leaves are more vertically arranged, as in the case of maize (Duncan, 1971). The rate of photosynthesis is also influenced by environmental factors such as temperature, light intensity, CO_2 concentration, available moisture and internal factors such as genetic differences in photosynthetic efficiency between species and cultivars (Evans, 1975; Good & Bell, 1980).

2.1.2   Transport of carbohydrates

There is good evidence that the loading of sucrose in the phloem cells in the leaves and sugar (mainly sucrose) absorption by the sink cells are metabolic events requiring energy and taking place against concentration gradients while its transport in the sieve tubes is a passive process taking place down the osmotic pressure gradients (Gifford & Evans, 1981).

It is generally accepted that the products of photosynthesis are transported in the phloem mainly in the form of sucrose. General terms such as carbohydrates and plant metabolities (Biddulph, 1969), photosynthates (Stoy, 1969) and assimilates (Gifford & Evans, 1981) are used to include all these products.

Much research has been done on assimilate translocation in the phloem. The data indicates that translocation capacity out of the leaf is not a limiting factor in photosynthesis (Gifford & Evans, 1981) and that the phloem has a capacity for translocation beyond that measured in most systems (Evans, 1975).

2.1.3   Partitioning of carbohydrates

When the leaf is very young it imports photosynthetic products from other parts of the plant (acting as a sink) to build up its own structure. It starts exporting assimilates immediately after becoming self supporting

and thus the function changes to that of a source. As long as the plant is young this export is directed mainly towards centres of active growth such as developing leaves, root tips or shoot apices (vegetative sinks). Later much of the assimilate transport is diverted to storage organs such as fruits, grains or tubers (reproductive sink) (Stoy, 1969). The pattern of assimilate distribution is determined by photosynthesis on the one hand (source) and by the strength and proximity of the various sinks on the other hand and is modified to some extent by vascular connections and environmental conditions (Wardlaw, 1968).

The bean plant produces an axillary inflorescence. The nutritional unit consist of a trifoliate leaf on the main axis together with the flower-bearing raceme in its axil and a second smaller trifoliate leaf borne on the peduncle subtending the basal florets of the raceme (Adams, 1967). According to Adams (1967) primary competition for nutrients takes place among developing yield components within this unit and more or less simultaneously within several units of a given plant. Within each unit there is a fixed order of preference: (i) rapidly developing young pods, (ii) unopened flowers, (iii) open flowers, (vi) young fertilized ovules in developing pods and (v) freshly pollinated embryos and very young pods.

In the absence of genetic increases in NAR, past improvements in yield potential have been made largely in the area of the partitioning of accumulated dry mass which is invested in the organs harvested by man, the harvest index (HI) (Donald, 1962). This has been attained by increasing the size and duration of the photosynthetic apparatus, by increased rate of storage or by means of more and larger storage organs (Gifford & Evans, 1981).

Although much progress towards higher yields has been made by means of selection for these traits, it has become necessary to determine whether there is still room for further improvement as far as this aspect is concerned. A better knowledge of whether source or sink is limiting yield in a crop such as dry beans is necessary in order to gain more information on

the situation during different development stages. Evans (1975) pointed out that the seasonal sequence of conditions plays a major role in determining whether source or sink is the more limiting factor.

In situations where several sinks are competing for a limited supply of assimilates, the relative magnitude of the sinks may be of overriding importance in partitioning, with a pronounced bias in favour of the largest sinks. Such bias may increase yield, up to a point, by increasing the proportion of assimilates stored in the harvested organs. It would also operate to increase synchrony of storage and ripening since later formed sinks will tend to fail. The development of a substantial storage bias is made possible by the separation in time of the growth and storage phases of a crop (Evans, 1975).

2.1.4   Plant development

2.1.4.1   Development stages

A plant develops in a pre-determined way from the germinating seed through the vegetative and reproductive phases until it dies at physiological maturity after having produced seed to ensure the survival of the species.

Attempts to describe the development of the bean plant have been published by Lebaron (1974) and Fernandez, Gepts & Lopez (1986). According to Lebaron's system (based on the system of Fehr, Caviness, Burmood & Pennington (1971) for soybeans) the development of the bean plant can be divided into vegetative (V) and reproductive (R) stages. The different vegetative stages are determined by counting the number of nodes on the main stem including the primary leaf node. Reproductive stages are described with the aid of pod and seed characteristics. The reproductive stages commence with the first open flower on the plant (R1). At R5, seeds are discernible by feel and at R9, physiological maturity is reached.

Due to differences in temperature, soil moisture and day length much variation in the length of the growing season is experienced at different localities. There is however, little difference in the relative length of the growing season (or development stages) of the same cultivars at different localities (Liebenberg & Joubert, 1986).

As the active developing organs have preference to the available photosynthate, the centre of preference will differ throughout the season. Consequently stress of the same type and intensity will have a different effect on the developing plant depending on the development stage at which it occurs and the genotype.

2.1.4.2   Growth habit

Bean cultivars differ in their growth habits. These are referred to in common practice as determinate or indeterminate and bush or runner types. CIAT (1979) has proposed the following standard classification: Type I, determinate; Type II, indeterminate small vine; Type III, indeterminate large vine; and Type IV, indeterminate climbing. The yield potential of the determinate growth habit is lower than that of the indeterminate growth habits. The indeterminate growth habits do not differ much among themselves (CIAT, 1981). In South Africa the local dry bean cultivars belong to Types I, II and III, with most genotypes placed in the Type II and Type III categories (Liebenberg & Joubert, 1986).

In general Type I cultivars are found to have a shorter growing season, shorter stems, less LA per plant, fewer leaves, smaller leaf area ratios (LAR) and HI values, slower CGR prior to anthesis, fewer racemes per plant, fewer pods per plant, fewer seeds per pod and larger seeds than Type II and Type III (Kueneman & Wallace, 1979). Type II cultivars produce heavy biological yields coupled with high HI values and thus, high seed yields (Kueneman & Wallace, 1979). Type I cultivars are considered by some researchers to respond less favourably to denser between row spacings than Types II and III (Kueneman, Hernandez-Bravo & Wallace, 1978) and by

others, as subject to less competitive stress than the indeterminate ones at higher plant populations (Westermann & Crothers, 1977).

2.1.4.3   Growth and yield

Much has been written on the subject of plant growth and many excellent reviews published (Watson, 1952; Kvet, Ondok, Necas & Jarvis, 1971; Evans, 1972; Evans & Wardlaw, 1976).

In beans there is a positive linear relationship between leaf area duration (LAD) for the whole growth period and the node number and a positive correlation between LAD and seed yield. The CGR and LAI is curvilinear with a mean maximum growth rate of 12 g m^{-2} day^{-1} at LAI between 3,0 and 4,0 (CIAT, 1979).

CIAT (1981b) reported that the HI and yield/LAD ratios of dry beans are comparable with those of soybeans, and higher than those of other grain legume species studied. The growth pattern of the two species were similar. However, dry beans mature much earlier and thus have lower LAI and CGR values. The peak grain growth rate (GGR) of beans is much faster and the grain growth phase is proportionally much shorter than other grain legumes.

In a growth analysis study Brandes (1971) found the dry mass of each plant part divided by the number of leaves or pods was not influenced by the planting density or planting date. The total number of leaves had a very strong influence on biological and economic yield. Leaves and roots were the first parts to stop growing. Stem growth continued for a very short while until pods began to develop. In the phase of fastest development, pods received photosynthetic products first and this stimulated NAR.

2.2   Reproductive physiology

2.2.1   Flowering and pod development

Work with both temperate and tropical grain legumes has shown that many more flowers than pods are formed. Flower losses due to abscission may vary between species, for example: 85% in *Vicia faba* v. *minor* (L.) (Soper, 1952), 83% in soybeans (*Glycine max* (L.) Merr.) (van Schank & Probst, 1958) and 54% in cowpeas (*Vigna unguiculata* L.) (Ojehomon, 1970). In dry beans flower abscission varies between 66 and 76% (Subhadrabandhu, Adams & Reicosky, 1978; CIAT, 1980).

The degree of flower abscission varies quite widely among cultivars (Smith & Pryor, 1962; Subhadrabandhu *et al.*, 1978). Smith and Pryor (1962) found marked cultivar differences in percentage pod set as well as in the number of seeds per pod. The highest yielding cultivar also had the highest degree of pod retention. They found a positive relationship between the sensitivity of a cultivar to high temperature and the percentage flower abscission. Cultivar differences in flowering pattern were found by Subhadrabandhu *et al.* (1978). Some cultivars had a short concentrated flowering period of six days (reaching a peak at three days) during which most of the pods were retained while others had a longer less concentrated flowering period of 15 to 18 days (reaching a peak at eight days) and retained pods over a longer period. Flower abscission is also positively correlated with temperatures above 24°C (Davis, 1945; Smith & Pryor, 1962). The failure to set pods at high temperatures was found to be the result of embryo sac degeneration (Stobbe, Ormrod & Wooley, 1966).

Almost all the pods are set from the first 60% flowers formed (CIAT, 1981b). In general the first formed flowers have the highest probability of setting pods and producing mature seed (Smith & Pryor, 1962; Subhadrabandhu *et al.*, 1978; Binnie & Clifford, 1981).

The onset of flowering is influenced by photoperiod as well as temperature (Wallace, 1980). Short days will stimulate flowering in day length sensitive cultivars and high temperatures will have the same effect in all cultivars. Flowering is postponed by wider day/night temperature differences (Wallace, 1980).

Moisture stress during the vegetative stage postpones the onset of the flowering period and decreases the number of pods and seeds per pod when it occurs during the flowering and seed fill stage. During the seed fill stage moisture stress accelerates plant development and maturity (Robins & Domingo, 1956).

2.2.2   Yield components

According to Adams (1967) the yield components of the bean plant occur in a specific order of development: first the number of pods (per plant or unit area) followed by the number of seeds per pod and finally, the seed size (100 seed mass). The product of these three components represents the economic yield. Under conditions where either nutrients or metabolic substances (or both) are limited in the nutritional unit, the plant adjusts by dropping the most recently set pods followed, if the stress continues, by abortion of fertilized ovules in older pods (Adams, 1967).

The number of pods per plant is the yield component with the predominant influence on the yield of beans (Chung & Goulden, 1971; Duarte & Adams, 1972; Westermann & Crothers, 1977); soybeans (Pandey & Torrie, 1973) and *Vicia faba* v. *minor* (L.) (Yassin, 1973), since it incorporates the other two yield components. There is a positive correlation between number of pods per plant and leaves per plant, and between leaf size (area of individual leaves) and seed size (Duarte & Adams, 1972).

Pods per plant can be partitioned into four components: pods per raceme, racemes per node, nodes per branch and branches per plant. Bennett, Adams & Burga (1977) concluded that most of the variation in pods per plant,

induced by plant population stress, can be attributed to changes in the number of branches and racemes developed. These two components are negatively correlated with each other. The other two components have little influence on yield.

2.2.3   Yield component compensation

The yield components of beans are believed to be genetically independent. Under stressed situations, however, negative correlations arise as induced relationships. According to a hypothesis proposed by Adams (1967) the rate of metabolic input for the formation and development of reproductive structures is relatively invariable and limiting. As component x (the first in the sequence) uses up more or less of the input, y (the next component in the sequence), tends to vary in a compensatory direction. Component z (the last in the sequence) may also vary in reaction to x and y. Within each nutritional unit the order of preference for photosynthate is as described in par. 2.1.3. If, therefore, the photosynthate is limited then young embryos and pods will abort, and consequently less pods per plant and seeds per pod will be formed. As seed size is the last component to develop, it will react to the available photosynthate during the seed fill period.

Duarte and Adams (1972) come to the conclusion that the direct effect of a particular component upon yield is in nearly every case partially counterbalanced by negative indirect effects through the other two components. These negative forces are mostly smaller in value. However, in combination two such indirect forces can offset much of the determination of yield by the direct force. They maintain that this is a clear case of yield component compensation in beans.

2.3   Source-sink relationships

2.3.1   Stress and yield potential

The best yields obtainable with the present dry bean cultivars are rela-
tively low in comparison with other field crops (Denis & Adams, 1978).
Average bean yields differ very much, however, between countries and also
within the same country as a result of many different stress factors such
as climate, soil and diseases and pests which prevent the crop from attai-
ning its maximum yield. The main production constraints for dry beans in
the lowland tropics are high temperatures, low and unreliable rainfall,
excess water, diseases, insects, nutritional deficiencies and weed compe-
tition (Camacho, 1973; Hernandez-Bravo, 1973). Most of these stress fac-
tors have an effect on growth and development via a reduced source of
photosynthate. However, sensitivity to high temperatures or other damage
to the reproductive organs are stress factors which are more related to
the sink.

The objectives of bean breeding programmes are, on the one hand, to reduce
the risk of crop failure by incorporating resistance to the different
stress factors in new cultivars and on the other to increase the yield
potential by incorporating physiological traits which might lead to im-
proved yield potential (CIAT, 1981b).

2.3.2   Is source or sink limiting yield?

Evans (1975) points out that in many cases it is very difficult to decide
whether source or sink is the limiting factor as the demands for assimi-
lates for storage can have a pronounced feedback effect on the rate of
photosynthesis. For example spare photosynthetic capacity is increased.

The relationship between photosynthesis and crop yield is very complex.
According to Nasyrov (1978) there is no direct relationship, probably as a
result of the dependence of the crop on the NAR, which in turn is

determined by photosynthesis, LA, LAD, canopy structure, dark and light respiration, translocation and partitioning of assimilates.

The yield of a crop depends on all the variables to which it has been exposed during its previous growth. If the aim is to understand how and by how much yield can be increased, then information is needed on the changes that occur throughout the growth period, on how they depend on properties of the plant and are affected by environmental factors (Watson, 1971).

In his extensive review on the subject of whether source or sink is limiting yield, Evans (1975) comes to the conclusion that it is not a question of the one or the other. Even if source or sink is limiting in a particular case, it is doubtful whether that conclusion would apply to other crops in the same environment or to the same crop in other environments as the seasonal sequence of conditions plays a major role in whether source or sink is more limiting.

To determine whether the growth of the useful plant parts at any time is controlled by the supply of photosynthate or by the sinks, it is necessary to change one or the other and measure the effect on growth. Watson (1971) points out that the photosynthate production in a field crop cannot be increased suddenly but it can be decreased by shading or partial defoliation. Similarly the demand for photosynthate by the sink cannot suddenly be increased but it can be decreased by removing part of the sink. The results might often be difficult to interpret as the photosynthetic and storage capacity are often in balance or nearly so. This is often the case in modern cultivars of all the major crops (Evans, 1975).

Beans differ from most other crops in that they have a very short growing season especially in tropical regions. CIAT (1981b) comes to the conclusion that beans adjust potential sink size (pod numbers) to available source (LA) and then proceed to fill the sink (seed crop growth rate) as quickly as possible.

Examples of sink limitation of yield in rice (in warmer areas), potatoes and tobacco and source limitation in cotton (at high temperatures) are cited by Evans (1975). The findings indicate a very complex situation where generalisations can be made only with the utmost caution. An attempt at finding some general principles behind source-sink relationships should, however, be made in order to predict crop behaviour.

2.3.3   Manipulation of the source

Photosynthetic supply can be altered artificially by changing the light intensity by shading or plant population, manipulating LA through partial defoliation, increasing the CO_2 concentration in the air, water stress and temperature changes. Leaf area and light intensity are referred to more specifically in the following sections since they formed part of the present study though water stress is included in view of its relevance in South Africa.

2.3.3.1   Leaf area

In his studies on the physiological causes of variation in crop yield, Watson (1952) concluded that variations in LA and LAD were the main causes of yield differences. Researchers have found that differences in CGR are related to variations in NAR in different crops (Yoshida, 1972).

Thorne (1971) found that yield is limited by LA at certain times of the year and that there is still scope for improvement, especially for increasing LA early in the vegetative period and extending the survival of leaves during seed fill. The effect of defoliation and hence LA, on dry matter production and yield is proportional to the level of defoliation in dry beans (Link, Costa & Pachini, 1980; Hohmann & Carvalho, 1983; Waddill, Pohronezny, McSorley & Bryan, 1984), groundnuts (*Arachis hypogaea* L.), soybeans and green gram (*Vigna radiata* L.) (Enyi, 1975), sorghum (*Sorghum*

bicolor L.) (Enyi, 1973), lupin (*Lupinus angustifolius* L.) (Downes & Gladstones, 1984) and cowpeas (Pandey, 1983).

The response to defoliation depends very much on the development stage at the time of treatment. Most researchers agree that defoliation has the least effect on beans during the pre-flowering stage and that the flowering and pod formation stages are more sensitive (Galvez, Galindo & Alvarez, 1977; Edje, 1981; Vieira, 1981; Bartoli, Nakano & Perecin, 1982; Hohmann & Carvallo, 1983). Cultivar differences in reaction to defoliation are quite common in beans. Vieira (1981) found that Carioca was more tolerant to 33% and 66% defoliation than S-182-N (both indeterminate cultivars). Duque & Quintero (1977) also found differences between two cultivars depending on the level and development stage when the defoliation treatment was applied. In a trial with four cultivars, Link *et al.* (1980) found that the removal of one trifoliate only, at 35 days after emergence, reduced yields in one cultivar. Removal of two trifoliates at 49 days after emergence reduced the yields of all the cultivars.

The number of pods is the yield component most adversely influenced by defoliation in beans (Edje, 1981; Bartoli *et al.*, 1982), groundnuts (Wilkerson, Jones & Poe, 1984) and soybeans (Edje & Leggett, 1976). Reductions in the other yield components of beans are also reported, for example: seeds per pod (Bartoli *et al.*, 1982) and seed size (Edje, 1981).

Enyi (1975) concludes that in the case of groundnuts, cowpeas and green gram, the assimilates produced by the leaves during the early development stages are used for stem growth and new leaves, but that the assimilates produced during the reproductive stage are mainly used for the growth of pods. In groundnuts the pod number and seed yield correlated positively with stem mass. It appears that defoliation reduced pod number by depressing stem growth, which in turn reduced the number of flowering nodes. According to Wilkerson *et al.* (1984), defoliation in groundnuts appears to alter the normal partitioning of photosynthate between plant parts: lower

stem mass to length ratios, lower pod mass and equal or higher leaf masses.

Partial defoliation reduced starch levels in soybean leaves (Hanson & West, 1982) and glucose and sucrose levels in stems and pod walls of pigeonpea (*Cajanus cajan* (L.) Mill.) (Setter, McDavid & Lopez, 1984). There are indications of stored reserves in bean stems and roots which differ between cultivars. It is not clear whether these can be mobilized in case of a limited supply, but they are usually found to decline during the seed filling period (Adams, Wiersma & Salazar, 1977). In maize stored carbohydrates in the stem can contribute to ear mass in the case of complete defoliation (Duncan, Hatfield & Ragland, 1965).

Partial defoliation increases the CO_2 assimilation rate in the remaining leaves of beans (Wareing, Khalifa & Treharne, 1968; Caemmerer & Farquhar, 1984), pigeonpea (Setter *et al.*, 1984), soybean (Hanson & West, 1982), and maize (Wareing *et al.*, 1968). This provides experimental evidence that demand for assimilates by the sink has a stimulating influence on the photosynthetic rate. This effect is associated with a rise in the leaf protein content and the ribulose-1,5-diphosphate carboxylase activity in bean and maize leaves (Wareing *et al.*, 1968; Caemmerer & Farquhar, 1984) under saturating light intensities. Partial defoliation, however, enhances light penetration to lower leaves in the canopy. This can to some extent compensate for a loss in LA.

2.3.3.2   Light intensity

Shading is frequently employed as a means of limiting the source in a crop. It has repeatedly been found that the photosynthetic response of a plant is affected by the light intensity to which it is exposed. Crops in which this response is well established include beans (Crookston, Treharne, Ludford & Ozbun, 1975), soybeans (Johnston, Pendleton, Peters & Hicks, 1969), pigeonpea (Setter *et al.*, 1984) and wheat (Jenner, 1980). Photosynthesis is reduced in proportion to the decrease in light

intensity. The reduced CO_2 exchange under shading is influenced by increased intra-cellular resistance and by reduced enzyme activity in beans (Crookston *et al.*, 1972). Reduced respiration rates as well as a very distinct reduction in CO_2 exchange rates at deeper canopy levels were observed in experiments in soybeans conducted by Johnston *et al.* (1969). An increase in the efficiency of solar energy conversion with decreasing light intensity levels was recorded by Lopez, Oliva, Freitas, Melgers & Beltrao (1982) in beans.

Photosynthesis in the leaf produces carbohydrates which are translocated to other plant organs, which in turn act as a sink at a particular development stage. Shading reduces the starch and sugar levels in the leaves of beans (Crookston *et al.*, 1975) and pigeonpeas (Setter *et al.*, 1984) which indicates that the demand for photosynthate is bigger than the supply. Carbohydrate reserves in the stem (nonstructural carbohydrates) decrease as a result of shading in soybeans (Trang & Giddens, 1980) and pigeonpea (Setter *et al.*, 1984)

The reduced availability of photosynthate as a result of shading influences the growth and development of the whole plant. A reduction in LA, leaf thickness (an increase in LAR) and the number of leaves (nodes) has been reported in beans (Crookston *et al.*, 1975; Lopez *et al.*, 1982) and reduced N_2-fixation in soybeans (Wahua & Miller, 1978). The inevitable result is a reduction in the dry matter production with decreasing light intensity in beans (Escalante & Kohashi-Shitaba, 1982; Lopez *et al.*, 1982; Martinez, 1982; Eriksen & Whitney, 1984) and in soybeans (Schou, Jeffers & Streeter, 1978; Trang & Giddens, 1980).

The growth habit of cultivars influences their reaction to shading. Martinez (1982) found that the total dry matter and seed yield of cultivars with an indeterminate climbing growth habit were unaffected by as much as 79% shading before flowering and at the onset or during mid flowering, indicating a sink limitation. Portez & Silveira (1982) found that seed yields of four cultivars, with different growth habits, were reduced

between 54% and 90% by 79% shading during the whole growing period. Pod numbers were reduced in all cultivars. In the case of the non-climbing cultivars a decrease in seed yield with decreasing light intensity is experienced, which is in proportion to the light intensity. This response has been recorded in beans (Martinez, 1982; Portez & Silveira, 1982; Eriksen & Whitney, 1984; Scheps & Ashley, 1985) and soybeans (Johnston et al., 1969; Schou et al., 1978; Wahua & Miller, 1978; Eriksen & Whitney, 1984).

Yield reductions at low light intensity in these studies were mainly as a result of a reduced number of pods per plant or unit area. The number of seeds per pod seems to be less severely affected and no reference to a reduction in this yield component could be found in the literature for beans or soybeans. An increase in seed size was reported by Martinez (1982) for indeterminate climbing bean cultivars and a decrease in seed size of soybeans at low light intensities by Wahua & Miller (1978).

Shading seems to have little influence on the chemical composition of soybean seed (Wahua & Miller, 1978). In studies conducted by Martinez (1982), shading increased the number of empty pods in beans while Struik (1983) recorded a higher percentage aborted kernels in maize under similar conditions. Changes in the growth habit of beans due to shading have been observed, for example indeterminate bush types may change to indeterminate runner types (Lopez et al., 1982). Shading may extend the growing period in beans (Eriksen & Whitney, 1984) and maize (Struik, 1983).

The effect of shading differs during different stages. It is more harmful during the reproductive than during the vegetative stage of beans (Escalante et al., 1982). Shades have a moderating influence on air temperature which was found to be as much as 6°C cooler than control plots at noon in experiments conducted by Schou et al., 1978.

As a result of mutual shading the light intensity in a canopy decreases from the top down to the soil surface. This effect is more pronounced at higher plant densities. Attempts to study the effect of increased light intensity at lower canopy levels by means of artificial lighting or reflectors are reported in soybeans and maize. These treatments gave increased yields in soybeans (Johnston *et al.*, 1969; Schou *et al.*, 1978) and maize (Pendleton *et al.*, 1967) with the greatest effect occurring at the lower canopy levels in the soybeans. Light rich soybean plants had more pods, seeds, seeds per pod, nodes, pods per node, a higher oil content, smaller seeds and a lower protein content than the controls (Johnston *et al.*, 1969). Maize in light rich environments had more tillers, more plants with two ears, shorter and thicker stalks and grain yields were greatly increased compared with the controls (Pendleton *et al.*, 1967).

In the experiment of Schou *et al.*, (1978) reflectors had no significant temperature effect at night but raised plant temperatures significantly at noon in soybeans. Air temperature did not differ in the rows of treated plants probably due to air turbulence. The increase in plant temperature is considered by these authors as a possible cause of increased pod development in the case of the reflector treatments.

2.3.3.3   Interplant competition for light

Plants in a pure stand compete for light and CO_2 in the air and moisture and nutrients in the soil. Due to the air turbulence, competition for CO_2 in the canopy is unlikely (Allen, Desjardins & Lemon, 1974). There is no evidence of yield reductions due to competition for nutrients in a fertile soil (Fischer & Laing, 1976). Similarly under conditions of frequent irrigation, soil moisture does not impose stress even under varying plant populations (Robins & Domingo, 1956). Under well watered and fertilized conditions, competition for light amongst plants is the overriding consideration in plant population manipulations.

Results of plant population studies in beans vary widely with regard to the optimum plant configuration, as well as plant population. It is virtually impossible to compare different studies as a result of interactions between cultivars, growth habit and especially length of growing season.

An increase in light interception and total dry matter was recorded at denser bean plant populations in the experiments of Aguilar, Fischer & Kohashi, (1977). They found a positive correlation between CGR and LAI values (up to 5,0) while Wien (1971) found that NAR varied inversely with LAI. The increase in dry matter production is also reflected in seed yield as harvest indices do not show changes over a wide range of plant populations (Leakey, 1972; Aguilar *et al.*, 1977). Plant maturity can be advanced by seven to ten days in denser plant spacings (Crothers & Westermann, 1976; Lucas & Milbourn, 1976). A decrease in the number of branches per plant is experienced at higher plant populations (Lucas & Milbourn, 1976). A high plant mortality at higher plant populations was observed by Leakey (1972).

The number of pods per plant is the yield component which is affected most by increasing plant density. There is a decrease in the number of pods per plant but an increase per unit area (Crothers & Westermann, 1976; Aguilar *et al.*, 1977; Westermann & Crothers, 1977). Reduced pod retention was, however, observed at higher plant populations in studies conducted by Lucas & Milbourn (1976). The number of seeds per pod is less responsive to plant population and no reaction was found by Leakey (1972) or Lucas & Milbourn (1976) while Aguilar *et al.* (1977) experienced a decrease in seeds per pod at higher plant populations. No reaction in seed size to varying plant populations was reported in any of the cited studies.

Growth habit has an influence on the bean plants reaction to plant population stress. Determinate cultivars appear to be less subject to competitive stress than indeterminate cultivars in some cases (Crothers & Westermann, 1976; Westermann & Crothers, 1977) and more so in others (Kueneman *et al.*, 1978).

Thinning treatments have been valuable in showing when and to what extent yield components are influenced by inter-plant competition in for example maize (Prine, 1971), wheat (Fischer & Laing, 1976) and beans (Aguilar et al., 1977). Aguilar et al., (1977) reported a lower total dry mass (TDM) and higher HI, more pods per plant and seeds per pod as well as no change in seed size as a result of thinning. Relative growth rate increased for the rest of the growing period in plants thinned before the end of the flowering period. They observed no competition until two weeks before flowering or after the end of the flowering period. Fisher & Laing (1976) and Darwinkel (1984) found similar trends in wheat. Compensation decreased the later the thinning was done. Thinned plants reacted by producing more ears, more seeds per ear and larger seeds. After flowering compensation was small and resulted only in increased seed size.

2.3.3.4   Water stress

The rate of initiation and differentiation of vegetative and reproductive primordia in the apical meristems as well as the amount of enlargement of the differentiated cells are all very sensitive to water stress. Cell enlargement is the more sensitive component. This is first reflected in reduced leaf enlargement at very small water deficits. Net photosynthesis is reduced by water stress. The effect of water stress tends to be most pronounced in those tissues which are in a rapid stage of development (Slatyer, 1969).

Water stress in beans results in yield reductions which expresses itself in the yield components, depending on the development stage of the plants during the stress period. Robins & Domingo (1956) found that water stress before blooming reduced the number of pods, reduced the pods and beans per pod during blooming and reduced seed size during the seed fill period. Plant development was retarded by stress before blooming and hastened during blooming and seed fill. They also found that irrigation before visible water stress, caused no yield advantage. Cultivar differences in tolerance to water stress have been observed (CIAT, 1983).

In soybeans Shaw & Laing (1966) found that the compensation among yield components is responsible for the yield stability of soybeans under water stress. During the early flowering period water stress resulted in flower and pod drop in the lower parts of the plant, but more pods set on upper nodes. At mid-flowering and early podding stage, increased pod set on upper nodes as well as larger bean size on the lower nodes, compensated for a reduced number of pods on the lower nodes. As development proceeded the compensatory capacity diminished and the major effects shifted from pod number to number of beans per pod and seed size.

Wheat is relatively insensitive to drought until approximately halfway to flowering, which corresponds to the period of production of floral primordia (Fisher, Lindt & Glave, 1978). They found that in wheat water stress before ear emergence reduced seed number. After anthesis seed number was insensitive to water stress.

According to Fischer & Turner (1978) assimilate allocation to the reproductive organs of annual plants is not substantial until flowering is approached. Due to a lack of available assimilate and interplant competition as in crops, some primordia fail. Water stress accelerates these processes but probably in part via reduced assimilation (source) as the proportion of the total assimilate allocated to reproductive organs is unchanged or may increase with water stress (Fischer & Turner, 1978).

2.3.3.5 CO_2 concentration

It has been found that crops are more productive in an atmosphere enriched with CO_2). In CO_2 enrichment trials during the early flowering period increased pod set in beans (CIAT, 1977) and soybeans (Hardman & Brun, 1971) resulted in marked yield increases. This indicates that the photosynthate supply during this phase is of critical importance. CO_2 had no influence on the number of seeds per pod or seed size of beans but increased the seed size in soybeans.

2.3.4   Manipulation of the sink

2.3.4.1   Reducing storage capacity

If the sink size is a limiting factor, higher yields could be achieved if more pods were retained by the plant. Many attempts have been made to investigate source-sink relationships by means of the removal of reproductive structures. If complete removal is maintained for a long period, its main effect is to limit the photosynthetic rate of the leaves in beans (Plaut & Mayoral, 1984) and soybeans (Mondal, Brun & Brenner, 1978).   This is the opposite mechanism to that observed when the source (LA) is reduced (see 3.3.3.1). The apparent inhibition of senescence as indicated by the soybean leaves retaining their green colour until the plants are killed by frost is one of the most striking features of depodded plants (Hicks & Pendleton, 1969). Although depodding delays the loss of leaf chlorophyll, it does not delay the onset of functional leaf senescence accompanied by stomatal closure. In fact the leaf photosynthesis was found to decline earlier in depodded than control plants and depodding appears to change the function of the leaf to a storage organ resulting in an increase in the specific leaf mass and starch content (Wittenbach, 1982; Wittenbach, 1983).

The effect of a lack of storage capacity on dry matter production seems to vary depending on the crop, intensity and duration of the treatment. It appears that if all the reproductive structures are removed for a limited period, the dry matter production is not adversely affected. A redistribution of the dry matter production takes place and more vegetative organs (branches, leaves and roots) are produced. New reproductive organs are formed resulting in a normal yield but a somewhat extended growing season. In cases of continued depodding a drop in the rate of dry matter production is experienced accompanied by an increase in the nonstructural carbohydrate (mainly starch) content of the leaves, and especially the petioles (Ciha & Brun, 1978).

The effect of depodding on seed yield is similar to that on dry matter production. Complete flower removal for a limited period results in a normal yield from later formed pods in beans (Binnie & Clifford, 1981; Santos, 1984). In cases of partial pod removal yield reductions seem to depend on the intensity of the treatment. No yield reductions with as much as 33 to 40% depodding were experienced in soybeans as the plants compensated by producing larger seeds (McAllister & Krober, 1958; Hicks & Pendleton, 1969). An increase in seed size rather than an increase in the number of seeds per pod was found to be the most common way of yield component compensation in beans (Olufajo et al., 1981) and soybeans (McAllister & Krober, 1958; Hicks & Pendleton, 1969; Egli & Leggit, 1976; Openshaw et al., 1979). Olufajo et al. (1981) found that the removal of the immature edible bean pods within 18 to 24 days after the onset of flowering (partial pod removal) resulted in a insignificant yield reduction, mainly due to increased seed size. Yield reductions increased with later treatments.

No reference to the effect of pod removal on the chemical composition of bean seed was found in the literature. In soybeans an increase in the protein and a decrease in the oil content of the seed were observed (McAllister & Krober, 1958; Hicks & Pendleton, 1969; Openshaw, 1979).

CHAPTER 3

DEFOLIATION STUDIES

3.1   Introduction

A convenient method of determining whether the source represents a yield
limitation in dry beans is to manipulate the LA by manual defoliation.
Watson (1952) pointed out that variation in LA and LAD are the main causes
of differences in yield. This implies that the intensity as well as the
stage of defoliation will have an influence on the sink size (yield and
yield components).

When defoliated at different development stages and intensities the plants
will react by deviating from the normal development pattern. A study of
these changes in vegetative and reproductive development may help to quan-
tify the relative importance of the source at a particular development
stage. Cultivar response to defoliation treatments provides data regarding
genotypic interactions which are of value in breeding programmes and crop
management.

3.2   Methods and materials

3.2.1   General information

The trials were conducted in 1979/80 and 1980/81. Meteorological data and
details of irrigation applied are given in Appendix 1.1 (1979/80) and
Appendix 1.2 (1980/81). Chemical analyses of the soil and fertilizer
applications are set out in Appendix 2.

3.2.2   Defoliation trial, 1979/80

This experiment incorporated levels and times of defoliation. The times of defoliation were related to development stages, as classified in Table 3.1.

The treatments were as follows:

Control

CO   no defoliation.

Levels of defoliation

P1   33%, one leaflet per trifoliate removed over the entire plant,
P2   66%, two leaflets per trifoliate removed over the entire plant.

Time of defoliation

Excision of unfolded leaflets took place twice a week for the duration of the relevant periods of defoliation, as listed below:

S1   (V2-V6f) between first trifoliate and six leaves on the main stem,
S2   (V2-R1) first trifoliate to 50% flowering,
S3   (V6f-R1) end of S1 to 50% flowering,
S4   (R1-R5) 50% flowering to beginning of pod fill,
S5   (R1-R9) 50% flowering to physiological maturity,
S6   (R5-R9) beginning of pod fill to physiological maturity,
S7   (V2-R9) first trifoliate to physiological maturity.

The cultivar Teebus (Table 3.2) was planted on 1979/11/30 in a 2 x 7 fac-torial experiment with an added control, the control being repeated twice in each of the four replications (blocks) for balance. This provided an extra degree of freedom for error. A plot size of four rows of 5 m in

Table 3.1 Development stages adopted in the present study (after Lebaron, 1974)

Stage	General description
V0	Emergence - cotyledons appear above ground.
V1	Completely unfolded leaves at the primary (unifoliate) leaf node.
V2	First node above primary leaf node. The stage is counted when leaf edges no longer touch.
V3	Three nodes on the main stem including the primary leaf node. Secondary branching begins to show at the primary leaf node.
V(n)	n nodes on the main stem.
V(n)f	n nodes on the main stem and one flower bud visible on 50% of plants (flower initiation).
R1	50% flowering: one blossom open at any node on 50% of the plants.
R2	Pods 12 mm long at first blossom position.
R3	Pods 25 mm long at first blossom position.
R4	Pods 50 mm long at first blossom position.
R5	Onset of seed fill, pods 75 mm or longer, seed discernible by feel.
R6	Pods 100 mm to 125 mm long (maximum length). Seeds at least 6 mm in long axis.
R7	Oldest pods have fully developed green seeds. Other parts of the plant will have full length pods with seeds near the same size.
R8	Leaves yellowing over half of plant, very few small new pods developing, small pods may be drying.
R9	Physiological maturity, at least 90% of the pods showing yellow and mostly ripe.

Table 3.2 Description of dry bean cultivars included in the field experiments

Cultivar	Classification (CIAT, 1979)	Trade description	Growth habit
Teebus	Type I	Small white canning bean	Determinate bush
NEP 2	Type II	Small white canning bean	Indeterminate bush
Bonus	Type III	Speckled sugar bean	Indeterminate short runner

length and an interrow spacing of 750 mm was adopted. The intra-row spacing was 75 mm. Two seeds were planted per hill and the seedlings thinned to one, a week after emergence, to provide a population of 177 778 plants ha^{-1}.

Samples (for growth analysis) were collected from each plot at three stages of development: R1 (50% flowering), R5 (beginning pod fill) and R9 (physiological maturity). The R1 samples were taken on the day following the initiation of treatments S4 and S5 while the R5 samples were collected on the day following the initiation of treatment S6. The sample plots consisted of the two centre rows, 0,675 m in length (1,01 m^2) which provided 18 plants. In order to avoid disturbance in the whole plot, the sample plots were selected in series beginning at either end of the plot. The discard between sample plots and at the end of the rows, consisted of one plant. The samples were collected in the early morning (07:00-08:00), washed, placed in plastic bags and transported to the laboratory where LA (R1 and R5 only) and number and mass of plant organs were determined. The fresh material consisting of the whole sample (R1, R5) or a subsample (R9) was oven dried at 100°C for 48 hours and the results expressed in terms of oven dry mass per plant.

The measurement procedures in the laboratory are given below together with the sampling stage at which each parameter was measured.

(i)   The LA (R1, R5) of one plant drawn at random from each sample was measured with a LI-COR Model 3100 Area Meter. The total LA of the sample was measured as:

LA = z/y.(x+y)   (1)

where LA is the total LA of the sampled plants, x is the total leaf mass of all the plants minus one, y is the leaf mass of one plant and z is the total LA (m^2) of one plant.

(ii)   All the plants were dissected and the oven dry mass of the follo-
         wing fractions was determined: stems and branches with petioles
         attached (R1, R5, R9); leaves (R1, R5); pods (seed and podwall)
         (R5, R9) and seed (R9). The sum of the relevant fractions of the
         first three components gave the total above ground dry mass (TDM)
         (R1, R5, R9). The HI (R9) was derived as follows:

$$HI = \frac{seed\ mass}{TDM} \cdot 100 \qquad\qquad\qquad (2)$$

         An estimate of seed size was obtained by counting the number of
         seeds in a random oven dry sample of known mass and expressing the
         result as: $g\ (100\ seed)^{-1}$ (R9)

(iii)   Prior to oven drying the number of nodes (R5); leaves (R1, R5);
         racemes (R5); pods and seeds (R9) were counted. The quotient of the
         number of seeds and the number of pods in each sample gave the num-
         ber of seeds per pod (R9).

3.2.3   Defoliation trial, 1980/81

The results of the 1979/80 trial showed that there was a strong negative
relationship between the intensity of defoliation and dry matter and seed
yield. The effect of time of defoliation was less distinct and for this
reason more emphasis was placed on this variable in 1980/81. In order to
identify interactions between genotype and defoliation, two additional
cultivars (Table 3.2) were included in the trial. A single level of defo-
liation (66%) was applied at 11 times, each time consisting of a 7 day
period. Two leaflets per trifoliate were excised at the beginning and the
end of each period. An undefoliated control plot of each cultivar was
included in each replicate. The treatments were as follows:

Cultivars

C1   Teebus,

C2   NEP 2,

C3   Bonus.

Time of defoliation

S0   control (no defoliation)

S1   (V3) defoliated 8 to 14 days days after emergence,

S2   (V5) defoliated 15 to 21 days days after emergence,

S3   (V7f) defoliated 22 to 28 days days after emergence,

S4   (V9f) defoliated 29 to 35 days days after emergence,

S5   (R1) defoliated 36 to 42 days days after emergence,

S6   (R2) defoliated 43 to 49 days days after emergence,

S7   (R3) defoliated 50 to 56 days days after emergence,

S8   (R5) defoliated 57 to 63 days days after emergence,

S9   (R6) defoliated 64 to 70 days days after emergence,

S10   (R7) defoliated 71 to 77 days days after emergence,

S11   (R8) defoliated 78 to 84 days days after emergence.

The trial was planted on 1980/12/09. The design was a 3 x 12 factorial with three replicates (blocks). The plot size and spacing were the same as in the preceding season.

Growth analysis procedures were the same as in the 1979/80 season except that sampling was restricted to the R9 stage. The measured parameters consisted of (i) vegetative components: stem mass and number of nodes; (ii) reproductive components: number of racemes, pods, seeds and seeds per pod; 100 seed mass and the mass of pods and seeds, (iii) total above ground dry mass and (iv) HI.

3.2.4   Correlation matrix

Simple correlations were calculated between all the measured parameters in each experiment and expressed in terms of a correlation matrix.

3.2.5   Statistical analysis

All trials were designed according to the standard procedures for randomized complete-block factorial experiments (Cochran and Cox, 1957; Rayner, 1967). The 1979/80 trial was analysed on a Burroughs B 7900 computer using the Genstat V Mark 4.04B B5900 Release package system. The 1980/81 trial was analysed on a Hewlett Packard 9826 computer using the manufacturers package system. The least significant difference (LSD) test was used to compare treatment means (Steel and Torrie, 1960). Throughout the thesis tests of significance are given at the 0,01(**) and 0,05(*) levels of probability.

3.3   Results, 1979/80

3.3.1   Vegetative sink

3.3.1.1   Leaf area

The sampling conducted at the R1 stage (50% flowering) (Table 3.3) indicated that there was no significant difference between the control and the treatment (S1) which was defoliated between emergence and the six leaf stage. This suggests that compensation had occurred in this treatment though the effect was less marked at the higher intensity of defoliation. Leaf areas in treatments (S2, S7) in which defoliation had continued for a longer period since emergence or was initiated at the six leaf stage (S3), were lower than the control with a very marked reduction at the higher intensity. The LA of treatments defoliated the day before sampling (S4, S5) tended to be a little lower than those in which defoliation had taken

Table 3.3 The effect of levels and time of defoliation on the leaf
area (m^2 x 10^{-4} plant^{-1}) of dry beans (cv. Teebus) at R1
stage, Potchefstroom, 1979/80 (see Appendix 3)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 3289			
S1 (V2-V6f)	3231	2839	3035
S2 (V2-R1)	2483	1770	2126
S3 (V6f-R1)	2681	1678	2180
S4 (R1-R5)	2072	1453	1762
S5 (R1-R9)	2408	1348	1878
S6 (R5-R9)	3557	3232	3394
S7 (V2-R9)	2644	1493	2068
Mean	2725	1973	2467
CV	14,4%		

	SE	LSD 0,05	0,01
Co vs P means	± 101	287	383
P means	± 67	191	255
Co and S means	± 126	358	477
Co vs P x S	± 178	NS	NS
P x S	± 154	NS	NS

place previously. As would be expected there was no significant difference between the control and the treatment which had not been defoliated.

The control and the S1 treatment continued to maintain similar leaf areas at the R5 sampling (Table 3.4). Compensation appeared to have occurred in the S2 treatment at the lower intensity (P1) between the R1 and R5 sampling and there was little difference between this treatment and the control in the latter sampling. Leaf area was lower than the control in all the other treatments which entered the pod filling stage with mean leaf areas of 2347 m^2 x 10^{-4} (P1) and 1874 m^2 x 10^{-4} (P2) compared to 2776 m^2 x 10^{-4} in the control.

3.3.1.2   Leaf mass

As may be seen in Tables 3.5 and 3.6, the effect of treatments on leaf dry mass was virtually the same as that of LA.

3.3.1.3   Leaf number

The effect of treatments on this parameter which was measured at the R6 stage only, was different to that observed in the measurements of LA and mass. Here both intensity and duration of defoliation increased leaf number significantly (Table 3.7).

The control produced significantly fewer leaves than the 66% (P=0,01) level of intensity. Similarly defoliation at any time between flower initiation and the onset of the seed fill period (S2, S3 S4, S5 and S7) tended to cause an increase in the number of leaves per plant. In the case of the three treatments which were defoliated between flower initiation and flowering (S2, S3 and S7) this increase was significant.

Table 3.4 The effect of levels and time of defoliation on the leaf
area (m^2 x 10^{-4} plant^{-1}) of dry beans (cv. Teebus) at the
R5 stage, Potchefstroom, 1979/80 (see Appendix 3)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 2776			
S1 (V2-V6f)	2810	2960	2885
S2 (V2-R1)	2755	1977	2366
S3 (V6f-R1)	2184	2087	2135
S4 (R1-R5)	2164	1434	1799
S5 (R1-R9)	2264	1733	1998
S6 (R5-R9)	1956	1456	1705
S7 (V2-R9)	2296	1474	1885
Mean	2347	1874	2194
CV	14,7%		

	SE	LSD	
		0,05	0,01
Co vs P means	± 91	260	347
P means	± 61	173	231
Co and S means	± 114	324	432
Co vs P x S	± 161	458	NS
P x S	± 139	397	NS

Table 3.5 The effect of levels and time of defoliation on the leaf dry mass (g plant^{-1}) of dry beans (cv. Teebus) at the R1 stage, Potchefstroom, 1979/80 (see Appendix 4)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 10,63			
S1 (V2-V6f)	10,15	9,30	9,73
S2 (V2-R1)	7,68	5,65	6,66
S3 (V6f-R1)	8,30	5,15	6,73
S4 (R1-R5)	6,30	4,23	5,26
S5 (R1-R9)	7,28	3,98	5,63
S6 (R5-R9)	11,50	10,28	10,89
S7 (V2-R9)	7,90	4,43	6,16
Mean	8,43	6,14	7,71
CV	15,0%		

	SE	LSD	
		0,05	0,01
Co vs P means	± 0,33	0,93	1,24
P means	± 0,22	0,62	0,83
Co and S means	± 0,41	1,16	1,55
Co vs P x S	± 0,58	NS	NS
P x S	± 0,50	NS	NS

Table 3.6 The effect of levels and time of defoliation on the leaf dry mass (g plant^{-1}) of dry beans (cv. Teebus) at the R5 stage, Potchefstroom, 1979/80 (see Appendix 4)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
	Co 10,68		
S1 (V2-V6f)	10,13	10,48	10,30
S2 (V2-R1)	10,48	7,80	9,14
S3 (V6f-R1)	9,38	7,53	8,45
S4 (R1-R5)	8,63	5,80	7,21
S5 (R1-R9)	9,48	· 7,20	8,34
S6 (R5-R9)	7,45	5,40	6,43
S7 (V2-R9)	8,8	6,10	7,45
Mean	9,19	7,19	8,50
CV	16,8%		

	SE	LSD	
		0,05	0,01
Co vs P means	± 0,14	1,15	1,54
P means	± 0,27	0,77	1,03
Co and S means	± 0,51	1,44	1,92
Co vs P x S	± 0,72	NS	NS
P x S	± 0,62	NS	NS

Table 3.7 The effect of levels and time of defoliation on the number
of leaves per plant of dry beans (cv. Teebus) at the R5
stage, Potchefstroom, 1979/80 (see Appendix 5)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 39,25			
S1 (V2-V6f)	39,00	40,00	39,50
S2 (V2-R1)	42,00	48,75	45,38
S3 (V6f-R1)	39,25	48,00	43,63
S4 (R1-R5)	42,00	42,00	42,00
S5 (R1-R9)	43,00	42,00	42,50
S6 (R5-R9)	35,25	39,00	37,13
S7 (V2-R9)	42,00	47,25	44,63
Mean	40,38	43,86	41,75
CV	10,7%		

	SE	LSD	
		0,05	0,01
Co vs P means	$\pm$ 1,27	3,62	4,83
P means	$\pm$ 0,85	2,41	3,22
Co and S means	$\pm$ 1,59	4,51	6,03
Co vs P x S	$\pm$ 2,24	NS	NS
P x S	$\pm$ 1,94	NS	NS

3.3.1.4   Node number

The effect of treatments on node number (Table 3.8) followed virtually the same pattern as that of leaf number. These results suggest that defoliation stimulated node and hence leaf production but the area of these leaves was less than those removed by defoliation. Thus at the onset of the pod filling stage, the defoliated plants carried more leaves and nodes but LA was lower.

3.3.1.5   Stem mass

As shown in Tables 3.9, 3.10 and 3.11 dry matter accumulation in the stems was virtually complete at 50% flowering and values for this parameter were about the same at each of the three samplings.

The mean stem mass of the plants receiving the 66% level of defoliation was significantly lower than that of the 33% level at development stages R1, R9 (P=0,01) and R5 (P=0,05). The control had a higher stem mass than the 33% defoliation level and this difference was significant at the R1 development stage. At each of the three sampling dates (Tables 3.9, 3.10 and 3.11) defoliation resulted in a significant reduction in stem mass in all treatments which were defoliated at times between the onset of flower initiation and the beginning of pod fill: S3, S4, S5 and S7 (except S5 at the R5 stage). However, when defoliation was applied before flower initiation (S1 and S2), a very sharp increase in stem mass was observed at R5 and R9. These results suggest that early defoliation resulted an increase in stem mass during the reproductive period. On the other hand, defoliation after the appearance of flower buds (V6f) did not influence stem mass.

Table 3.8 The effect of levels and time of defoliation on the number of nodes per plant of dry beans (cv. Teebus) at the R5 stage, Potchefstroom, 1979/80 (see Appendix 6)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 42,38			
S1 (V2-V6f)	42,25	43,50	42,88
S2 (V2-R1)	46,00	51,25	48,63
S3 (V6f-R1)	41,25	50,75	46,00
S4 (R1-R5)	45,25	45,25	45,25
S5 (R1-R9)	46,25	44,75	45,50
S6 .(R5-R9)	38,50	42,75	40,63
S7 (V2-R9)	45,75	49,75	47,75
Mean	43,61	46,86	44,88
CV	10,5%		

	SE	LSD 0,05	0,01
Co vs P means	± 1,33	3,80	NS
P means	± 0,89	2,53	NS
Co and S means	± 1,66	4,74	NS
Co vs P x S	± 2,35	NS	NS
P x S	± 2,04	NS	NS

Table 3.9 The effect of levels and time of defoliation on the stem
mass (g plant^{-1}) of dry beans (cv. Teebus) at the R1 stage,
Potchefstroom, 1979/80 (see Appendix 7)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
	Co 12,21		
S1 (V2-V6f)	10,98	9,93	10,45
S2 (V2-R1)	10,05	8,23	9,14
S3 (V6f-R1)	10,65	8,20	9,43
S4 (R1-R5)	9,83	10,70	10,26
S5 (R1-R9)	11,35	9,23	10,29
S6 (R5-R9)	13,35	11,68	12,51
S7 (V2-R9)	10,98	8,30	9,64
Mean	11,03	9,46	10,49
CV	13,1%		

	SE	LSD 0,05	0,01
Co vs P means	± 0,39	1,11	1,49
P means	± 0,26	0,74	0,99
Co and S means	± 0,49	1,39	1,85
Co vs P x S	± 0,69	NS	NS
P x S	± 0,60	NS	NS

Table 3.10 The effect of levels and time of defoliation on the stem mass (g plant^{-1}) of dry beans (cv. Teebus) at the R5 stage, Potchefstroom, 1979/80 (see Appendix 7)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 11,99			
S1 (V2-V6f)	11,85	11,05	11,45
S2 (V2-R1)	11,58	9,45	10,51
S3 (V6f-R1)	10,20	8,10	9,15
S4 (R1-R5)	11,28	10,13	10,70
S5 (R1-R9)	11,63	10,25	10,94
S6 -(R5-R9)	10,18	11,88	11,03
S7 (V2-R9)	10,10	8,03	9,06
Mean	10,97	9,84	10,60
CV	17,7%		

	SE	LSD	
		0,05	0,01
Co vs P means	± 0,53	1,51	NS
P means	± 0,35	0,01	NS
Co and S means	± 0,66	NS	NS
Co vs P x S	± 0,94	NS	NS
P x S	± 0,81	NS	NS

Table 3.11 The effect of levels and time of defoliation on the stem mass (g plant^{-1}) of dry beans (cv. Teebus) at the R9 stage, Potchefstroom, 1979/80 (see Appendix 7)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 12,70			
S1 (V2-V6f)	12,12	12,42	12,27
S2 (V2-R1)	12,41	9,81	11,11
S3 (V6f-R1)	9,64	9,70	9,67
S4 (R1-R5)	10,75	10,56	10,65
S5 (R1-R9)	11,28	9,01	10,14
S6 (R5-R9)	12,56	10,29	11,43
S7 (V2-R9)	11,74	8,10	9,92
Mean	11,50	9,98	10,99
CV	15,7%		

	SE	LSD	
		0,05	0,01
Co vs P means	+ 0,49	1,39	1,86
P means	+ 0,33	0,93	1,24
Co and S means	+ 0,61	1,74	NS
Co vs P x S	+ 0,86	NS	NS
P x S	+ 0,75	NS	NS

3.3.2   Reproductive sink

3.3.2.1   Number of racemes

The number of racemes at the onset of seed growth (R5) was not influenced by any of the different defoliation treatments (Table 3.12).

3.3.2.2   Pod number

At the R5 sampling stage the 66% defoliation level reduced the number of pods significantly (P=0,01) in comparison with the 33% level. The number of pods at R9 was reduced significantly (P=0,01) at both levels of defoliation when compared with the control (Co) and with one another (Tables 3.13 and 3.14).

3.3.2.3   Pod mass

At the R5 sampling the differences between the control and means of times of defoliation were not statistically significant though there was a tendency for pod number to decrease in the defoliated treatments (Table 3.15). Mean pod mass in the 66% defoliation treatments was significantly (P=0,01) lower than in the 33% treatments. The 66% defoliation produced a significantly (P=0,01) lower pod mass than the control. Differences between the 33% level and the control were not significant.

The response to defoliation followed the same pattern at R9 in terms of comparisons between mean levels of intensity and the control although both defoliation levels had a significantly (P=0,01) lower pod mass than the control. With regard to time of defoliation, defoliation prior to the six leaf stage (S1) did not reduce pod mass significantly in comparison with the control, but at all other times of defoliation there was a significant reduction in pod yield (Table 3.16).

Table 3.12 The effect of levels and time of defoliation on the number of racemes per plant of dry beans (cv. Teebus) at the R5 stage, Potchefstroom, 1979/80 (see Appendix 8)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 39,38			
S1 (V2-V6f)	37,75	38,50	38,13
S2 (V2-R1)	40,50	39,50	40,00
S3 (V6f-R1)	35,75	35,25	35,50
S4 (R1-R5)	37,00	35,00	36,00
S5 (R1-R9)	37,50	35,25	36,38
S6 (R5-R9)	37,75	44,25	41,00
S7 (V2-R9)	37,25	33,50	35,38
Mean	37,64	37,32	37,72
CV	14,9%		

	SE	LSD 0,05	0,01
Co vs P means	± 1,59	NS	NS
P means	± 1,06	NS	NS
Co and S means	± 1,98	NS	NS
Co vs P x S	± 2,80	NS	NS
P x S	± 2,43	NS	NS

Table 3.13 The effect of levels and time of defoliation on the number
of pods per plant of dry beans (cv. Teebus) at the R5
stage, Potchefstroom, 1979/80 (see Appendix 9)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
	Co 26,13		
S1 (V2-V6f)	26,50	26,25	26,38
S2 (V2-R1)	26,75	21,25	24,00
S3 (V6f-R1)	21,75	21,00	21,38
S4 (R1-R5)	22,50	21,25	21,88
S5 (R1-R9)	23,50	19,75	21,63
S6 (R5-R9)	25,75	22,75	24,25
S7 (V2-R9)	25,50	18,25	21,88
Mean	24,61	21,50	23,44
CV	18,0%		

	SE	LSD 0,05	0,01
Co vs P means	± 1,20	3,40	4,54
P means	± 0,80	2,27	3,03
Co and S means	± 1,49	NS	NS
Co vs P x S	± 2,11	NS	NS
P x S	± 1,83	NS	NS

Table 3.14 The effect of levels and time of defoliation on the number
of pods per plant of dry beans (cv. Teebus) at the R9
stage, Potchefstroom, 1979/80 (see Appendix 9)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
	Co 21,81		
S1 (V2-V6f)	19,33	17,81	18,57
S2 (V2-R1)	17,07	15,61	16,34
S3 (V6f-R1)	16,67	16,17	16,42
S4 (R1-R5)	19,57	18,61	19,09
S5 (R1-R9)	18,90	14,58	16,74
S6 (R5-R9)	17,68	18,60	18,14
S7 (V2-R9)	20,50	15,67	18,08
Mean	18,53	16,72	18,15
CV	12,2%		

	SE	LSD 0,05	0,01
Co vs P means	± 0,63	1,78	2,38
P means	± 0,44	1,19	1,59
Co and S means	± 0,78	NS	NS
Co vs P x S	± 1,10	NS	NS
P x S	± 0,96	NS	NS

Table 3.15 The effect of levels and time of defoliation on the pod
mass (g plant^{-1}) of dry beans (cv. Teebus) at the R5
stage, Potchefstroom, 1979/80 (see Appendix 10)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 14,50			
S1 (V2-V6f)	13,75	11,58	12,66
S2 (V2-R1)	13,83	8,20	11,01
S3 (V6f-R1)	12,23	9,88	11,05
S4 (R1-R5)	13,05	11,23	12,14
S5 (R1-R9)	11,13	8,10	9,61
S6 (R5-R9)	12,43	11,20	11,81
S7 (V2-R9)	12,03	10,75	11,39
Mean	12,63	10,13	11,77
CV	27,0%		

	SE	LSD 0,05	0,01
Co vs P means	± 0,90	2,56	3,42
P means	± 0,60	1,71	2,28
Co and S means	± 1,12	NS	NS
Co vs P x S	± 1,59	NS	NS
P x S	± 1,37	NS	NS

Table 3.16 The effect of levels and time of defoliation on the pod mass (g plant^{-1}) of dry beans (cv. Teebus) at the R9 stage, Potchefstroom, 1979/80 (see Appendix 10)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 27,84			
S1 (V2-V6f)	26,55	26,98	26,76
S2 (V2-R1)	24,75	21,85	23,30
S3 (V6f-R1)	24,75	21,83	23,29
S4 (R1-R5)	24,28	22,57	23,42
S5 (R1-R9)	25,07	20,77	22,92
S6 (R5-R9)	24,26	19,91	22,08
S7 (V2-R9)	25,38	19,24	22,31
Mean	25,00	21,88	23,99
CV	10,4%		

	SE	LSD	
		0,05	0,01
Co vs P means	± 0,71	2,02	2,69
P means	± 0,47	1,34	1,80
Co and S means	± 0,88	2,52	NS
Co vs P x S	± 1,25	NS	NS
P x S	± 1,08	NS	NS

3.3.2.4   Seeds per pod

There was no significant difference between the two levels of defoliation.

Defoliation before flowering (S1, S2 and S3) tended to increase the number of seeds per pod (Table 3.17). The differences between these treatments and the control attained the 0,05 level of significance in the S1 and S3 treatments only. Defoliation after flowering did not affect the number of seeds per pod significantly though in the case of S5 which was defoliated throughout the reproductive period, there was a small but not statistically significant increase in seeds per pod.

3.3.2.5   Seed number

Defoliation reduced seed number significantly at both intensities. Values for seed number at the various times of defoliation (S1-S7) varied between 98 and 81 seeds plant^{-1}. Apart from S1, seed number was reduced significantly at all times of defoliation (Table 3.18).

3.3.2.6   Hundred seed mass

The 100 seed mass of the 66% defoliation was significantly (P=0,05) smaller than that of the 33% level but no other significant differences occurred (Table 3.19).

3.3.2.7   Seed yield

The response to treatments was virtually the same as that recorded for pod mass (par. 3.3.2.3). Levels and times of defoliation reduced seed yield significantly except in the case of very early defoliation (S1). There was very little difference in yield between the treatments (S2-S7) incorporating extended or later times of defoliation (Table 3.20).

Table 3.17 The effect of levels and time of defoliation on the number
of seeds per pod of dry beans (cv. Teebus) at the R9 stage,
Potchefstroom, 1979/80 (see Appendix 11)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 4,65			
S1 (V2-V6f)	5,11	5,61	5,36
S2 (V2-R1)	5,32	5,23	5,28
S3 (V6f-R1)	5,72	5,04	5,38
S4 (R1-R5)	4,60	4,39	4,49
S5 (R1-R9)	5,06	5,43	5,24
S6 (R5-R9)	4,98	4,10	4,54
S7 (V2-R9)	4,62	4,81	4,72
Mean	5,06	4,94	4,96
CV	12,9%		

	SE	LSD 0,05	0,01
Co vs P means	± 0,18	NS	NS
P means	± 0,12	NS	NS
Co and S means	± 0,23	0,64	NS
Co vs P x S	± 0,32	NS	NS
P x S	± 0,28	NS	NS

Table 3.18 The effect of levels and time of defoliation on the number
of seeds per plant of dry beans (cv. Teebus) at the R9
stage, Potchefstroom, 1979/80 (see Appendix 12)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 101,09			
S1 (V2-V6f)	97,24	98,74	97,99
S2 (V2-R1)	88,15	79,93	84,04
S3 (V6f-R1)	94,21	81,11	87,66
S4 (R1-R5)	87,97	81,58	84,78
S5 (R1-R9)	92,14	78,50	85,32
S6 (R5-R9)	87,78	75,92	81,85
S7 (V2-R9)	92,01	74,85	83,30
Mean	91,38	81,48	88,25
CV	8,8%		

	SE	LSD 0,05	0,01
Co vs P means	± 2,20	6,27	8,37
P means	± 1,47	4,18	5,58
Co and S means	± 2,75	7,28	10,44
Co vs P x S	± 3,89	NS	NS
P x S	± 3,37	NS	NS

Table 3.19 The effect of levels and time of defoliation on the 100
seed mass (g) of dry beans (cv. Teebus) at the R9 stage,
Potchefstroom, 1979/80 (see Appendix 13)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 23,73			
S1 (V2-V6f)	23,53	23,33	23,43
S2 (V2-R1)	24,20	23,75	23,98
S3 (V6f-R1)	22,93	23,18	23,05
S4 (R1-R5)	23,75	24,15	23,95
S5 (R1-R9)	23,60	23,00	23,30
S6 (R5-R9)	23,83	21,80	22,81
S7 (V2-R9)	23,85	22,75	23,30
Mean	23,67	23,14	23,44
CV	3,9%		

	SE	LSD	
		0,05	0,01
Co vs P means	± 0,26	0,74	NS
P means	± 0,17	0,49	NS
Co and S means	± 0,32	NS	NS
Co vs P x S	± 0,46	NS	NS
P x S	± 0,40	NS	NS

Table 3.20 The effect of levels and time of defoliation on the seed yield (g plant^{-1}) of dry beans (cv. Teebus) at the R9 stage, Potchefstroom, 1979/80 (see Appendix 14)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 21,58			
S1 (V2-V6f)	20,57	20,83	20,70
S2 (V2-R1)	19,22	17,13	18,17
S3 (V6f-R1)	19,42	16,99	18,20
S4 (R1-R5)	18,82	17,75	18,28
S5 (R1-R9)	19,60	16,30	17,95
S6 (R5-R9)	18,81	14,89	16,85
S7 (V2-R9)	19,76	15,22	17,49
Mean	19,46	17,02	18,65
CV	10,8%		

	SE	LSD 0,05	0,01
Co vs P means	± 0,57	1,63	2,17
P means	± 0,38	1,09	1,45
Co and S means	± 0,71	2,03	NS
Co vs P x S	± 1,01	NS	NS
P x S	± 0,87	NS	NS

3.3.3   Total dry mass

The sampling conducted at the R1 stage (50% flowering) (Table 3.21) indicated that there was no significant difference between the control (including S6 which was still undefoliated) and the treatment which was defoliated between emergence and the six leaf stage (S1). This suggests that compensation had occurred in this treatment during the development stages V6f to R1 although this was less marked at the higher intensities of defoliation.   A similar trend was observed in the sampling at the R5 stage (onset of seed growth) (Table 3.22) although no significant differences occurred while a nearly identical reaction was observed at the R9 stage (maturity) (Table 3.23). It should be noted that postponing defoliation until the R5 stage (S6 treatment) had no advantage above earlier treatments (in spite of a shorter stress period) in terms of TDM production at the R5 and R9 samplings. There was a significant (P=0,01) reduction in TDM production with each successive higher defoliation level at all three sampling stages (R1, R5, R9) indicating a direct relationship between LA and TDM.

The reaction of TDM to defoliation shows a close relationship with that found for leaf mass (at R1 and R5), pod mass and seed yield (at R9) indicating the important contribution of seed yield to TDM.

3.3.4   Harvest index

There was no significant difference in the influence of the two levels of defoliation on the HI (Table 3.24).

Defoliation during the seed fill stage (S6) resulted in a lower (P=0,01) HI than any of the other treatments. The highest HI was produced by defoliation between flower initiation and the onset of flowering (S3).   It differed significantly from all treatments except S5 (Table 3.24).

Table 3.21 The effect of levels and time of defoliation on the total dry mass (g plant^{-1}) of dry beans (cv. Teebus) at the R1 stage, Potchefstroom, 1979/80 (see Appendix 15)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 22,84			
S1 (V2-V6f)	21,13	19,23	20,18
S2 (V2-R1)	17,23	13,88	15,80
S3 (V6f-R1)	18,95	13,85	16,15
S4 (R1-R5)	16,13	14,93	15,53
S5 (R1-R9)	18,62	13,20	15,91
S6 (R5-R9)	24,85	21,95	23,40
S7 (V2-R9)	18,88	12,73	15,80
Mean	19,47	15,61	18,20
CV	12,9%		

	SE	LSD	
		0,05	0,01
Co vs P means	± 0,67	1,90	2,53
P means	± 0,44	1,26	1,69
Co and S means	± 0,83	2,37	NS
Co vs P x S	± 1,18	NS	NS
P x S	± 1,02	NS	NS

Table 3.22 The effect of levels and time of defoliation on the total dry mass (g plant^{-1}) of dry beans (cv. Teebus) at the R5 stage, Potchefstroom, 1979/80 (see Appendix 15)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 37,16			
S1 (V2-V6f)	35,73	33,10	34,41
S2 (V2-R1)	35,88	25,45	30,66
S3 (V6f-R1)	31,80	25,50	28,65
S4 (R1-R5)	32,95	27,15	30,05
S5 (R1-R9)	32,23	25,55	28,89
S6 (R5-R9)	30,20	28,48	29,34
S7 (V2-R9)	30,93	24,88	27,90
Mean	32,81	27,16	30,88
CV	17,0%		

	SE	LSD 0,05	0,01
Co vs P means	± 1,49	4,25	5,67
P means	± 0,99	2,83	3,78
Co and S means	± 1,86	NS	NS
Co vs P x S	± 2,63	NS	NS
P x S	± 2,28	NS	NS

Table 3.22 The effect of levels and time of defoliation on the total dry mass (g plant^{-1}) of dry beans (cv. Teebus) at the R5 stage, Potchefstroom, 1979/80 (see Appendix 15)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
Co 37,16			
S1 (V2-V6f)	35,73	33,10	34,41
S2 (V2-R1)	35,88	25,45	30,66
S3 (V6f-R1)	31,80	25,50	28,65
S4 (R1-R5)	32,95	27,15	30,05
S5 (R1-R9)	32,23	25,55	28,89
S6 (R5-R9)	30,20	28,48	29,34
S7 (V2-R9)	30,93	24,88	27,90
Mean	32,81	27,16	30,88
CV	17,0%		

	SE	LSD 0,05	0,01
Co vs P means	± 1,49	4,25	5,67
P means	± 0,99	2,83	3,78
Co and S means	± 1,86	NS	NS
Co vs P x S	± 2,63	NS	NS
P x S	± 2,28	NS	NS

Table 3.23 The effect of levels and time of defoliation on the total dry mass (g plant^{-1}) of dry beans (cv. Teebus) at the R9 stage, Potchefstroom, 1979/80 (see Appendix 15)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
	Co 40,59		
S1 (V2-V6f)	38,75	39,44	39,09
S2 (V2-R1)	37,19	31,69	34,44
S3 (V6f-R1)	34,44	30,44	32,44
S4 (R1-R5)	35,06	33,19	34,13
S5 (R1-R9)	36,38	29,81	33,09
S6 .(R5-R9)	36,88	30,25	33,56
S7 (V2-R9)	37,19	27,38	32,28
Mean	36,55	31,74	34,95
CV	11,1%		

	SE	LSD	
		0,05	0,01
Co vs P means	± 1,10	3,14	4,19
P means ·	± 0,74	2,09	2,80
Co and S means	± 1,38	3,29	NS
Co vs P x S	± 1,95	NS	NS
P x S	± 1,69	NS	NS

Table 3.24 The effect of levels and time of defoliation on the harvest
index (%) per plant of dry beans (cv. Teebus) at the R9
stage, Potchefstroom, 1979/80 (see Appendix 16)

Time of defoliation	Levels of defoliation (P)		Mean
	P1 (33%)	P2 (66%)	
	Co 53,15		
S1 (V2-V6f)	52,99	52,76	52,87
S2 (V2-R1)	51,75	53,93	52,84
S3 (V6f-R1)	56,44	56,15	56,30
S4 (R1-R5)	53,79	53,62	53,71
S5 (R1-R9)	54,00	54,83	54,42
S6 (R5-R9)	51,01	49,23	50,12
S7 (V2-R9)	53,01	55,62	54,31
Mean	53,28	53,73	53,46
CV	3,7%		

	SE	LSD	
		0,05	0,01
Co vs P means	± 0,56	NS	NS
P means	± 0,37	NS	NS
Co and S means	± 0,69	1,98	2,64
Co vs P x S	± 0,98	NS	NS
P x S	± 0,85	NS	NS

3.3.5   Correlation matrix

There was a strong positive correlation between LA and leaf mass at R5 and LA was correlated (P=0,01) with number of pods (Table 3.23).   The number of leaves and nodes were well correlated (P=0,01) but did not show a rela- tionship with any other parameter at R5. In addition to its positive relationship with the vegetative parameter leaf area, stem mass was corre- lated positively (P=0,05) with the reproductive parameters: number of racemes (R5), pods (R5) and seeds (R9) as well as seed yield (R9). (Tables 3.25 and 3.26).   Leaf area at R5 had a positive correlation (P=0,05) with the vegetative parameter stem mass as well as with the reproductive para- meters: seed yield and seed number (Table 3.26).

The reproductive parameters, number of seeds per plant and 100 seed mass were correlated positively with seed yield at R9. The yield components in turn were either not related to each other (100 seed mass with pod number and seeds per pod) or gave a negative correlation (P=0,01) (seeds per pod and number of pods).

3.4   Results, 1980/81

3.4.1   Vegetative sink

3.4.1.1   Node number

Teebus consistently produced fewer nodes per plant than NEP 2 and Bonus (P=0,01) which did not differ significantly from each other (Table 3.27).

The response to time of defoliation was not significant and no clear ten- dency can be observed in the data.

Table 3.25 Correlation matrix (r values and tests of significance) of
the components of the vegetative and reproductive sink of
dry beans at development stage R5, 1979/80,

	Stem mass	Pod mass	Leaf number	Node number	Pod number	Leaf area	Raceme number
Leaf mass	0,46	0,32	0,13	0,13	0,64**	0,89**	0,35
Stem mass		0,37	0,07	0,08	0,66**	0,51*	0,55*
Pod mass			0,08	0,08	0,57*	0,24	0,08
Leaf number				0,97**	0,16	0,12	0,16
Node number					0,16	0,16	0,19
Pod number						0,62**	0,39
Leaf area							0,34

Table 3.26 Correlation matrix (r values and tests of significance) of the components of the vegetative and reproductive sink of dry beans at development stage R9 and leaf area at R5, 1979/80

	Seed yield	Pod number	Seeds per pod	100 seed mass	Seed number	Stem mass
Leaf area	0,68**	0,27	0,26	0,33	0,68**	0,52*
Seed yield		0,42	0,34	0,61*	0,97**	0,72**
Pod number			-0,68**	0,15	0,44	0,43
Seeds per pod				0,18	0,34	0,12
100 seed mass					0,39	0,49
Seed number						0,69**

Table 3.27 The effect of time of defoliation on the number of nodes per plant of three dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 17)

Time of defoliation (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	21,94	23,24	25,30	23,49
S1 (V2)	23,67	23,44	23,98	23,70
S2 (V3)	22,50	23,30	27,33	24,38
S3 (V4)	20,96	26,78	25,17	24,30
S4 (V6f)	19,11	27,24	24,17	23,51
S5 (V9f)	19,80	22,13	25,83	22,59
S6 (R1)	22,22	23,78	23,63	23,21
S7 (R3)	22,78	22,59	22,30	22,56
S8 (R5)	22,13	25,11	23,50	23,58
S9 (R6)	21,41	22,56	23,72	22,56
S10 (R7)	22,89	24,07	23,02	23,33
S11 (R8)	23,80	23,76	26,11	24,56
Mean	21,93	24,00	24,51	23,48
CV	10,41%			

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 0,41	1,15	1,53
Time (S)	± 0,81	NS	NS
C x S	± 1,41	NS	NS

3.4.1.2   Stem mass

The mean stem mass of Bonus was significantly (P=0,01) greater than that
of Teebus and NEP 2 (Table 3.28). This trend was apparent at all times of
defoliation.

There was a clear tendency for stem mass to decrease with each successive
defoliation until the lowest value was reached in the S3 treatment which
corresponded with the onset of flower bud initiation. Defoliation in the
S4 (flower bud) and S5 (50% flowering) treatment also reduced stem mass
significantly but the effect was less severe than in the S3 treatment.
Subsequent defoliations during the pod development stages did not effect
stem mass significantly.

3.4.2   Reproductive sink

3.4.2.1   Number of racemes

As in the case of node number, Teebus carried more racemes (P=0,01) in all
treatments, than NEP 2 and Bonus, which did not differ significantly from
each other (Table 3.29).

Although the effect of the stage of defoliation was not significant, the
number   of racemes tended to decline when defoliation was done at flower
bud initiation (S3) and during the following stages, the response being
most pronounced in the S4 treatment.

3.4.2.2   Pod number

Bonus produced significantly (P=0,01) less pods than the other two culti-
vars. Teebus was superior (P=0,05) to NEP 2 in terms of pod number
(Table 3.30).

Table 3.28 The effect of time of defoliation on the stem mass (g plant^{-1}) of three dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 18)

Time of defoliation (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	8,07	8,08	12,63	9,59
S1 (V2)	7,84	7,28	11,63	8,92
S2 (V3)	7,46	6,63	11,69	8,59
S3 (V4)	5,73	6,08	9,09	6,97
S4 (V6f)	5,62	7,28	9,49	7,46
S5 (V9f)	6,84	6,89	10,39	8,04
S6 (R1)	7,95	8,42	10,64	9,00
S7 (R3)	8,41	7,69	10,42	8,84
S8 (R5)	8,24	9,72	11,70	9,89
S9 (R6)	8,35	8,61	11,84	9,60
S10 (R7)	8,00	8,35	9,50	8,62
S11 (R8)	8,71	9,67	10,83	9,74
Mean	7,60	7,89	10,82	8,77

CV   14,79%

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 0,22	0,61	0,81
Time (S)	± 0,43	1,22	1,63
C x S	± 0,75	NS	NS

Table 3.29 The effect of time of defoliation on the number of racemes per
plant of three dry bean cultivars, Potchefstroom, 1980/81 (see
Appendix 19)

Time of defoliation (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	11,80	10,54	11,28	11,20
S1 (V2)	12,02	10,96	11,48	11,49
S2 (V3)	12,78	10,61	12,74	12,04
S3 (V4)	10,85	11,20	10,46	10,84
S4 (V6f)	9,57	10,39	10,22	10,06
S5 (V9f)	10,82	10,35	11,37	10,85
S6 (R1)	12,57	10,52	10,30	11,13
S7 (R3)	11,94	10,67	8,93	10,51
S8 (R5)	12,15	11,50	9,15	10,93
S9 (R6)	11,83	11,48	9,19	10,83
S10 (R7)	11,69	11,85	9,32	10,95
S11 (R8)	13,04	10,32	11,56	11,64
Mean	11,76	10,87	10,50	11,04
CV	12,15%			

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 0,22	0,63	0,84
Time (S)	± 0,45	NS	NS
C x S	± 0,77	NS	NS

Table 3.30 The effect of time of defoliation on the number of pods per
plant of three dry bean cultivars, Potchefstroom, 1980/81 (see
Appendix 20)

Time of defoliation (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	27,52	20,26	18,15	21,98
S1 (V2)	25,07	25,59	15,15	21,94
S2 (V3)	23,94	22,54	16,78	21,09
S3 (V4)	20,52	20,11	14,69	18,44
S4 (V6f)	19,82	23,87	14,54	19,41
S5 (V9f)	21,35	22,56	13,41	19,11
S6 (R1)	21,83	17,56	11,52	16,97
S7 (R3)	24,43	21,28	11,06	18,92
S8 (R5)	25,89	22,89	12,09	20,29
S9 (R6)	29,63	23,74	15,46	22,94
S10 (R7)	28,04	25,63	13,74	22,46
S11 (R8)	30,63	29,06	14,35	24,68
Mean	24,89	22,92	14,24	20,69
CV	17,92%			

	SE	LSD 0,05	0,01
Cultivars (C)	± 0,62	1,75	2,32
Time (S)	± 1,24	3,49	4,65
C x S	± 2,14	NS	NS

Early defoliation (S1 and S2) did not have any effect on pod number and there were no significant differences between these treatments and the control. Subsequent treatments including S3 (flower bud initiation) and extending to S8 (onset of seed growth) all reduced pod number, though significant differences were recorded at S3 (P=0,05) and S6 (P=0,01)) only. Defoliation during the seed growth period (S9 to S11) tended to increase pod number slightly.

3.4.2.3 Pod mass

There was a significant interaction between cultivars and time of defoliation (Table 3.31). In comparisons with the control, NEP 2 suffered no significant loss in pod mass at any stage of defoliation though there was a tendency for pod mass to increase in the final defoliation treatment (S11). Both Teebus and Bonus showed a significant loss in pod mass when comparing the S3 (flower initiation) and S0 (control) treatments. In Bonus this reduction in pod yield persisted in all the later defoliation treatments. In contrast, defoliation of Teebus during the late pod fill stage (S11) did not cause a decline in pod yield.

Considering only the control treatments, of the three cultivars, there was no significant difference between pod yield of Teebus and Bonus, but both cultivars produced more pods than NEP 2 (P=0,01). These differences tended to persist in the very early (S1 and S2) and very late (S11) defoliations but were much less pronounced in the mid-season treatments.

3.4.2.4 Seeds per pod

The three cultivars differed significantly (P=0,01) in the number of seeds per pod, the overall range extending from 5,1 seeds pod^{-1} in NEP 2 to 3,6 seeds pod^{-1} in Bonus (Table 3.32).

There was a significant decline in the number of seeds per pod as a result

Table 3.31 The effect of time of defoliation on the pod mass (g plant^{-1}) of three dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 21)

Time of defoliation (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	39,44	27,96	43,13	36,84
S1 (V2)	34,82	27,84	34,87	32,51
S2 (V3)	32,65	27,27	39,53	33,15
S3 (V4)	30,66	28,59	31,92	30,39
S4 (V6f)	24,44	30,48	27,32	27,41
S5 (V9f)	29,68	25,75	33,89	29,77
S6 (R1)	30,59	23,04	30,16	27,93
S7 (R3)	27,61	23,62	24,64	25,29
S8 (R5)	27,06	26,29	20,64	24,66
S9 (R6)	33,03	25,67	26,07	28,26
S10 (R7)	36,95	27,14	25,61	29,90
S11 (R8)	41,09	36,13	28,59	35,28
Mean	32,34	27,48	30,53	30,12
CV	17,65%			

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 0,89	2,51	3,33
Time (S)	± 1,77	5,01	6,67
C x S	± 3,07	8,68	11,55

Table 3.32 The effect of time of defoliation on the number of seeds per
pod of three dry bean cultivars, Potchefstroom, 1980/81 (see
Appendix 22)

| Time of defoliation (S) | Cultivars (C) | | | Mean |
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	4,97	5,93	4,27	5,06
S1 (V2)	4,53	4,67	3,63	4,28
S2 (V3)	4,50	4,90	3,87	4,42
S3 (V4)	4,90	5,80	3,60	4,77
S4 (V6f)	4,13	5,47	3,60	4,40
S5 (V9f)	4,80	4,33	4,17	4,43
S6 (R1)	4,77	5,47	4,33	4,86
S7 (R3)	3,90	4,60	3,63	4,04
S8 (R5)	3,60	4,70	2,87	3,72
S9 (R6)	4,40	4,73	3,40	4,18
S10 (R7)	4,80	4,63	2,97	4,13
S11 (R8)	4,50	5,47	3,50	4,49
Mean	4,48	5,06	3,65	4,40

CV   12,41%

| | SE | LSD | |
		0,05	0,01
Cultivars (C)	± 0,09	0,26	0,34
Time (S)	± 0,18	0,51	0,68
C x S	± 0,32	NS	NS

of defoliation during the late pod set and seed fill stages (S7 to S11).
When compared with the control, the response to earlier defoliations was
less clear though there was a trend towards fewer seeds per pod in treat-
ments other than S3 and S6.

3.4.2.5   Seed number

There was a strong interaction between cultivars and time of defoliation.
The two small seeded cultivars (Teebus and NEP 2) produced more seeds than
Bonus and both of the former cultivars reacted in the same way to defolia-
tion except when defoliated during the period of flower initiation (S3 and
S4). In these treatments, seed number declined in Teebus and increased in
NEP 2. Defoliation treatments (S5-S8) applied during the flowering and
pod set stages reduced seed number in both Teebus and NEP 2 in comparisons
with the control. However, during the seed fill stage (S9, S10, S11)
there was no significant difference in seed number between these cultivars
and the control (S0) (Table 3.33).

Bonus tended to produce fewer seeds than the control in all defoliation
treatments. The differences were statistically significant in S6 (onset
of flowering) and all following treatments.

3.4.2.6   Hundred seed mass

There were pronounced differences (P=0,01) in 100 seed mass between each
of the three cultivars. Bonus produced by far the largest seeds (46,6 g
100 seeds^{-1}) followed by Teebus (23,5 g 100 seeds^{-1}) and then NEP 2 (19,1
g 100 seeds^{-1}).

The differences in 100 seed mass between defoliation treatments were not
significant (Table 3.34) and thus defoliation at the times included in the
experiment, did not appear to influence this parameter.

Table 3.33 The effect of time of defoliation on the number of seeds per
plant of three dry bean cultivars, Potchefstroom, 1980/81 (see
Appendix 23)

Time of defoliation (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	135,89	118,46	77,85	110,74
S1 (V2)	114,13	116,76	55,06	95,32
S2 (V3)	107,52	108,93	64,87	93,77
S3 (V4)	100,07	117,28	53,02	90,12
S4 (V6f)	82,28	129,98	51,98	88,08
S5 (V9f)	100,98	96,46	55,70	84,38
S6 (R1)	103,13	95,87	50,17	83,06
S7 (R3)	96,26	92,96	40,13	76,45
S8 (R5)	93,37	106,00	34,48	77,95
S9 (R6)	130,11	114,20	40,93	95,08
S10 (R7)	133,54	117,56	40,67	97,25
S11 (R8)	137,74	136,87	50,63	108,41
Mean	111,25	112,61	51,29	91,72

CV   16,42%

	SE	LSD 0,05	0,01
Cultivars (C)	± 2,51	7,10	9,44
Time (S)	± 5,02	14,20	18,89
C x S	± 8,70	24,60	32,72

Table 3.34 The effect of time of defoliation on the 100 seed mass (g) of three dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 24)

Time of defoliation (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	23,63	18,87	45,93	29,48
S1 (V2)	24,03	19,27	50,73	31,34
S2 (V3)	25,10	20,13	48,23	31,16
S3 (V4)	25,13	20,07	48,67	31,29
S4 (V6f)	23,80	18,80	41,23	27,94
S5 (V9f)	24,13	20,83	47,43	30,80
S6 (R1)	24,37	19,13	47,13	30,21
S7 (R3)	23,03	20,10	48,13	30,42
S8 (R5)	22,03	19,17	45,63	29,03
S9 (R6)	20,13	17,40	43,80	27,11
S10 (R7)	22,33	17,60	48,29	29,40
S11 (R8)	24,33	18,80	43,83	28,72
Mean	23,53	19,11	46,59	29,74
CV	11,38%			

	SE	LSD		
		0,05	0,01	
Cultivars (C)	± 0,56	1,60	2,12	
Time (S)	± 1,13	NS	NS	
C x S	± 1,95	NS	NS	

3.4.2.7   Seed yield

As may be seen in Table 3.35 the effect of treatments on seed yield was
virtually the same as that recorded for pod mass (Table 3.31).

3.4.3   Total dry mass

There was a significant interaction between cultivars and time of defolia-
tion (Table 3.36). The response pattern to treatments was very similar to
that obtained for pod mass and seed yield (Tables 3.31 and 3.35).

Teebus gave the largest reduction in TDM during the period between flower
initiation and the beginning of seed fill (S4 to S8). This decline was
less severe when defoliation was applied towards the beginning and end of
the growing season.

NEP 2 was influenced by defoliation to a lesser degree than the other two
cultivars and in fact, the TDM of the different defoliation treatments did
not differ significantly from that of the control (S0).   There was,
however, a tendency for TDM of this cultivar to increase in S11.

Defoliation caused a significant (P=0,01) loss in TDM in Bonus in the S3
(flowering initiation) and later treatments. This response persisted in
the late defoliations and differed from the other two cultivars which
tended to show increased TDM in the last defoliation.

3.4.4   Harvest index

The HI of the three cultivars differed significantly (P=0,01) throughout
the experiment.   Teebus had the highest and Bonus the lowest HI (Table
3.37).

Defoliation near the onset of flower initiation tended to produce higher
HI values than that of the control. At S3 this difference was highly

Table 3.35 The effect of time of defoliation on the seed yield (g plant^{-1}) of three dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 25)

Time of defoliation (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	32,14	22,34	31,68	28,72
S1 (V2)	27,99	22,21	27,61	25,94
S2 (V3)	26,93	21,82	31,53	26,76
S3 (V4)	25,09	23,48	25,17	24,58
S4 (V6f)	19,59	24,44	21,28	21,77
S5 (V9f)	24,39	20,06	26,53	23,66
S6 (R1)	25,04	18,37	23,94	22,45
S7 (R3)	22,15	18,65	19,43	20,08
S8 (R5)	20,87	20,31	15,77	19,00
S9 (R6)	26,19	19,64	19,88	21,90
S10 (R7)	29,84	20,69	19,44	23,32
S11 (R8)	33,53	28,54	21,98	28,02
Mean	26,15	21,72	23,69	23,85

CV   18,45%

	SE	LSD 0,05	0,01
Cultivars (C)	± 0,73	2,07	2,76
Time (S)	± 1,47	4,15	5,52
C x S	± 2,54	7,19	9,56

Table 3.36 The effect of time of defoliation on the total dry mass (g plant^{-1}) of three dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 26)

Time of defoliation (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	47,51	36,03	55,76	46,43
S1 (V2)	42,66	35,12	46,50	41,43
S2 (V3)	40,11	33,90	51,22	41,74
S3 (V4)	36,39	34,27	41,02	37,22
S4 (V6f)	30,06	37,76	36,81	34,88
S5 (V9f)	36,52	32,64	44,28	37,81
S6 (R1)	38,54	31,46	40,80	36,93
S7 (R3)	36,02	31,31	35,06	34,13
S8 (R5)	35,30	36,01	32,34	34,55
S9 (R6)	41,38	34,28	36,47	37,38
S10 (R7)	44,95	35,49	35,13	38,52
S11 (R8)	49,80	45,84	39,42	45,02
Mean	39,94	35,34	41,23	38,84

CV   16,35%

	SE	LSD 0,05	0,01
Cultivars (C)	± 1,06	2,99	3,98
Time (S)	± 2,12	5,99	7,96
C x S	± 3,67	10,37	13,79

Table 3.37 The effect of time of defoliation on the harvest index (%) of three dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 27)

Time of defoliation (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	67,60	61,97	57,00	62,20
S1 (V2)	64,80	63,20	59,37	62,46
S2 (V3)	67,00	64,40	61,20	64,20
S3 (V4)	68,67	68,70	61,23	66,20
S4 (V6f)	65,07	64,77	57,73	62,52
S5 (V9f)	66,87	61,53	59,60	62,67
S6 (R1)	65,07	58,30	58,13	60,50
S7 (R3)	61,13	59,43	55,20	58,59
S8 (R5)	58,83	56,50	48,67	54,67
S9 (R6)	63,33	56,67	54,10	58,03
S10 (R7)	66,40	57,77	54,97	59,71
S11 (R8)	67,30	62,40	55,77	61,82
Mean	65,18	61,30	56,91	61,13
CV	4,83%			

	SE	LSD		
		0,05	0,01	
Cultivars (C)	± 0,49	1,39	1,85	
Time (S)	± 0,99	2,79	3,71	
C x S	± 1,71	NS	NS	

significant. Once flowering had commenced, the effect of defoliation was reversed and the HI was significantly lower (P=0,01) than the control in treatments S7 to S9 inclusive (late pod set and early seed fill stages). Towards the end of the seed fill stage (S10 and S11), no significant reduction was brought about by defoliation.

3.4.5   Correlation matrix

There was a significant positive correlation (P=0,05) between the two vegetative parameters: stem mass and node number. Stem mass correlated positively with 100 seed mass and negatively with the other yield components: seed per plant and seeds per pod (Table 3.38).

There was a positive relationship (P=0,01) between the number of racemes per plant and pods and seeds per plant as well as between pods and seeds per plant. Both these parameters showed positive (P=0,01) relationships with seed yield and seeds per pod and a negative correlation (P=0,01) with 100 seed mass. The number of pods and seeds per plant were positively correlated. The number of pods per plant was the only yield component to show a positive correlation (P=0,01) with seed yield. One hundred seed mass and seeds per pod showed no relationship with yield.

3.5   Discussion

During the 1979/80 season the reduction in TDM production in Teebus was proportional to the loss in LA at all three sampling dates. This is in agreement with the findings of other researchers (Link *et al.*, 1980; Hohmann & Carvalho, 1983; Waddill *et al.*, 1984). The same effect was found to hold true for the masses of all the organs comprising TDM (leaf mass, stem mass and pod mass) (Figure 3.1a) as well as the components of the reproductive sink (number of pods, number of seeds and seed yield)

Table 3.38 Correlation matrix (r values and tests of significance) of the components of the vegetative and reproductive sink at harvest, 1980/81

	100 seed mass	Pod number	Seed number	Seeds per pod	Raceme number	Node number	Stem mass
Seed yield	0,10	0,48**	0,45**	0,19	0,57**	0,30	0,28
100 seed mass		-0,69**	-0,81**	-0,65**	-0,20	0,19	0,65**
Pod number			0,87**	0,31	0,49**	-0,03	-0,26
Seed number				0,70**	0,44**	0,00	-0,43**
Seeds per pod					0,14	0,03	-0,42**
Raceme number						0,32	0,08
Node number							0,36*
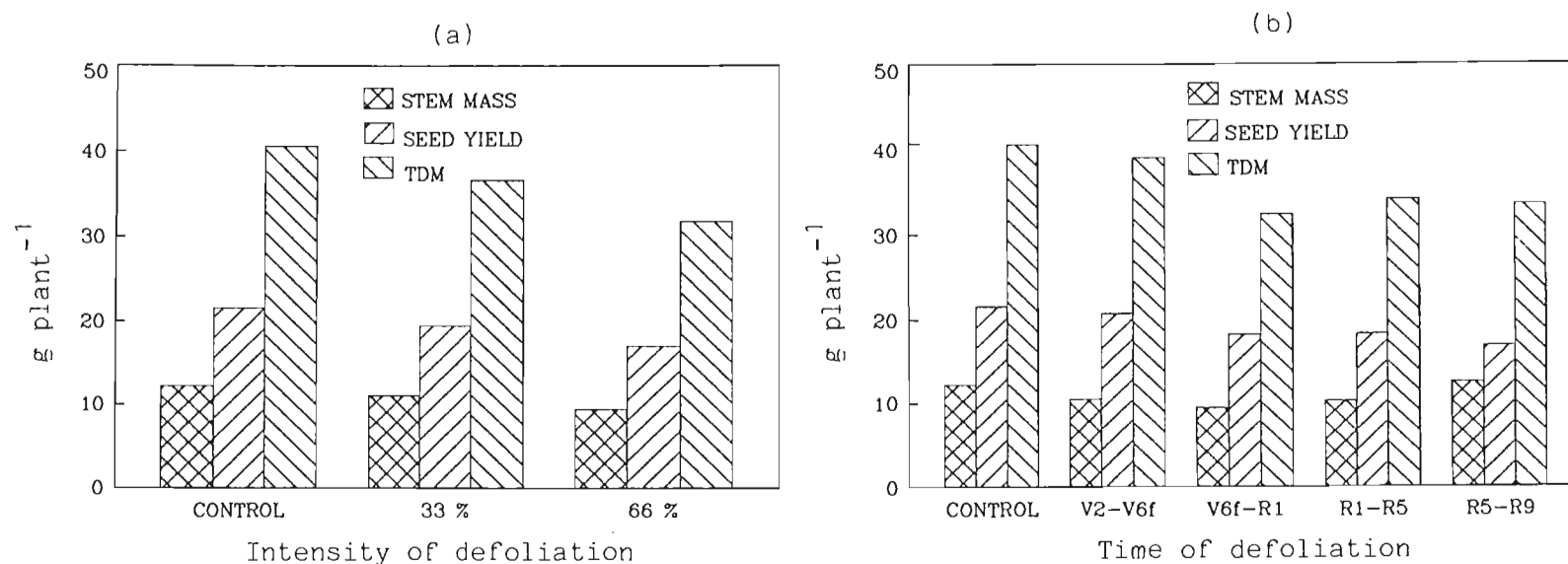
Figure 3.1   The effect of (a) intensity and (b) times of defoliation on the stem mass, seed yield and TDM of dry beans, Potchefstroom, 1979/80 (tests of significance are presented in Tables 3.11, 3.20 and 3.23)
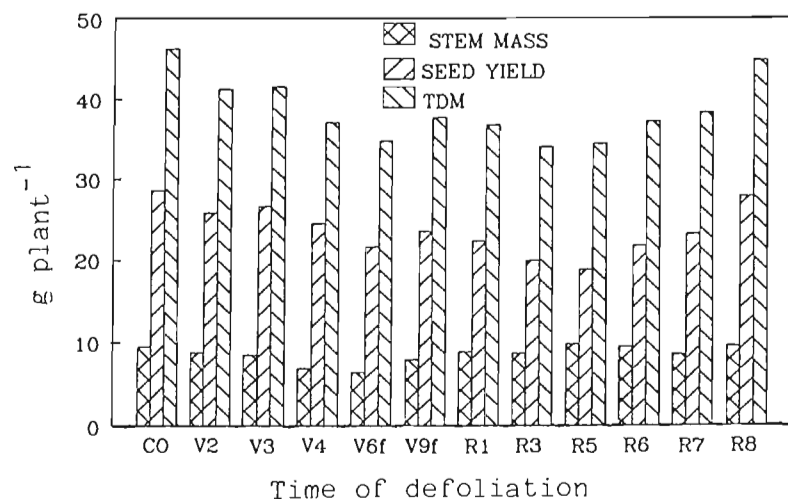
Figure 3.2   The effect of times of defoliation on the stem mass, seed yield and TDM of dry beans, Potchefstroom, 1980/81 (tests of significance are presented in Tables 3.28, 3.35 and 3.36)

thus confirming the findings of Watson (1952) who pointed out that the variation in LA is one of the main causes of differences in grain yield.

The results of the 1980/81 trial clearly indicate cultivar differences in sensitivity to loss in LA at different development stages. Before the flower initiation stage (V6f) all three cultivars were relatively insensitive to defoliation and there was virtually no difference between treatments in TDM production or in any of its components (leaf mass, stem mass and seed mass). NEP 2 was insensitive to defoliation in all the following stages. In Bonus and Teebus on the other hand, defoliation during the flower initiation period (V6f to R1) and pod set period (R1 to R5) reduced TDM significantly. During the seed fill period (R5 to R9) this response persisted in Bonus only. In general this pattern of results in the sensitive cultivars confirms the work of other researchers who have identified the flowering (pod formation) stage as the most sensitive to defoliation (Galves et al., 1977; Edje, 1981; Vieira, 1981; Bartoli et al., 1982; Hohmann & Carvalho, 1983). However, it is not clear in much of the literature whether "flowering" refers to the R1 stage (50% flowering) only or includes Vnf (flower initiation). In this study defoliation during both periods resulted in a permanent loss of LA and lower yields of dry matter and grain (Figures 3.1b and 3.2).

The wide variation between cultivars in sensitivity to defoliation is difficult to explain though its occurrence has been recorded quite frequently (Duque & Quintero, 1977; Link et al., 1980; Vieira, 1981). No difference was observed among cultivars in node number (and hence, leaves) which indicates that the indeterminate cultivars (Bonus and NEP 2) did not form additional leaves as a result of early defoliation, that is they reacted in the same way as the determinate cultivar Teebus. Consequently similar response patterns would be expected . Several hypotheses can be put forward to explain the results. An increase in the photosynthetic rate of the remaining leaves as observed by Wareing et al. (1968) and Caemmerer & Farquhar (1984) might have compensated for the loss of LA in NEP 2. Furthermore stored carbohydrate reserves might have played a role

as high starch levels have been recorded in stems of NEP 2 (Adams *et al.*, 1977) but it is not known if these reserves can be mobilized in the case of a limited supply. The most likely explanation is related to a limited sink size in NEP 2 which in the control, gave significantly lower seed and pod masses than Bonus and Teebus. Evans (1975) points out that a lack of yield reduction in the case of partial defoliation implies a sink limitation, except where sufficient LA is still present for full light interception. The latter is very unlikely in this case as a high intensity (66%) of defoliation was applied and the other two cultivars both reacted to this level of defoliation.

During both seasons defoliation during flower initiation (V6f-R1) resulted in significantly lower stem masses than in the control (Figure 3.1b and 3.2). This indicates that the vegetative organs were most seriously harmed by defoliation during their most active development stage. A similar conclusion may be drawn from the high HI values with defoliation during the flower initiation period (Vnf). The close relationship between the stem mass and the HI can be seen in the highly significantly negative correlation between them in both seasons. The fact that defoliation prior to flowering resulted in high HI values also indicates that the reproductive structures which are formed later in the development of the plant, were less harmed by this treatment than the stem mass.

The adverse effect of defoliation on the partitioning of carbohydrates to the reproductive organs (pod number, pod mass) persisted for a period of four weeks (V4 to R3) compared with a relatively short period of two weeks (V4 to V9f) in the case of the vegetative organs (stem mass). The detrimental effect of defoliation was associated with the permanent loss of LA during Vnf and flowering (R1 to R4) periods, indicating that a limited source resulted in the setting of a smaller reproductive sink.

In both trials and for all cultivars, partitioning to the reproductive organs was most adversely affected by defoliation at the onset of seed growth (R5), as indicated by the exceptionally low HI (high stem mass/low

seed yield). Taking into account that no significant leaf growth takes place after the onset of the flowering period, plants retaining their LA for a longer period would be expected to have a yield advantage over earlier defoliated plants. However, this did not occur in the present study. In both seasons plants defoliated at the onset of seed growth (R5) had a stem mass equal to that of the control but a seed yield equal to or lower than plants defoliated after the onset of the development of flowering structures (V6f) (Figures 3.1b and 3.2). This is reflected in the very low HI values. With still later defoliations (during seed fill period) the HI in 1980/81 increased to the same level as the control, while the stem mass stayed constant. This indicates that the reproductive sink was less sensitive to a restricted source at this stage. Thus source size (LA in this case) during the whole flowering and pod set period (R1 to the end of R4) is important in determining the final sink size. In fact the available source at the onset of the R5 stage seems to be the main factor determining the sink size. This is confirmed by the finding that in 1980/81 the number of pods per plant in all three cultivars did not differ from the control when defoliated after the R5 stage and indicates that the number of pods per plant (the most important yield component according to Adams, 1967) was fixed at the onset of the seed fill stage. Cultivar differences in seed yield must therefore be sought in the area of yield component compensation.

With regard to the interactions between sensitivity and time of defoliation, the early vegetative stages (until V6f) were relatively insensitive as the plants were able to recover normal LA at the onset of flowering, and showed no difference from the controls in any of the growth and yield parameters. During the late vegetative period (V6f to R1) partial defoliation appeared to result in a permanent loss in vegetative material, as indicated by the LA and stem mass. This indicates that the assimilates produced in the leaves during this period are used mainly for the growth of vegetative material. Enyi (1975) found similar results in groundnuts, cowpeas and green gram. However, in the present study reduced stem mass was not accompanied by a reduced number of leaves and flowering nodes as

recorded by Enyi in groundnuts. Defoliation either stimulated the deve-
lopment of additional leaves (1979/80) or had no influence on the number
of nodes (leaves) (1980/81).

All the defoliation treatments between V6f and and R5 were equally detri-
mental to the reproductive structures. The early reproductive period,
(flowering and pod set) was shown to be the period when the potential sink
size (the number of pods per plant) was determined. Thus this period was
more important in determining the final yield than the seed fill period.
Greater yield differences between cultivars were also found in this latter
period indicating that it is, at least for some cultivars, less important
in determining yield than the early reproductive period.

In both seasons and for all three cultivars, the component that was harmed
the most by partial defoliation was the number of pods per plant. Similar
results have been recorded by other researchers (Edje, 1981; Bartoli *et
al.*, 1982). The effect of treatments on pods per plant was more consis-
tent than that recorded for seed yield which is the product of the former
variable and two other variables: seeds per pod and mass per seed.

According to Adams (1967) the number of pods per plant is the first formed
yield component. As described earlier, the number of pods per plant in
this study was fixed just after the onset of the seed fill stage (R5). It
can therefore be assumed that the magnitude of the other two yield compo-
nents (seeds per pod and mass per seed (100 seed mass)) was established
during the seed fill stage and in the chronological order proposed by
Adams (1967).

The number of seeds per pod responded to time of defoliation in both sea-
sons but not to the level of defoliation. Cultivars reacted similarly to
the different times of defoliation during the same season. Defoliation
increased the number of seeds per pod of Teebus in 1979/80 but gave the
opposite result in 1980/81. Despite this inconsistency there was a signi-
ficant positive correlation between this parameter and number of seeds per

plant in both seasons. Since the number of seeds per plant has a similar relationship with seed yield, number of seeds per pod is likely to be an important factor determining reproductive sink size.

Seed size (100 seed mass) was very insensitive to partial defoliation at all times and levels. Large differences in seed size were observed between cultivars but none of the treatments affected the seed size of a particular cultivar.

Significant cultivar differences were observed in seed yield and its components. Seed yield, however, showed an interaction between cultivars and time of defoliation which is in contrast with the yield components where this interaction was absent. Since seed yield is the product of its components, this indicates that cultivar differences in seed yield were the result of differences within a particular yield component.

The results can now be interpreted in terms of yield component compensation. In both seasons the greatest reduction in pod number occurred when photosynthate supply was limited between onset of flowering (R1) and onset of the seed growth (R5). In terms of the yield component compensation concept of Adams (1967), pod number is the first formed yield component. Thus limited photosynthate supply (reduced LA) during the pod formation period would result in a reduced number of pods per plant, as was the case in these trials. According to Adams (1967) the number of seeds per pod, which is the next yield component to form, is determined by the amount of photosynthate available at the onset of seed growth (R5). The very strong negative correlation between the number of seeds per pod and the number of pods per plant in Teebus in 1979/80 supports this contention. The same tendency is apparent when the results of both seasons are assessed. The treatments which included defoliation during the pod formation period all showed pronounced negative relationships between pod number and seeds per pod in 1979/80. In 1980/81 the number of seeds per pod tended to have a positive correlation with pod number while a negative relationship was

shown by the 100 seed mass. In this case the last formed yield component reacted to the previously set sink size.

The evidence outlined in the previous paragraph indicates that yield component compensation does occur under stress, and in such a way that it brings the reproductive sink in balance with the source. The critical stage associated with this process appears to be the period between flowering and the onset of seed fill.

No evidence of utilisation of stored reserves was found in this study. The fact that the stem masses of plants defoliated at the onset of the seed development stage and later, did not differ from the control, indicates that the no measurable amounts of non-structural reserves from the stem were utilized. It does not rule out the possible contribution of root reserves which were not measured, or leaf reserves which cannot be distinguished from normal leaf drop in these trials. The fact that leaves are removed reduces the possible contribution of leaf reserves in the defoliated treatments.

3.6   Conclusions

The results of the defoliation trial support the following aspects of the working hypothesis.

(i)   The effect of defoliation on the vegetative as well as reproductive sinks is in proportion to the intensity of the treatment. This is indicated by the effect of the different levels of defoliation.

(ii)   No convincing evidence was found to indicate that the effect of defoliation is in proportion to the length of the remaining growing period (with reduced LA). The results show marked reductions in the number of pods per plant and seed yield with defoliations as late as the onset of seed growth (R5). These reductions were

comparable to those incurred by defoliations at (R1) and indicate a critical period for determining reproductive sink size.

(iii)   The results very clearly indicate that the effect of defoliation on the partitioning of photosynthate to plant organs varied according to the development stage at which it was applied. Differences in HI due to different stages of defoliation were observed independent of the influence of the level of defoliation or the cultivar used.

(iv)   Defoliation during flower initiation (Vnf) reduced the LA as well as the stem mass. The plant could not compensate for this loss at any later stage and therefore it had negative influence on the size of the reproductive sink as represented by the number of pods per plant.

(v)   Defoliation during the reproductive period had little influence on partitioning to the vegetative (structural) organs as represented by the stem mass but reduced the number of pods significantly. Thus at this stage of development, the effect of defoliation stress was restricted mainly to the reproductive structures.

(vi)   No evidence of the mobilisation of non-structural carbohydrate reserves was found as indicated by the fact that defoliation after the onset of seed growth (final number of pods was fixed) did not reduce stem mass. It does not, however, rule out the possibility of reserves drawn from the roots or leaves.

(vii)   Evidence of yield component compensation was found especially when defoliation had a direct influence on the first formed yield component (pods per plant) and there was a negative relationship between this parameter and either seeds per pod or 100 seed mass.

(viii) Evidence was found that the reproductive sink size was determined by the source (LA) at the end of the pod set stage and beginning of seed fill (R5). This indicates that the reproductive sink tends to be in balance with the source at this stage.

(ix) As far as vegetative sink size (represented by node number and stem mass), as well as the yield components, are concerned, no interaction between cultivars and time of defoliation was observed and source-sink relationships held true. The observed differences were in the area of seed yield which is the product of the yield components.

CHAPTER 4

THINNING STUDIES

4.1   Introduction

On fertile soils well supplied with soil moisture, competition for light
amongst plants is the overriding factor affecting their response to varia-
tion in population density.   The removal of plants during the growing
season provides a means of reducing the stress of mutual shading. This has
the advantage that the development stage and the intensity of mutual
shading can be chosen. On the other hand it has the disadvantage that the
treatment is permanent and influences the plant throughout the remainder
of the growing season.

Reduced mutual shading has the effect of increasing photosynthesis and the
resulting additional carbohydrates are distributed to the various vegeta-
tive and reproductive sinks. The way in which the different plant organs
are affected can indicate which organ has preference at a particular stage
as well as to what extent and in which way, the plant can overcome the
effects of an earlier stress period.

The trials described in this chapter were planned with the view to evalua-
ting the effects of different levels of mutual shading at different deve-
lopment stages as well as cultivar differences. The results will be inter-
preted in terms of the hypothesis on source-sink relationships.

4.2   Materials and methods

4.2.1   General information

The trials were conducted in 1979/80 and 1980/81. The information per-
taining to the experimental site is the same as for the defoliation
studies given in paragraph 3.2.1.

4.2.2   Thinning trial, 1979/80

The treatments were as follows:

Control

Co   no thinning: intrarow spacing 75 mm (18 plants m^{-2}).

Levels of thinning

L1   every third plant removed which gave an average intrarow spacing of
      112,5 mm (12 plants m^{-2}) (66,7% of the control),

L2 · every other plant removed which gave an average intrarow spacing of
      150 mm (9 plants m^{-2}) (50% of the control),

L3   two of three plants removed which gave an average intrarow spacing of
      225 mm (6 plants m^{-2}) (33,3% of the control).

Time of thinning

Plants at the initial intrarow spacing (75 mm) were thinned at four dif-
ferent development stages during the season, as follows:

S1 (V2) at the appearance of the first trifoliate,

S2 (V6f) beginning of flower initiation: six leaves on the main stem,

S3 (R1) beginning of the flowering period: 50% of the plants with at
         least one open flower,

S4 (R5) beginning of pod fill.

The cultivar Teebus was planted on 1979/12/14 in a factorially arranged randomized block design with four replications. The trial consisted of a 3 x 4 factorial design with an added control which was repeated four times in each of the four replications. This provided an extra three degrees of freedom for error. A plot size of four rows of 5 m each and an interrow spacing of 750 mm and 75 mm in the row was used. Two seeds per plant site were planted and thinned to the desired stand (one plant per plant site) one week after emergence to provide a population of 177778 plant ha^{-1}. Thinning was done with care in order to prevent damage to the remaining plants.

Sampling was confined to the R9 stage. Sampling procedure and methods of measurement were the same as described in 3.2.2.

4.2.3   Thinning trial, 1980/81

For the same reasons given in 3.2.3, a cultivar variable was included in this trial and levels of thinning were reduced to two. In the thinned treatment, every alternate plant in the row was removed to give a stand of 50% of the control (150 mm apart instead of 75 mm in the control). The treatments were as follows:

Cultivars

C1   Teebus,
C2   NEP 2,
C3   Bonus.

Time of thinning

Thinning was done at weekly intervals at 11 times starting 8 days after emergence:

S0   control (no thinning),

S1 (V3)   thinned 8 days after emergence,

S2 (V5)   thinned 15 days after emergence,

S3 (V7f)   thinned 22 days after emergence,

S4 (V9f)   thinned 29 days after emergence,

S5 (R1)   thinned 36 days after emergence,

S6 (R2)   thinned 43 days after emergence,

S7 (R3)   thinned 50 days after emergence,

S8 (R5)   thinned 57 days after emergence,

S9 (R6)   thinned 64 days after emergence,

S10 (R7)   thinned 71 days after emergence,

S11 (R8)   thinned 78 days after emergence.

The trial was planted on 1980/12/07 following the same procedures as in the 1979/80 thinning trial. A 3 x 4 factorial design in three replications was adopted. There was one control plot (no thinning) per replicate for each of the three cultivars.

The sampling procedure was the same as in 1979/80 except that branch number (excluding main stem) as well as the other parameters, was recorded.

4.2.4   Correlation matrix

Simple correlations were calculated between all measured parameters in each experiment and expressed in terms of a correlation matrix.

4.2.5   Statistical analysis

The statistical analysis of the 1979/80 trial was done on a Burroughs B7900 computer using a Genstat V Mark 4.04B Release package system. The 1980/81 trial was analyzed on a Hewlett Packard 9826 computer using the manufacturers package system.

4.3 Results, 1979/80

4.3.1 Vegetative sink

4.3.1.1 Leaf mass

An increase in the leaf mass above that of the control was observed at each higher thinning level. The differences were significant at the 50% (L2) (P=0,05) and the 66% (L3) (P=0,01) levels. Thinning during the vegetative period (S1 and S2) tended to increase leaf mass but not significantly (Table 4.1).

4.3.1.2 Stem mass

The two highest levels of thinning (L2 and L3) resulted in a significant (P=0,01) increase in stem mass in comparisons with the control and the lowest thinning level (L1). Thinning during the vegetative period (S1 and S2) gave significantly (P=0,01) higher stem masses than that of the control and of treatments applied during the reproductive period (S3 and S4) (Table 4.2).

4.3.2 Reproductive sink

4.3.2.1 Pod number

A significant increase in the number of pods per plant (P=0,01) was observed at each higher level of thinning while the lowest level (L1) did not differ from the control. The greatest increase in pod number occurred with thinning before flower initiation (S1) and decreased significantly at each later time of thinning. All times of thinning increased pod number significantly (P=0,01) except at the onset of seed growth (S4) when no difference occurred (Table 4.3).

Table 4.1 The effect of levels and time of thinning on the leaf mass
(g plant^{-1}) of dry beans (cv. Teebus), Potchefstroom,
1979/80 (see Appendix 28)

Time of thinning (S)	Level of thinning (L)			Mean
	L1 (33%)	L2 (50%)	L3 (66%)	
		Co 5,30		
S1	7,24	8,36	9,63	8,41
S2	6,80	5,41	9,51	7,24
S3	4,94	6,39	8,21	6,51
S4	5,24	6,91	6,41	6,81
Mean	6,05	6,77	8,44	6,64
CV	25,1%			

	SE	LSD	
		0,05	0,01
Co and L means	± 0,42	1,19	1,58
Co vs S means	± 0,48	NS	NS
S means	± 0,45	NS	NS
Co vs L x S	± 0,83	NS	NS
L x S	± 0,66	NS	NS

Table 4.2 The effect of levels and time of thinning on the stem mass
(g plant^{-1}) of dry beans (cv. Teebus), Potchefstroom,
1979/80 (see Appendix 29)

Time of thinning (S)	Level of thinning (L)			Mean
	L1 (33%)	L2 (50%)	L3 (66%)	
		Co 8,14		
S1	10,28	13,17	15,08	12,84
S2	9,00	10,52	12,71	10,74
S3	7,15	8,47	9,17	8,26
S4	7,69	7,91	9,15	8,25
Mean	8,52	10,02	11,53	9,55
CV	16,2%			

	SE	LSD	
		0,05	0,01
Co and L means	± 0,39	1,10	1,46
Co vs S means	± 0,43	1,27	1,69
S means	± 1,42	1,18	1,58
Co vs L x S	± 0,77	NS	NS
L x S	± 0,61	NS	NS

Table 4.3 The effect of levels and time of thinning on the number of
          pods per plant of dry beans (cv. Teebus), Potchefstroom,
          1979/80 (see Appendix 30)

Time of thinning (S)	Level of thinning (L)			Mean
	L1 (33%)	L2 (50%)	L3 (66%)	
	Co 19,37			
S1	25,87	31,77	38,01	31,88
S2	24,64	26,55	34,09	28,43
S3	17,50	26,28	27,88	23,89
S4	17,50	19,66	21,61	19,59
Mean	21,38	26,06	30,39	30,39
CV	14,5%			

	SE		LSD	
			0,05	0,01
Co and L means	±	0,88	2,50	3,34
Co vs S means	±	1,02	2,89	3,85
S means	±	0,95	2,70	3,60
Co vs L x S	±	1,76	NS	NS
L x S	±	1,39	NS	NS

4.3.2.2   Pod mass

A significant increase in pod mass (P=0,01) was observed at each higher
thinning level while L1 had a significantly higher pod mass than the con-
trol.   The greatest increase in pod mass occurred with thinning before
flower initiation (S1) and decreased significantly with each later time of
thinning.   Thinning at the R5 stage (S4) had no effect on pod mass com-
pared to that of the control (Table 4.4).

4.3.2.3   Seeds per pod

Time but not intensity of thinning, affected the number of seeds per pod.
At the onset of flowering (S3) thinning tended to produce more seeds per
pod than the control. The other times of thinning showed an opposite
tendency especially at the onset of seed growth (S4) at which stage   a
significant difference between S3 and S4 (Table 4.5) was recorded.

4.3.2.4   Seed number

Thinning increased the number of seeds per plant. This effect was   more
pronounced at the higher thinning levels and in the earlier times of
treatment.   A significant increase in the number of seeds occurred when
thinning was done at times before the onset of seed growth (S1, S2, S3) at
the 50% (L2) and 66% (L3) levels and during the vegetative period (S1, S2)
at the 33% (L1) level. Late (S4) thinnings at all levels had no effect on
the number of seeds per plant. Lower seed numbers occurred at each later
time of thinning at the highest level (L3) while these differences were
smaller at the two lower thinning levels (Table 4.6).

Table 4.4 The effect of levels and time of thinning on the pod mass
(g plant^{-1}) of dry beans (cv. Teebus), Potchefstroom,
1979/80 (see Appendix 31)

Time of thinning (S)	Level of thinning (L)			Mean
	L1 (33%)	L2 (50%)	L3 (66%)	
		Co 29,29		
S1	37,82	50,70	56,30	48,27
S2	36,35	42,40	51,08	43,28
S3	30,55	42,98	45,39	39,64
S4	26,84	27,78	30,25	28,29
Mean	32,89	40,96	45,76	37,22
CV	13,3%			

		SE	LSD	
			0,05	0,01
Co and L means	±	1,24	3,53	4,71
Co vs S means	±	1,43	4,08	5,44
S means	±	1,34	3,81	5,09
Co vs L x S	±	2,48	NS .	NS
L x S	±	1,96	NS	NS

Table 4.5   The effect of levels and time of thinning on the number of
            seeds per pod of dry beans (cv. Teebus), Potchefstroom,
            1979/80 (see Appendix 32)

Time of thinning (S)	Level of thinning (L)			Mean
	L1 (33%)	L2 (50%)	L3 (66%)	
	Co 5,31			
S1	5,17	5,30	5,00	5,16
S2	5,20	5,21	5,11	5,17
S3	5,81	5,42	5,24	5,52
S4	5,25	4,90	4,92	5,02
Mean	5,36	5,21	5,09	5,24
CV	7,6%			

	SE	LSD	
		0,05	0,01
Co and L means	$\pm$ 0,10	NS	NS
Co vs S means	$\pm$ 0,11	0,33	NS
S means	$\pm$ 0,11	0,31	NS
Co vs L x S	$\pm$ 0,20	NS	NS
L x S	$\pm$ 0,16	NS	NS

Table 4.6 The effect of levels and time of thinning on the number of
          seeds per plant of dry beans (cv. Teebus), Potchefstroom,
          1979/80 (see Appendix 33)

Time of thinning (S)	Level of thinning (L)			Mean
	L1 (33%)	L2 (50%)	L3 (66%)	
	Co 100,94			
S1	132,76	168,02	189,62	163,47
S2	128,34	130,42	173,89	144,22
S3	101,35	142,08	147,84	130,42
S4	91,67	96,29	106,51	98,16
Mean	113,53	134,20	154,47	125,78
CV	13,2%			

	SE	LSD 0,05	0,01
Co and L means	± 4,14	11,77	15,70
Co vs S means	± 4,78	13,59	18,13
S means	± 4,47	12,71	16,96
Co vs L x S	± 8,28	23,54	NS
L x S	± 6,54	18,61	NS

4.3.2.5   Hundred seed mass

The hundred seed mass of the control was significantly lower than treat-
ments which were thinned at the onset of the flowering period (S3)
(Table 4.7).

4.3.2.6   Seed yield

Thinning increased seed yield per plant. This effect was more pronounced
at higher thinning levels and when thinning took place early. A signifi-
cant increase in seed yield (P=0,01) occurred when the plants were thinned
at any time before the onset of seed growth (S1, S2, S3) at the 50% (L2)
and 66% (L3) levels. The 33% (L1) thinning level increased seed yield
significantly before, but not after, flower initiation (S1). The effect
of thinning on seed yield decreased with each later time of thinning.
This effect was most pronounced at the 66% (L3) level (Table 4.8).

4.3.3   Total dry mass

The TDM increased significantly (P=0,01) at each increasing level of thin-
ning (L1 to L3). The TDM of the control was significantly lower than all
three thinning levels except the lowest (L1) where no significant diffe-
rence was observed. The TDM increase was greatest when thinning was done
before flower initiation (S1). A significant decrease (P=0,01) in TDM
occurred with each later time of thinning. All times of thinning resulted
in a significant (P=0,01) increase in TDM above that of the control except
when done at R5 (S4) when no increase in mass occurred (Table 4.9).

4.3.4   Harvest index

Thinning during the vegetative period (S1, S2) tended to increase the
harvest index but the differences were not statistically significant.
However, thinning at the onset of the flowering period (S3) resulted in a
significant increase (P=0,01) (Table 4.10).

Table 4.7 The effect of levels and time of thinning on the 100 seed
          mass (g) of dry beans (cv. Teebus), Potchefstroom, 1979/80
          (see Appendix 34)

Time of thinning (S)	Level of thinning (L)			Mean
	L1 (33%)	L2 (50%)	L3 (66%)	
	Co 22,99			
S1	22,45	24,08	23,48	23,33
S2	22,60	23,78	23,05	23,14
S3	24,00	24,06	23,85	23,97
S4	23,08	22,30	23,10	22,83
Mean	23,03	23,55	23,37	23,24
CV	4,1%			

	SE	LSD 0,05	0,01
Co and L means	± 0,24	NS	NS
Co vs S means	± 0,27	0,78	NS
S means	± 0,26	0,73	NS
Co vs L x S	± 0,47	NS	NS
L x S	± 0,38	NS	NS

Table 4.8 The effect of levels and time of thinning on the seed yield
(g plant^{-1}) of dry beans (cv. Teebus), Potchefstroom,
1979/80 (see Appendix 35)

Time of thinning (S)	Level of thinning (L)			Mean
	L1 (33%)	L2 (50%)	L3 (66%)	
		Co 23,25		
S1	30,12	40,48	44,49	38,36
S2	28,81	33,18	40,03	34,06
S3	24,28	34,15	35,29	31,24
S4	21,19	21,66	23,51	22,12
Mean	26,10	32,36	35,83	29,39
CV	13,3%			

	SE	LSD 0,05	0,01
Co and L means	± 0,98	2,78	3,72
Co vs S means	± 1,13	3,22	4,29
S means	± 1,06	3,01	4,01
Co vs L x S	± 1,96	5,57	NS
L x S	± 1,55	4,40	NS

Table 4.9 The effect of levels and time of thinning on the total dry
mass (g plant^{-1}) of dry beans (cv. Teebus), Potchefstroom,
1979/80 (see Appendix 36)

Time of thinning (S)	Level of thinning (L)			Mean
	L1 (33%)	L2 (50%)	L3 (66%)	
		Co 42,73		
S1	55,34	72,23	81,00	69,52
S2	52,16	58,33	73,29	61,26
S3	42,63	57,83	62,76	54,41
S4	39,75	41,10	45,81	42,22
Mean	47,47	57,37	65,72	53,32
CV	13,2%			

	SE	LSD	
		0,05	0,01
Co and L means	± 1,78	5,00	6,67
Co vs S means	± 2,03	5,78	7,71
S means	± 1,76	5,00	6,67
Co vs L x S	± 3,52	NS	NS
L x S	± 1,76	NS	NS

Table 4.10 The effect of the levels and time of thinning on the har-
vest index (%) of dry beans (cv. Teebus), Potchefstroom,
1979/80 (see Appendix 37)

Time of thinning (S)	Level of thinning (L)			Mean
	L1 (33%)	L2 (50%)	L3 (66%)	
		Co 54,40		
S1	54,49	56,05	54,95	55,16
S2	55,47	56,70	54,65	55,61
S3	57,03	59,08	56,59	57,57
S4	53,03	52,40	52,65	52,82
Mean	55,10	56,06	54,71	55,07
CV	3,4%			

	SE	LSD	
		0,05	0,01
Co and L means	± 0,49	NS	NS
Co vs S means	± 0,57	1,61	2,14
S means	± 0,53	1,50	2,01
Co vs L x S	± 0,98	NS	NS
L x S	± 0,77	NS	NS

4.3.5   Correlation matrix

There was a positive correlation (P=0,01) between the parameters represen-
ting the vegetative sink (stem mass and leaf mass) and between components
of the reproductive sink (pod number, seed number and seed yield).   In
turn the parameters within each group were strongly inter-correlated
(r>0,95).   There was no significant correlation between the three yield
components: pod number, seeds per pod and 100 seed mass. Pod number was
positively correlated with seed yield (P=0,01) (Table 4.11).

4.4   Results, 1980/81

4.4.1   Vegetative sink

4.4.1.1   Leaf mass

The leaf mass of the three cultivars reacted in a similar way to thinning.
There were no statistically significant differences between cultivars but
Bonus tended to have the highest leaf mass.

Thinning during the vegetative period (S1, S2, S3, S4 and S5) resulted in
greater leaf masses (P=0,01) than that of the control. Thinning after the
onset of flowering (S6 and later), had no significant effect on leaf mass
though   there was an overall decline (P=0,01) in leaf mass during this
period (Table 4.12).

4.4.1.2   Node number

The number of nodes per plant (indicating the number of leaves) was in-
fluenced in the same way in all three cultivars. Teebus had significantly
fewer nodes (P=0,01) than NEP 2 and Bonus which did not differ signifi-
cantly from each other (Table 4.13).

Table 4.11 Correlation matrix (r values and tests of significance) of the components of vegetative and reproductive sink at harvest, 1979/80

	Leaf mass	Seed yield	Pod number	Seed number	100 seed mass	Seeds per pod
Stem mass	0.64**	0.85**	0.89**	0.85**	0.23	-0.20
Leaf mass		0.66**	0.66**	0.71**	0.02	0.01
Seed yield			0.94**	0.98**	0.35	0.03
Pod number				0.95**	0.16	-0.27
Seed number					0.20	0.01
100 seed mass						0.15

Table 4.12 The effect of the time of thinning on the leaf mass (g plant^{-1}) of three dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 38)

Time of thinning (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP2)	C3 (Bonus)	
S0 (Control)	8,85	8,19	9,34	8,79
S1 (V2)	13,51	14,08	17,90	15,16
S2 (V3)	12,54	18,26	12,74	14,51
S3 (V4)	14,40	11,65	17,58	14,54
S4 (V6f)	15,52	13,02	12,92	13,82
S5 (V9f)	13,90	14,16	15,63	14,57
S6 (R1)	10,88	11,63	12,67	11,73
S7 (R3)	11,26	8,96	10,47	10,23
S8 (R5)	8,66	7,80	10,76	9,07
S9 (R6)	10,99	8,22	12,75	10,65
S10 (R7)	8,22	4,98	11,65	8,28
S11 (R8)	6,82	6,86	6,52	6,73
Mean	11,30	10,65	12,58	11,51
CV	30,8%			

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 0,59	NS	NS
Times (S)	± 1,18	3,33	4,42
C x S	± 2,04	NS	NS

Table 4.13 The effect of the time of thinning on the number of nodes
           per plant of three dry bean cultivars, Potchefstroom,
           1980/81 (see Appendix 39)

Time of thinning (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP2)	C3 (Bonus)	
S0 (Control)	23,02	23,85	23,87	23,58
S1 (V2)	23,91	31,49	29,06	28,15
S2 (V3)	26,37	31,48	32,74	30,20
S3 (V4)	23,26	29,94	31,93	28,38
S4 (V6f)	23,85	28,48	24,67	25,67
S5 (V9f)	20,52	26,02	25,83	24,12
S6 (R1)	22,69	21,61	25,48	23,26
S7 (R3)	21,69	21,28	23,41	22,12
S8 (R5)	19,46	22,63	26,41	22,83
S9 (R6)	21,33	21,22	22,94	21,83
S10 (R7)	19,65	22,35	23,22	21,74
S11 (R8)	19,37	20,87	22,54	20,93
Mean	22,09	25,10	26,01	24,40

CV = 12,5%

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 0,51	1,43	1,91
Times (S)	± 1,01	2,87	3,81
L x S	± 1,76	NS	NS

Thinning during the period before flower bud initiation (S1, S2 and S3) produced more nodes (P=0,01) than the control. From V9f onwards (S4 and later) there was a fairly constant decline in the number of nodes per plant but the differences were not significant in comparisons with the control. There were however, significant differences between the three last thinnings which were applied in the seed growth period (S9, S10 and S11) and all thinning treatments during the vegetative phase (S1 to S5) (Table 4.13).

4.4.1.3   Branch number

The number of branches per plant of the three cultivars differed in their reaction to thinning at different stages. Teebus (C1) was little influenced by the thinning treatments except in the S2 treatment which produced significantly more branches than the control. Thinning before flower bud initiation (S1, S2 and S3) increased the number of branches significantly in both NEP 2 and Bonus. In the case of NEP 2, this increase was significant throughout the vegetative period (S1 to S5). During the reproductive period, thinning did not influence the branch number of any of the cultivars (Table 3.14).

4.4.1.4   Stem mass

All cultivars showed a significant increase in stem mass in comparison with the control when thinning was applied before flower initiation (S1, S2 and S3). Subsequently strong interactions were evident. Thinning had no significant effect on the stem mass of Teebus during any of the later stages while the stem mass of NEP 2 increased significantly above that of the control in S10 (R7). Bonus produced a similar response to thinning in treatment S5 (V9) (Table 4.15).

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Table 4.14 The effect of the time of thinning on the number of bran-
ches per plant of three dry bean cultivars, Potchefstroom,
1980/81 (see Appendix 40)

Time of thinning (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP2)	C3 (Bonus)	
S0 (Control)	1,870	2,259	2,222	2,117
S1 (V2)	2,241	3,241	3,019	2,833
S2 (V3)	2,667	3,463	3,278	3,136
S3 (V4)	2,000	3,389	3,093	2,827
S4 (V6f)	1,648	2,981	2,426	2,352
S5 (V9f)	1,870	2,778	2,500	2,383
S6 (R1)	2,019	2,167	2,222	2,136
S7 (R3)	1,963	1,981	2,167	2,037
S8 (R5)	1,630	2,204	2,370	2,068
S9 (R6)	2,000	2,000	1,981	1,994
S10 (R7)	1,815	2,241	1,963	2,006
S11 (R8)	1,481	2,093	2,093	1,889
Mean	1,934	2,566	2,444	2,315
CV	12,2%			

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 0,047	0,133	0,177
Times (S)	± 0,094	0,266	0,354
C x S	± 0,163	0,462	0,614

Table 4.15 The effect of the time of thinning on the stem mass (g plant^{-1}) of three dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 41)

Time of thinning (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP2)	C3 (Bonus)	
S0 (Control)	7,92	9,90	12,32	10,05
S1 (V2)	11,81	12,94	17,26	14,00
S2 (V3)	12,34	13,48	19,09	14,97
S3 (V4)	10,47	12,19	18,73	13,79
S4 (V6f)	8,89	12,11	13,84	11,61
S5 (V9f)	9,31	10,73	15,11	11,72
S6 (R1)	8,85	10,74	12,63	10,74
S7 (R3)	9,24	9,21	13,39	10,61
S8 (R5)	8,16	10,20	14,65	11,00
S9 (R6)	8,79	9,90	13,06	10,58
S10 (R7)	7,60	13,22	9,35	10,06
S11 (R8)	8,04	8,07	11,62	9,24
Mean	9,28	11,06	14,26	11,53

CV   13,4%

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 0,285	0,73	0,97
Times (S)	± 0,516	1,55	1,94
C x S	± 0,895	2,52	3,35

4.4.2   Reproductive sink

4.4.2.1   Pod number

The number of pods per plant of the three cultivars was influenced in a
similar way by thinning at different times. Bonus (C3) produced less pods
than Teebus (C1) and NEP 2 (C2) which did not differ significantly from
each other.   Treatments thinned during the vegetative phase (S1 to S5)
produced more pods (P=0,01) than the control. Thinning during the repro-
ductive phase showed no such difference except at S7 (pod set period) when
a significant decrease in the number of pods was recorded (Table 4.16).

4.4.2.2   Pod mass

The pod mass of the three cultivars reacted in the same way to thinning at
different stages.   Thinning during the vegetative period (S1 to S5) as
well as the onset of flowering (S6), resulted in a greater pod mass
(P=0,01) than that of the control. From S7 (pod set period) onwards,
thinning had no effect on pod mass (Table 4.17).

4.4.2.3   Seeds per pod

The number of seeds per pod was not influenced by time of thinning.   A
cultivar response was, however, present and the three cultivars differed
significantly (P=0,01) from each other. NEP 2 produced more seeds per pod
than Bonus with Teebus taking an intermediate position (Table 4.18).

4.4.2.4   Seed number

The number of seeds per plant was influenced strongly by cultivar and time
of thinning but there was no interaction between treatments. Seed number
in NEP 2 (171 seeds plant^{-1}) and Teebus (150 seeds plant^{-1}) was consid-
erably greater (P=0,01) than that in Bonus (75 seeds plant^{-1}). Although
smaller, the difference between the former two cultivars was significant

Table 4.16 The   effect of the time of thinning on the number of pods
            per plant of three dry bean cultivars, Potchefstroom,
            1980/81 (see Appendix 42)

Time of thinning (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP2)	C3 (Bonus)	
S0 (Control)	30,07	26,74	16,33	24,38
S1 (V2)	38,82	36,69	21,78	32,43
S2 (V3)	38,44	43,33	26,91	36,29
S3 (V4)	40,33	35,22	24,65	33,40
S4 (V6f)	36,35	38,33	18,48	31,06
S5 (V9f)	37,72	34,57	21,82	31,37
S6 (R1)	30,15	27,39	19,48	25,67
S7 (R3)	24,15	22,35	15,39	20,63
S8 (R5)	26,28	27,32	16,26	23,28
S9 (R6)	30,61	26,93	16,15	24,56
S10 (R7)	26,83	25,48	16,07	22,80
S11 (R8)	27,85	25,82	15,69	23,12
Mean	32,30	30,85	19,08	27,41
CV	14,0%			

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 0,64	1,81	2,40
Times (S)	± 1,28	3,62	4,81
C x S	± 2,21	NS	NS

Table 4.17 The effect of the time of thinning on the pod mass (g plant^{-1}) of three dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 43)

Time of thinning (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP2)	C3 (Bonus)	
S0 (Control)	36,22	36,56	39,45	37,41
S1 (V2)	53,33	49,13	46,72	49,73
S2 (V3)	53,41	53,43	54,10	53,65
S3 (V4)	51,29	48,97	59,89	53,38
S4 (V6f)	49,81	53,89	46,31	50,00
S5 (V9f)	55,04	50,12	51,74	52,30
S6 (R1)	48,07	40,76	48,53	45,79
S7 (R3)	37,24	30,82	38,29	35,45
S8 (R5)	31,08	35,58	39,92	35,53
S9 (R6)	35,18	31,47	27,80	31,48
S10 (R7)	31,90	27,10	34,44	31,15
S11 (R8)	39,47	33,96	30,55	34,66
Mean	43,50	40,98	43,15	42,54
CV	14,4%			

	SE	LSD 0,05	0,01
Levels (L)	± 1,02	NS	NS
Times (S)	± 2,04	5,76	7,66
C x S	± 3,53	NS	NS

Table 4.18 The effect of the time of thinning on the number of seeds
per pod of three dry bean cultivars, Potchefstroom, 1980/81
(see Appendix 44)

Time of thinning (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP2)	C3 (Bonus)	
S0 (Control)	4,267	5,867	3,967	4,700
S1 (V2)	4,800	5,500	3,667	4,656
S2 (V3)	4,567	4,733	3,867	4,389
S3 (V4)	4,367	5,733	3,967	4,689
S4 (V6f)	4,233	5,533	5,167	4,978
S5 (V9f)	4,700	6,300	4,233	5,078
S6 (R1)	4,867	5,333	4,533	4,911
S7 (R3)	5,200	5,000	4,000	4,900
S8 (R5)	5,267	5,267	4,200	4,911
S9 (R6)	4,333	5,067	4,000	4,467
S10 (R7)	4,300	5,233	3,733	4,422
S11 (R8)	4,967	5,600	3,633	4,733
Mean	4,656	5,472	4,081	4,736
CV	13,6%			

	SE	LSD	
		0,05	0,01
Cultivars(C)	$\pm$ 0,106	0,302	0,402
Times (S)	$\pm$ 0,213	NS	NS
C x S	$\pm$ 0,370	NS	NS

(P=0,01) (Table 4.19). Thinning during the vegetative phase (S1 to S5) resulted in the production of more seeds per plant (P=0,01) than in the control. This difference was maintained until the onset of flowering (S6). Thinning during the pod set and seed growth period (S7 to S11) gave no significant differences in comparisons with the control (Table 4.19).

4.4.2.5   Hundred seed mass

The hundred seed mass of the three cultivars reacted differently to time of thinning. Bonus had a significantly larger 100 seed mass than the other two cultivars at all stages of thinning. Teebus had larger seeds (P=0,05) than NEP 2 except when thinning took place during the pod set period (S7, S8 and S9) at which time the difference between the two cultivars persisted but was not statistically significant. The 100 seed mass of NEP 2 was not influenced by thinning at any stage. The 100 seed mass of Teebus was greatest when thinning was applied at the onset of flowering (S6). This level was significantly higher than that recorded in the subsequent pod formation and seed development stages (S7, S8, S9) but did not differ from the control. Thinning in Bonus tended to produce smaller seeds than the control, the difference being significant in the S4, S6, S9 and S11 treatments (Table 4.20).

4.4.2.6   Seed yield

The results are presented in Table 4.21. As may be seen in comparisons between the data in this table and in Table 4.17 (pod mass), the response of seed yield to the treatments was virtually the same as that of pod mass and the assessment given in paragraph 4.4.2.2 is applicable.

4.4.3   Total dry mass

The three cultivars showed similar reactions to the different stages of thinning. Bonus had a significantly greater TDM (P=0,01) than Teebus and NEP 2 which did not differ significantly (Table 4.22).

Table 4.19 The effect of the time of thinning on the number of seeds per plant of three dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 45)

| Time of thinning (S) | Cultivars (C) | | | Mean |
	C1 (Teebus)	C2 (NEP2)	C3 (Bonus)	
S0 (Control)	128,06	156,19	64,85	116,36
S1 (V2)	184,91	200,52	80,02	155,15
S2 (V3)	176,20	220,06	91,57	162,62
S3 (V4)	175,52	198,98	98,22	157,57
S4 (V6f)	155,09	214,85	97,24	155,73
S5 (V9f)	176,89	215,96	89,41	160,75
S6 (R1)	146,02	173,19	87,59	135,60
S7 (R3)	142,28	123,87	61,69	109,28
S8 (R5)	136,33	142,63	68,04	115,67
S9 (R6)	131,44	133,39	47,59	104,14
S10 (R7)	115,32	133,07	59,32	102,57
S11 (R8)	137,89	143,59	57,44	112,95
Mean	150,50	171,36	75,25	132,37
CV	14,3%			

| | SE | LSD | |
		0,05	0,01
Cultivars (C)	± 3,15	8,91	11,85
Times (S)	± 6,30	17,83	23,71
C x S	± 10,92	NS	NS

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Table 4.20 The effect of the time of thinning on the 100 seed mass (g)
of three dry bean cultivars, Potchefstroom, 1980/81 (see
Appendix 46)

Time of thinning (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP2)	C3 (Bonus)	
S0 (Control)	23,00	18,53	48,03	29,86
S1 (V2)	23,17	19,43	45,67	29,42
S2 (V3)	25,03	19,30	47,03	30,46
S3 (V4)	25,83	19,40	49,93	31,72
S4 (V6f)	25,50	20,27	37,13	27,63
S5 (V9f)	25,30	18,40	45,17	29,62
S6 (R1)	27,03	18,80	43,20	29,68
S7 (R3)	21,67	20,27	48,43	30,12
S8 (R5)	22,80	19,90	45,20	29,03
S9 (R6)	21,23	18,43	42,60	27,42
S10 (R7)	22,27	16,53	44,56	27,79
S11 (R8)	23,33	18,80	39,70	27,28
Mean	23,78	19,01	44,72	29,17
CV	9,1%			

	SE	LSD 0,05	0,01
Cultivars (C)	± 0,44	1,25	1,67
Times (S)	± 0,89	2,51	3,34
C x S	± 1,54	4,34	5,78

Table 4.21 The effect of the time of thinning on the seed yield
(g plant^{-1}) of three dry bean cultivars, Potchefstroom,
1980/81 (see Appendix 47)

Time of thinning (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP2)	C3 (Bonus)	
S0 (Control)	29,38	28,85	31,48	29,90
S1 (V2)	43,05	38,99	37,09	39,71
S2 (V3)	43,84	42,43	42,51	42,93
S3 (V4)	45,30	38,51	48,76	44,20
S4 (V6f)	39,58	43,03	35,82	39,48
S5 (V9f)	44,76	39,74	40,43	41,64
S6 (R1)	39,17	31,87	37,94	36,33
S7 (R3)	30,17	24,49	29,83	28,16
S8 (R5)	24,96	28,38	30,74	28,03
S9 (R6)	27,93	24,64	20,07	24,21
S10 (R7)	25,65	20,72	26,44	24,27
S11 (R8)	32,15	27,02	22,88	27,35
Mean	35,50	32,39	33,67	33,85
CV	15,7%			

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 0,89	NS	NS
Times (S)	± 1,78	5,02	6,68
C x S	± 3,07	NS	NS

Thinning during the vegetative period (S1 to S5) increased the yield of TDM per plant in all comparisons with the control. During the reproductive period thinning produced a higher TDM (P=0,05) than that of the control at the onset of flowering (S6) only (Table 4.22).

4.4.4   Harvest index

The HI of the three cultivars varied according to the time of thinning. In general, the HI of individual cultivars differed significantly with Teebus having the highest, and Bonus the lowest values. During the vegetative phase, thinning had no effect on the HI of any of the cultivars in comparison with the control. There was a general tendency for the HI to attain its maximum values in treatments S5 and S6 (late vegetative and early flowering) in Teebus; S4 and S5 (late vegetative) in NEP 2 and S6 (early flowering) in Bonus. In each cultivar, this was followed by lower HI during the reproductive phase: S7 to S10 (Teebus); S7, S9 and S10 (NEP 2) and S7, S8 S9 and S11 (Bonus) (Table 4.23).

4.4.5   Correlation matrix

There was a positive correlation (P=0,01) among the four parameters representing the vegetative sink (stem mass, leaf mass, branch number and node number) which in turn were positively correlated (P=0,01) with seed yield. Pod number, seed number and seed yield were positively correlated (P=0,01). The 100 seed mass was negatively correlated (P=0,01) with the other two yield components: pod number and seeds per pod (Table 4.24).

4.5   Discussion

The plants responded to reduced mutual shading by producing more TDM per plant which corresponds with the findings of Aguilar et al. (1977) (Figure 4.1a). At the earlier stages of thinning there was a strong positive relationship between TDM and intensity of thinning. However, the differences between intensities declined at the later stages of thinning and

Table 4.22 The effect of the time of thinning on the total dry mass (g plant^{-1}) of three dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 48)

Time of thinning (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP2)	C3 (Bonus)	
S0 (Control)	44,15	46,47	51,78	47,46
S1 (V2)	65,14	62,07	64,54	63,91
S2 (V3)	65,81	66,91	73,19	68,64
w3 (V4)	67,57	61,16	80,47	69,73
S4 (V6f)	58,70	66,00	60,15	61,62
S5 (V9f)	64,34	60,86	66,85	64,02
S6 (R1)	56,92	51,49	61,16	56,53
S7 (R3)	46,47	40,03	51,68	46,06
S8 (R5)	39,24	45,78	54,57	46,53
S9 (R6)	43,97	41,37	40,86	42,07
S10 (R7)	39,50	40,32	43,79	41,21
S11 (R8)	47,51	42,03	42,17	43,90
Mean	53,28	52,04	57,60	54,31
CV	13,5%			

	SE	LSD 0,05	0,01
Cultivars (C)	± 1,22	3,45	4,58
Times (S)	± 3,45	6,90	9,17
C x S	± 4,24	NS	NS

Table 4.23 The effect of the time of thinning on the harvest index (%)
of three dry bean cultivars, Potchefstroom, 1980/81 (see
Appendix 49)

Time of thinning (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP2)	C3 (Bonus)	
S0 (Control)	66,53	64,03	60,30	63,62
S1 (V2)	65,90	61,83	60,90	62,88
S2 (V3)	66,63	63,37	58,00	62,67
S3 (V4)	67,30	62,97	60,63	63,63
S4 (V6f)	66,99	65,23	58,93	63,71
S5 (V9f)	69,73	65,30	60,47	65,17
S6 (R1)	68,73	61,73	61,77	64,08
S7 (R3)	64,90	61,17	57,47	61,18
S8 (R5)	63,63	61,97	56,33	60,64
S9 (R6)	63,46	59,40	53,20	58,69
S10 (R7)	64,97	54,47	60,47	59,97
S11 (R8)	67,70	64,20	54,10	62,00
Mean	66,37	62,14	58,55	62,35
CV	3,5%			

	SE	LSD	
		0,05	0,01
Cultivars (C)	$\pm$ 0,37	1,04	1,38
Times (S)	$\pm$ 0,74	2,08	2,77
C x S	$\pm$ 1,27	3,60	4,79

Table 4.24 Correlation matrix (r values and tests of significance) of the components of vegetative and reproductive sink at harvest, Potchefstroom, 1980/81

	Leaf mass	Seed yield	Seed number	Pod number	100 seed mass	Branch number	Node number	Seeds per pod
Stem mass	0,42**	0,45**	-0,19	-0,08	0,59**	0,67**	0,70**	-0,24
Leaf mass		0,61**	0,19	0,34*	0,23	0,40*	0,55**	-0,15
Seed yield			0,48**	0,60**	0,12	0,47**	0,53**	0,06
Seed number				0,86**	-0,77**	0,27	0,17	0,63**
Pod number					-0,59**	0,24	0,24	0,23
100 seed mass						0,12	-0,26	-0,62**
Branch number							-0,84**	0,16
Node number								-0,01

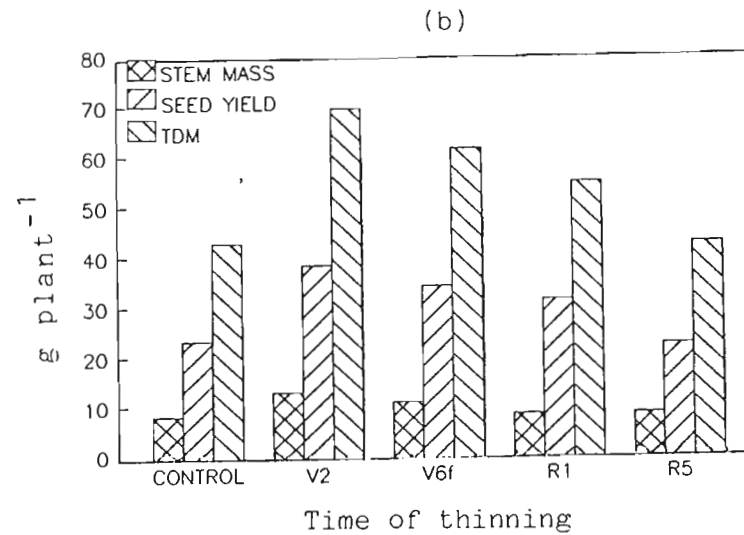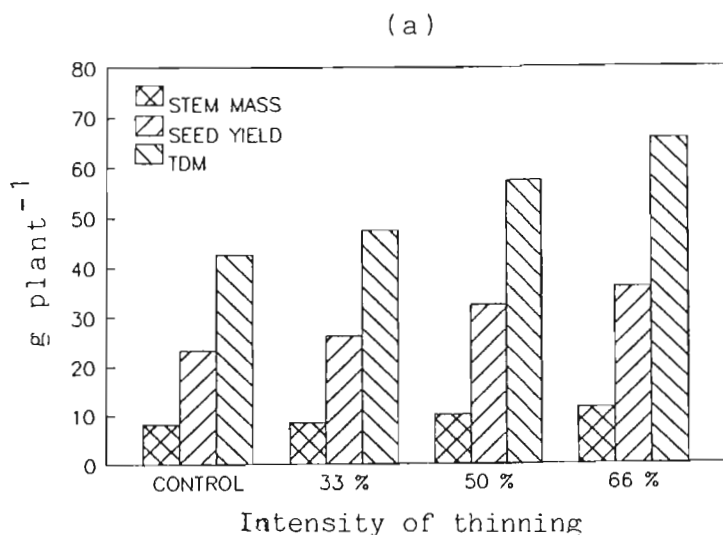Figure 4.1   The effect of (a) intensity of thinning and (b) times of thinning on the stem mass, seed yield and TDM of dry beans, Potchefstroom, 1979/80 (tests of significance are presented in Tebles 4.2, 4.8 and 4.9)
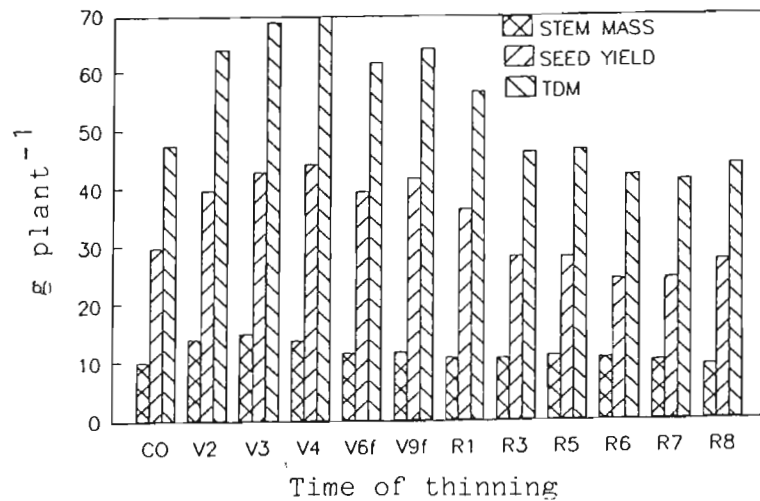
Figure 4.2   The effect of times of thinning on the stem mass, seed yield and TDM of dry beans, Potchefstroom, 1980/81 (tests of significance are presented in Tables 4.15, 4.12 and 4.22)

from the late pod set stage onwards, there were no differences between treatments. Thus plant response to higher light intensity declined as the crop advanced into the reproductive phase. Clearly later thinning meant that the plants were subjected to a longer period of mutual shading, leaving a shorter period during which benefit could be derived from high light intensity at lower canopy levels. Since all treatments matured at the same time, variations in length of growing period, did not contribute towards the measured differences in TDM. It follows, therefore, that reduced mutual shading was responsible for the increase in TDM in the earlier thinning treatments. This is in keeping with the results of Crookston et al. (1975), who found that increased light intensity at lower canopy levels improved the photosynthetic rate per unit LA. Referring more specifically to the components of TDM, thinning during the vegetative and early reproductive phase produced an increase in leaf number (nodes) and mass, stem mass, branch number and pod mass. Clearly this response increased the photosynthetic area per plant and as shown by Watson (1952), this would be expected to stimulate dry matter production. On the other hand, late thinning had no effect on the growth of both vegetative and reproductive organs, hence the absence of a response in dry matter accumulation (Figures 4.1b and 4.2).

There was no interaction between cultivars and the stages at which the thinning treatments were applied. This may be interpreted as indicating that cultivars of different genetic origins and growth habits react similarly to thinning.

The results of the two thinning trials would be expected to provide data regarding the time at which competition between unthinned plants begins to retard the growth of individual plants. If no difference is recorded between times of thinning, then there is no change in the intensity of interplant competition. Competition for light during early growth normally gives rise to reduced vegetative growth in individual plants (Crookston et al., 1975; Lopez et al. (1982). In 1979/80 the stem mass of Teebus tended to decline steadily at each later stage of thinning in

the vegetative period, indicating competition effects before flower initiation. In 1980/81 the stem mass and the number of nodes (leaf number) of all three cultivars began to decline at development stage V4 which occurred one week before flower initiation and three weeks before flowering (Figure 4.2). Thus at an intrarow spacing of 75 mm (177730 plant ha^{-1}) the effects of plant competition were apparent three weeks before flowering. Aguilar et al. (1977), in a similar experiment, found that competition between unthinned plants began a little later: two weeks before flowering. Comparisons of this nature are of course difficult to evaluate since plant spacings, temperatures and hence rate of development, and cultivars differ from trial to trial.

As described earlier, thinning during the vegetative period resulted in the development of more vegetative organs and therefore a larger source per plant. Very little vegetative development, however, took place during the reproductive period. Stem masses for Teebus (both seasons) in the thinned treatments were very similar to the controls and although rather variable stem masses were recorded for Bonus and NEP 2 in 1980/81, the overall trend was the same (Figures 4.1b and 4.2). The results relating to leaf number and mass were very similar: in both seasons and all cultivars, there was no significant difference between thinning treatments and the control. This confirms the hypothesis that the vegetative organs have preference for carbohydrate translocation during the vegetative period only, and corresponds with the findings of other researchers (Stoy, 1969). Thinning during the vegetative and early flowering stage stimulated reproductive development. This is expressed in the higher pod masses (a larger sink) of the thinned plants in both seasons and all cultivars. This response can be regarded as the result of a larger source (vegetative organs) developing after early thinning. During the late pod set and seed fill stages thinning had no effect on the pod mass (sink size). This corresponds with the inability of the plants to produce more vegetative organs during the same period. Thus source size and as indicated by the lack of reaction in pod mass, sink size were fixed at this stage.

The result that thinning during the first week of flowering gave higher seed yields than the control (Figures 4.1b and 4.2) cannot be explained in terms of the development of additional source organs, since vegetative development had stopped at that stage. This is reflected in the stem masses (both seasons) as well as the number of branches and nodes (1980/81). The most likely explanation is that thinning permitted better light penetration into the canopy and in that way, raised the potential for photosynthesis (source). The larger sink in the thinned plants indicates that source size was the major limiting factor affecting seed yield in the controls.

Thinning at later stages (even only one week later) during both seasons had no influence on seed yield. This indicates that sink size was the limiting factor during late pod set and seed fill. Thus potential sink size was determined during the first week of flowering. These results correspond with those of CO_2 enrichment studies in beans (CIAT, 1977).

Since HI is a function of the masses of both the vegetative and reproductive organs, a high HI indicates a source limitation during the vegetative period (a relatively low vegetative mass) or an increased source resulting in a larger sink (reproductive organs) during the reproductive period. On the other hand a low HI indicates a sink limitation which could be the result of a limited source or a direct limitation on the sink organs during the reproductive period, for example, flower abscission due to high temperatures (Stobbe et al., 1966) or pod removal (Ciha & Brun, 1978). In this study all three cultivars tended to have high HI values when thinning took place at the end of the vegetative period, indicating increased seed set as a result of the better light penetration. Thus there was a source limitation in the control populations. The decline in HI values with thinning during the seed fill stage was the result of a decline in seed mass rather than stem mass. This indicates (i) a sink limitation which prevented any benefit from better light penetration or (ii) since HI values were lower than the control, a detrimental effect of thinning. Possible explanations of the latter reaction include: (i) physical damage

to the plants as a result of thinning, (ii) loss of support from neighbouring plants, and (iii) damage to previously shaded lower leaves exposed to a sudden increase in light intensity.

With regard to the relative sensitivity of the plants to mutual shading during the various development stages, the results suggest that the effect is initiated about one week before flower initiation (of the control treatments). The magnitude of this response increased towards the beginning of the flowering period at R1 and was accompanied by an increased source limitation. During the first week of flowering the sink size was set and from the R3 stage onward, the fixed sink size remained the limiting factor during the remainder of the pod set and seed growth periods.

The integrated effect of thinning is reflected in yield and its components since these parameters are conditioned by the current and all the previous treatments. According to the yield component compensation concepts of Adams (1967), the reaction of yield components to applied treatments during reproductive progression will indicate how additional photosynthate is distributed. In the present study the number of pods per plant was the only yield component which showed a high positive correlation with seed yield. This response occurred in both seasons and was the major factor affecting seed yield. Similar results are recorded in the literature (Chung & Goulden, 1971; Duarte & Adams, 1972; Westermann & Crothers, 1977). In both seasons and all cultivars, thinning had a greater influence on pod number than on seeds per pod or seed size. As described previously, thinning during the vegetative period resulted in an increase in the size of the vegetative organs (larger source). This was accompanied by an increase in the number of pods per plant.

In both seasons thinning at the onset of flowering (R1) resulted in an increase in seed yield. In 1979/80 this was accompanied by an increase in the number of pods per plant (in the case of Teebus) but in 1980/81 none of the cultivars showed this reaction. In the latter season, more seeds

per pod and/or larger seeds than those of the control, gave rise to the higher yields. During both seasons thinning during this period was accompanied by larger seeds only in the case of Teebus. Thinning at a level of 50% or more at the R1 development stage did, however, result in an increase in the number of seeds per plant of all the cultivars in both seasons. This response combined with the effect of number of pods per plant and seeds per pod, continued to have an effect on yield until at least one week after the onset of flowering.

The results outlined above may be interpreted in terms of Adam's yield component compensation approach. The number of pods per plant in the yield component which has preference as far as the additional photosynthate in the reproductive period is concerned. Thus plants thinned during the vegetative period in this study produced additional source organs which resulted in the production of more pods. When additional photosynthate becomes available the plant will continue to produce more pods per plant until the number of pods is fixed. Under normal conditions almost all pods are set from the first 60% of flowers formed (CIAT, 1981b). After the potential number of pods is set, additional photosynthate due to reduced mutual shading can only result in less seed abortion, since the number of seeds per pod is the next yield component to be determined. Evidence of both types of compensation was found at the onset of flowering (both seasons) in this study. The lack of an increase in seed size due to thinning after R5 suggests that this last formed yield component was unable to utilize any excess of carbohydrates during the latter part of the reproductive period, or that no additional photosynthate was available due to some other stress factor. Evidence of the latter proposition was found in the reduced number of pods per plant when thinning was applied during the early pod set period (R3) and in the seed yield during the seed fill stage (R6 and R7) in 1980/81. The tendency of Teebus to produce smaller seeds in the late thinning treatment provides supporting evidence. These results (a negative relationship) are very similar to those recorded in other spacing studies in dry beans (Leakey, 1972; Crothers & Westermann, 1976; Aguilar *et al.*, 1977; Westermann & Crothers, 1977), In

none of the cited studies was a reaction of seed size upon plant population observed. In the 1979/80 season Teebus tended to have a negative correlation between the number of pods and seeds per pod. This indicates that source and sink were in balance early in the reproductive period. As a result seed size was not affected by either an excess or shortage of carbohydrates (except in Teebus at R1) and there was no correlation between this parameter and the two earlier formed yield components. In 1980/81 the positive correlation between the number of pods and seeds per pod indicated that conditions favouring more pods per plant also suppressed seed abortion. The negative correlation between pod number and the 100 seed mass in 1980/81, indicated that conditions favourable to pod and seed set had created such a large sink that the available carbohydrates had to be divided among more seeds, which suppressed seed growth to some extent. All this evidence suggests that the potential sink size is set very soon after the onset of flowering, probably within the first week.

No evidence of utilization of stored non-structural carbohydrate reserves was observed in the results of the thinning experiments. It is, however, unlikely this would occur under conditions where the stress of mutual shading had been removed. As previously discussed, convincing evidence was found supporting the hypothesis that a sink limitation prevented the plants from utilizing the additional sunlight available after thinning. Plaut & Mayoral (1984) found that a limited sink size reduced the photosynthetic rate of beans. Thus it is likely that lack of response to late thinning in the present study was related to reduced rates of photosynthesis.

4.6   Conclusions

The following aspects of the working hypothesis, proposed in Chapter 1, are supported by the results of the thinning trial.

(i)   The effect of release of the stress of mutual shading differed depending on the development stage during which it was applied.

(a) During the vegetative period the increased photosynthate supply was partitioned to additional vegetative organs. This was eventually reflected in a larger reproductive sink.

(b) During the reproductive period additional photosynthate was partitioned to the reproductive organs. This was limited to the early flowering stage. Later thinning had no effect on the size of the reproductive organs.

(ii)   There are clear indications of differences in sensitivity to mutual shading between different development stages. The three weeks before flowering determined the size of the source in that mutual shading had an adverse effect on vegetative development. During the first week of flowering the sink size was brought in balance with the available source. Later during the reproductive period the fixed sink size remained the limiting factor preventing the plant from utilizing additional sunlight.

(iii)   The mechanisms operating when mutual shading stress is relieved seem to be the opposite of those operating under stress: an increase in vegetative and/or reproductive development is experienced depending on the development stage at the time of the treatment.

(iv)   No evidence of the mobilization of non-structural reserves was observed as the treatments did not induce a source limitation at any development stage.

(v)   Evidence points towards a sub-optimal photosynthetic rate operating in plants thinned at the R3 stage or later as no TDM or yield increases were observed.

(vi)   Evidence of yield component compensation was found. The first
        formed yield component (pods per plant) benefits most form thin-
        ning. The other two yield components reacted to the sink size set
        by the number of pods. This reaction differed depending on the
        season and the cultivar. Seeds per pod and seed size tended to
        have a negative correlation with the earlier set yield components.

(vii)   The cultivars differed in the amount of photosynthate partitioned
        to vegetative and reproductive organs. Little difference in reac-
        tion to reduced mutual shading was, however, observed in the vege-
        tative or reproductive organs.

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CHAPTER 5

LIGHT MANIPULATION STUDIES

5.1   Introduction

Light interception by the leaves of a plant provides energy for photosyn-
thesis and has a major influence on crop yield. By varying the light
intensity at different development stages, source-sink relationships can
be studied without removing plant organs. For this reason shading and
supplying additional light at lower canopy levels are techniques that are
adopted widely in studies involving manipulation of the source. This
approach has practical applications in the area of weed competition and in
determining the optimum plant population.

The purpose of the experiments described in this chapter, was to test
certain aspects of the working hypothesis given in Chapter 1. Particular
attention was given to the effects of levels of light intensity at diffe-
rent development stages and cultivar interactions.

5.2   Materials and methods

5.2.1   General information

The trials were conducted in three seasons: 1979/80, 1980/81 and 1981/82.
Meteorological data and details of irrigation applied are given in
Appendix 1.1 (1979/80), Appendix 1.2 (1980/81) and Appendix 1.3 (1981/82).
Chemical analyses of the soil and fertilizer applications are set out in
Appendix 2.

5.2.2   Shading trial, 1979/80

This experiment incorporated levels and times of shading. The treatments
were as follows:

Control

Co   no shading

Levels of shading

Three levels of shading were induced.

L1   25% shading,

L2   50% shading,

L3   75% shading.

Time of shading

Shading was induced at one of the following times:

S1   (V1-V6f) between emergence and six leaves on the main stem,

S2   (V6f-R1) end of S1 until 50% of the plants in the control had open flowers (50% flowering),

S3   (R1-R5)   end of S2 until the beginning of pod fill in the control plots,

S4   (R5-R9) end of S3 until physiological maturity.

The cultivar Teebus was planted on 1979/12/14 in a factorially arranged randomized block design with four replications. The treatment combinations consisted of a 3 x 4 factorial arrangement with an added control which was repeated three times in each of the four replications. This provided an extra two degrees of freedom for error. A plot size of four rows of 5 m each at an interrow spacing of 750 mm was adopted. The intra-row spacing was 75 cm (177770 plants ha^{-1}). Two seeds per plant site were planted and thinned to the desired stand one week after emergence.

Shading was induced by placing two adjoining wooden racks (2,6 m x 2,0 m x 0,6 m high) over the two centre rows of the relevant plots. Both were covered with 40 mm wide parallel boards. The three levels of shading (25%, 50% and 75%) were achieved by varying the width of the opening between the boards.

At harvest an air dry sample of plants was taken on 1,01 m^2 and the measurements done as described in 3.2.2.

5.2.3   Light manipulation trial, 1980/81

Two cultivars were included in this trial and light manipulation treatments included both shading and reflected light. The treatments were as follows:

Control

Co   ambient light intensity.

Cultivars

The cultivars were as follows:

C1   Teebus,
C2   Bonus.

Light intensity levels

Two light intensity levels were induced:

L1   wooden racks (described in 5.2.1) were placed over the two centre rows, giving a 70% cover,

L2   additional light was supplied by means of reflectors placed at an angle of 45° at ground level on both sides of the two centre rows reflecting radiation towards them. The reflectors were made of Salisation 420 reflecting insulation strips mounted on wooden frames of 2 m X 0,36 m. Two frames were placed along each relevant inter-row in order to cover the full plot length (4 m).[1]

Time of light intensity treatment

The light intensity treatments were applied during each of the following development periods:

S1   (V1-V6f) between emergence and six leaves on the main stem,

S2   (V6f-R1) end of S1 until 50% of the plants in the control plots had open flowers,

S3   (R1-R5) end of S2 until the beginning of pod fill in the control plots,

S4   (R5-R9) end of S3 to physiological maturity.

The trial was planted on 1980/12/14. A factorially arranged randomized block design with three replications was used. The treatment combination consisted of a 2 x 2 x 4 factorial arrangement with an added control for each cultivar which was repeated four times in each of the three replications. This provided an extra six degrees of freedom for error. The plot size was the same as in 1979/80 (5.2.2.).

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1   In the event, the foliage covered the reflectors from the flowering stage onwards and it is probable that very little reflected light was transmitted to the lower canopy during this period.

Growth analyses were done on samples of five plants taken from the two middle rows of each plot starting at one end of a net row, leaving one plant between samples. Sampling started when all the plants in the control plots had started flowering and was continued at weekly intervals to physiological maturity at 98 days from planting. At harvest maturity (105 days) a sample of five plants per plot was taken for growth analysis. All the samples obtained at or before physiological maturity were oven dried while those collected at harvest maturity were air dried. Growth analysis techniques were the same as described in 3.2.2.

5.2.4   Light manipulation trial, 1981/82

The trial was planted on 1981/12/08. The treatments, experimental procedure and design were the same as those adopted in 1980/81 with the following exceptions: (i) an interrow spacing of 1,0 m was used in order to allow more light to penetrate to the reflectors during the latter part of the reproductive phase,[1] and (ii) no sequential growth analysis was conducted. At maturity a sample of five air dry plants was analysed as described in 3.2.2.

5.2.5   Correlation matrix

Simple correlations were calculated between all the measured parameters in each experiment and expressed in terms of a correlation matrix.

5.2.6   Statistical analysis

All the experiments were designed according to standard methods as described in 3.2.3. Growth functions were calculated according to the

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1   Even at the wider interrow spacing the reflectors were not entirely effective. In the determinate Teebus the lower leaves covered the base of the reflectors while in Bonus most of the reflector was covered by the foliage

procedures set out by Hunt (1982). Fitted TDM and LA values were calculated from the mean observed values of three replicates at seven day intervals between 49 and 98 days from planting. Net assimilation rate, CGR and LA values were calculated from the fitted values. The data taken at 56 days were omitted as it was considered unreliable because of an error in sample processing.

5.3   Results, 1979/80

5.3.1   Vegetative sink

5.3.1.1   Stem mass

A highly significant interaction between the level and time of shading was recorded. Two levels of shading (L2 and L3) resulted in significantly (P=0,01) lower stem masses than the unshaded control (Co) when applied during the period between flower initiation and the onset of flowering (S2). In the case of the 25% (L1) and 75% (L3) shading levels, significant reductions (P=0,05) in stem mass were observed when shading was applied between the onset of flowering and the onset of seed growth (S3). Shading before flower initiation or during the seed fill period, had no significant effect on stem mass. Shading during the flower initiation period (S2) was the only time of shading causing significant decreases in the stem mass at each increasing level of shading (Table 5.1).

5.3.2   Reproductive sink

5.3.2.1   Pod number

Shading at the 75% level (L3) reduced the number of pods per plant significantly (P=0,01) in comparison with the control (Co). Shading during the flower initiation and flowering periods (S2 and S3) reduced pod number significantly (P=0,01) (Table 5.2).

Table 5.1 The effect of level and time of shading on the stem mass (g
          plant^{-1}) of dry beans (cv. Teebus), Potchefstroom, 1979/80
          (see Appendix 50)

Time of shading (S)	Levels of shading (L)			Mean
	L1 (25%)	L2 (50%)	L3 (75%)	
	Co 6,83			
S1 (V1-V6f)	6,94	6,60	7,15	6,90
S2 (V6f-R1)	6,04	4,72	3,33	4,70
S3 (R1-R5)	5,49	6,04	5,49	5,67
S4 (R5-R9)	7,57	7,01	7,29	7,29
Mean	6,51	6,09	5,82	6,28

CV   11,8%

	SE	LSD 0,05	0,01
Co vs L means	± 0,20	0,57	0,76
L means	± 0,18	0,53	0,70
Co and S means	± 0,21	0,61	0,81
Co vs L x S	± 0,37	1,05	1,41
L x S	± 0,30	0,86	1,15

Table 5.2 The effect of level and time of shading on the number of pods per plant of dry beans (cv. Teebus), Potchefstoom, 1979/80 (see Appendix 51)

Time of shading (S)	Levels of shading (L)			Mean
	L1 (25%)	L2 (50%)	L3 (75%)	
	Co 18,14			
S1 (V1-V6f)	18,06	20,01	17,96	18,68
S2 (V6f-R1)	16,14	14,49	11,22	13,95
S3 (R1-R5)	12,61	12,40	9,39	11,47
S4 (R5-R9)	17,22	17,47	14,32	16,34
Means	16,01	16,09	13,22	15,72
CV	17,8%			

		SE	LSD 0,05	0,01
Co vs L means		± 0,75	2,14	2,85
L means		± 0,70	1,98	2,64
Co and S means		± 0,81	2,29	3,05
Co vs L x S		± 1,40	NS	NS
L x S		± 1,14	NS	NS

5.3.2.2 Pod mass

At all three shading levels pod mass was significantly lower than the control when shading was applied during flower initiation and flowering (S2 and S3). Treatments L2 and L3 produced a similar effect during the seed fill period (S4). Prior to flower initiation (S1), shading had no effect on pod mass (Table 5.3).

5.3.2.3 Seeds per pod

Shading had no significant effect on the number of seeds per pod at any level or time of shading (Table 5.4).

5.3.2.4 Seed number

There was a strong interaction between treatments in respect of this parameter (Table 5.5). Except in the S4 L2 treatment, the 50% and 75% levels of shading produced fewer seeds (P=0,05) than the control at all development stages after flower initiation. In the case of the 25% level, this was only applicable to the period between flowering and the onset of seed growth (S3). After flower initiation the negative effect of shading increased at each higher level of shading. The differences between the 50% and 75% levels were significant (P=0,05). Shading during the flowering period resulted in significantly less seeds than during any other time at all levels of shading.

5.3.2.5 Hundred seed mass

There was an interaction between level and time of shading in their effect on 100 seed mass (Table 5.6). All three shading levels had no effect on the 100 seed mass before flower initiation. Shading at a 25% level gave a significantly lower 100 seed mass than the control (Co) during the flower initiation period only. The 50% and 75% shading treatments, however, resulted in significantly larger seeds than the control when applied during the flowering period (S3) (highly significant for L3). The 75% and 50%

Table 5.3 The effect of level and time of shading on the pod mass (g plant^{-1}) of dry beans (cv. Teebus), Potchefstoom, 1979/80 (see Appendix 52)

Time of shading (S)	Levels of shading (L)			Mean
	L1 (25%)	L2 (50%)	L3 (75%)	
Co		27,82		
S1 (V1-V6f)	26,29	27,52	28,18	27,33
S2 (V6f-R1)	22,31	23,29	17,76	21,12
S3 (R1-R5)	18,46	19,52	16,09	18,03
S4 (R5-R9)	24,95	21,53	16,44	20,97
Means	23,00	22,96	19,62	23,05
CV	13,2%			

	SE	LSD 0,05	0,01
Co vs L means	± 0,82	2,33	3,12
L means	± 0,76	2,16	2,89
Co and S means	± 0,88	2,50	3,33
Co vs L x S	± 1,52	4,32	NS
L x S	± 1,24	3,53	NS

Table 5.4   The   effect of level and time of shading on the   number   of
            seeds   per   pod of dry beans (cv.   Teebus),   Potchefstroom,
            1979/80 (see Appendix 53)

Time of shading (S)	Levels of shading (L)			Mean
	L1 (25%)	L2 (50%)	L3 (75%)	
Co		5,36		
S1 (V-V6f)	5,38	5,25	5,70	5,44
S2 (V6f-R1)	5,38	5,55	5,58	5,50
S3 (R1-R5)	5,53	5,15	5,05	5,24
S4 (R5-R9)	5,73	4,68	4,63	5,01
Mean	5,50	5,16	5,24	5,31
CV	13,2%			

	SE	LSD	
		0,05	0,01
Co vs L means	± 0,19	NS	NS
L means	± 0,18	NS	NS
Co and S means	± 0,20	NS	NS
Co vs L x S	± 0,35	NS	NS
L x S	± 0,29	NS	NS

Table 5.5 The effect of level and time of shading on the number of seeds per plant of dry beans (cv. Teebus), Potchefstroom, 1979/80 (see Appendix 54)

Time of shading (S)	Levels of shading (L)			Mean
	L1 (25%)	L2 (50%)	L3 (75%)	
	Co	96,34		
S1 (V-V6f)	95,10	103,36	101,72	100,06
S2 (V6f-R1)	85,74	79,85	61,74	75,77
S3 (R1-R5)	68,99	62,58	47,49	59,69
S4 (R5-R9)	97,74	81,88	64,38	81,33
Mean	86,89	81,92	68,83	82,64
CV	13,0%			

	SE	LSD	
		0,05	0,01
Co vs L means	± 2,91	8,29	11,07
L means	± 2,69	7,67	10,25
Co and S means	± 3,11	8,86	11,83
Co vs L x S	± 5,38	15,34	NS
L x S	± 4,40	12,53	NS

Table 5.6 The effect of level and time of shading on the 100 seed
mass (g) of dry beans (cv. Teebus), Potchefstroom, 1979/80
(see Appendix 55)

Time of shading (S)	Levels of shading (L)			Mean
	L1 (25%)	L2 (50%)	L3 (75%)	
	Co 23,26			
S1 (V-V6f)	22,43	21,55	22,45	22,14
S2 (V6f-R1)	20,53	23,00	22,38	21,97
S3 (R1-R5)	22,75	25,50	26,78	25,01
S4 (R5-R9)	21,55	21,13	19,93	20,87
Mean	21,81	22,79	22,88	22,65

CV   6,4%

			LSD	
		SE	0,05	0,01
Co vs L means	±	0,39	NS	NS
L means	±	0,36	NS	NS
Co and S means	±	0,42	1,19	1,58
Co vs L x S	±	0,72	2,05	2,74
L x S	±	0,59	1,68	2,34

shading levels showed significant reductions in 100 seed mass (highly significant for L3) due to shading during the seed fill period (S4).

5.3.2.6   Seed yield

There was a significant interaction between the different levels and times of shading on seed yield (Table 5.7). Compared with the unshaded control, shading before flower initiation (S1) did not reduce seed yield significantly. Shading at stages after flower initiation resulted in a significantly lower seed yield at all three levels of shading except in the case of the 25% level during the seed fill stage (S4) where no reduction in seed yield was recorded. When applied after flower initiation (S2), the 75% treatment (L3) resulted in a significantly lower seed yield than that of the other two levels.

5.3.3   Total dry mass

There was a significant interaction between levels and time of shading. Shading at the 25% level (L1) applied during the period between flower initiation and the onset of seed growth (S2 and S3), resulted in a significantly lower TDM than that of the unshaded control. Both the 50% (L2) and 75% (L3) shading treatments gave a significantly (P=0,01) lower TDM than the control (Co) when shaded after flower initiation (S2, S3 and S4). When applied before flower initiation (S1) (Table 5.8), no level of shading caused any reduction in TDM in comparisons with the control.

5.3.4   Harvest index

The three levels of shading caused different reactions in the HI values when applied at different development stages (Table 5.9). The 25% shading level had no significant influence on the HI at any time. However, when applied during the seed fill stage (S4), 50% shading resulted in a significant reduction in HI compared with the control. In comparison with the control, the 75% shading level resulted in a decrease in the HI, the

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Table 5.7 The effect of level and time of shading on the seed
yield (g plant^{-1}) of dry beans (cv. Teebus), Potchefstroom,
1979/80 (see Appendix 56)

| Time of shading (S) | Levels of shading (L) | | | Mean |
	L1 (25%)	L2 (50%)	L3 (75%)	
	Co 22,35			
S1 (V-V6f)	21,36	22,17	22,83	22,12
S2 (V6f-R1)	17,72	18,36	13,80	16,63
S3 (R1-R5)	15,68	15,98	12,69	14,78
S4 (R5-R9)	21,20	17,15	12,76	17,03
Mean	18,99	18,41	15,92	18,58
CV	13,6%			

	SE	LSD 0,05	0,01
Co vs L means	± 0,68	1,95	2,60
L means	± 0,63	1,80	2,41
Co and S means	± 0,73	2,08	2,78
Co vs L x S	± 1,27	3,61	NS
L x S	± 1,03	2,95	NS

Table 5.8 The effect of level and time of shading on the total dry mass (g plant^{-1}) of dry beans (cv. Teebus), Potchefstroom, 1979/80 (see Appendix 57)

Time of shading (S)	Levels of shading (L)			Mean
	L1 (25%)	L2 (50%)	L3 (75%)	
Co		40,74		
S1 (V1-V6f)	39,51	39,93	42,01	40,19
S2 (V6f-R1)	33,61	31,67	23,89	29,92
S3 (R1-R5)	30,14	31,04	25,76	28,98
S4 (R5-R9)	39,72	34,38	31,60	35,23
Means	35,75	34,41	30,82	35,03
CV	11,4%			

	SE	LSD	
		0,05	0,01
Co vs L means	± 1,08	3,07	4,10
L means	± 1,00	2,84	3,79
Co and S means	± 1,15	3,28	4,38
Co vs L x S	± 1,99	5,68	NS
L x S	± 1,63	4,63	NS

Table 5.9 The effect of level and time of shading on the harvest index (%) of dry beans (cv. Teebus), Potchefstroom, 1979/80 (see Appendix 58)

Time of shading (S)	Levels of shading (L)			Mean
	L1 (25%)	L2 (50%)	L3 (75%)	
	Co 54,17			
S1 (V-V6f)	53,98	55,68	54,20	54,17
S2 (V6f-R1)	52,38	57,98	57,63	55,99
S3 (R1-R5)	52,10	51,83	49,30	51,08
S4 (R5-R9)	53,35	50,25	40,43	48,01
Mean	52,95	53,93	50,39	52,89
CV	5,9%			

	SE	LSD 0,05	0,01
Co vs L means	± 0.85	2,41	3,22
L means	± 0,78	2,23	2,98
Co and S means	± 0,90	2,58	3,44
Co vs L x S	± 1,57	4,46	5,96
L x S	± 1,27	3,64	4,87

differences being significant at 0,01 and 0,05 probabilities during flowe-
ring and seed fill periods, respectively.

5.3.5   Correlation matrix

There was a positive correlation (P=0,05) between stem mass (representing
the vegetative sink) and the reproductive parameters: pod number, seed
number and seed yield which in turn were positively (P=0,01) correlated
with each other. Pod number, seed number, seeds per pod tended to be
negatively correlated with 100 seed mass. However, none of these rela-
tionships were significant (Table 5.10).

5.4   Results, 1980/81

5.4.1   Physiological development

While reflected light did not have an effect on the rate of plant develop-
ment, a distinct response was recorded in the shading treatment (Table
5.11). In comparison with the control, flowering in Teebus was delayed by
7 to 13 days when shading took place before flower initiation (V1 to V6f).
A delay of the same magnitude was recorded when Bonus was shaded between
flower initiation and flowering (V6f to R1). Shading at all times of
application delayed physiological maturity (R9) in Bonus by at least a
week.

5.4.2   Vegetative sink

5.4.2.1   Leaf area

The fitted values of the leaf areas of plants sampled between 49 and 98
days after planting showed very small differences between cultivars except
towards physiological maturity when Bonus had a higher LA and LAI than
Teebus.   Shading before the onset of seed growth, reduced the maximum

Table 5.10 Correlation matrix (r values and tests of significance) of
          the components of the vegetative and reproductive sink at
          harvest, Potchefstroom, 1979/80

	Seed number	Pod number	Seeds per pod	100 seed mass	Seed yield
Stem mass	0,60*	0,63*	-0,13	-0,23	0,54*
Seed number		0,87**	0,19	-0,36	0,93**
Pod number			-0,31	-0,38	0,79**
Seeds per pod				-0,02	0,21
100 seed mass					-0,01

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Table 5.11 The effect of level of light intensity and times of appli-
cation on the rate of development of two dry bean cultivars
at different sampling dates, Potchefstroom, 1980/81

Treatment[1]	Development stage at different sampling dates (days after planting)							
	49	56	63	70	77	84	91	98
C1 (Control)	R2	R3	R5	R6	R7	R8	R9	R9
C1 L1 S1	V10	R1	R3	R5	R7	R8	R9	R9
C1 L1 S2	R2	R3	R5	R6	R7	R8	R9	R9
C1 L1 S3	R2	R3	R5	R6	R7	R8	R9	R9
C1 L1 S4	R2	R3	R5	R6	R7	R8	R9	R9
C1 L2 S1	R3	R3	R5	R6	R7	R8	R9	R9
C1 L2 S2	R2	R3	R5	R6	R7	R8	R9	R9
C1 L2 S3	R2	R3	R5	R6	R7	R8	R9	R9
C1 L2 S4	R2	R3	R5	R6	R7	R8	R9	R9
C2 (Control)	R1	R2	R5	R6	R7	R8	R8	R9
C2 L1 S1	R1	R2	R3	R5	R7	R7	R8	R8
C2 L1 S2	V11	R1	R3	R5	R6	R7	R8	R8
C2 L1 S3	R1	R2	R5	R6	R6	R7	R8	R8
C2 L1 S4	R1	R2	R5	R6	R7	R8	R8	R8
C2 L2 S1	R2	R3	R5	R6	R7	R8	R8	R9
C2 L2 S2	R2	R3	R5	R6	R7	R8	R8	R9
C2 L2 S3	R1	R2	R5	R6	R7	R8	R8	R9
C2 L2 S4	R1	R2	R5	R6	R7	R8	R8	R9

[1] Treatment code: C1 Teebus
C2 Bonus
L levels of light intensity: L1 70% shading,
L2 reflectors.
S time of application of light intensity treatments

leaf area and LAI of both cultivars during the early flowering period (49 to 63 days) but maintained these values at a higher level than the controls towards physiological maturity. Shading during the seed growth period (S4) had little effect on LA. Treatment L2 had very little effect on LA at any time of application (Tables 5.12).

5.4.2.2   Node number

In the control treatments Bonus produced significantly (P=0,01) more nodes (indicating leaves) than Teebus though both cultivars reacted similarly to light intensity levels at different times. Shading before flower initiation tended to increase the number of nodes while shading during the reproductive period had the opposite effect. The differences between these treatments were significant (P=0,05) though both did not differ significantly from the control (Table 5.13).

5.4.2.3   Stem mass

The stem mass of plants sampled during the reproductive phase showed a tendency to increase between 49 and 63 days from planting, after which it remained constant in most treatments. Shading before flowering (S1 and S2) reduced stem mass markedly compared to that of the control at 49 days (onset of flowering) but no such difference was observed at 63 days for S1 and 77 days for S2. Shading during the flowering period (S3) resulted in a lower stem mass up to 98 days from planting while shading during the seed fill stage (S4), tended to reduce stem mass at 91 and 98 days. The plants receiving treatment L2, tended to produce heavier stems throughout the growing season (Table 5.14).

At harvest (Table 5.15) the stem mass of Teebus was significantly lower (P=0,01) than that of Bonus. The stem mass of the two cultivars reacted in the same way to the light intensity treatments at different times. Plants receiving treatment L2 did not differ from that of the control in terms of

Table 5.12 The effect of level of light intensity and times of application on the leaf area ($m^2 \times 10^{-4}$) of two dry bean cultivars at different sampling dates, Potchefstroom, 1980/81. Fitted values are given in brackets

Treatment[1]	Days after planting							Regression equations and R^2 values: fitted vs observed data
	49	63	70	77	84	91	98	
C1 (Control)	2935 (3616)	3240 (2342)	1970 (1885)	2425 (1517)	1345 (1221)	722 (982)	722 (790)	ln Y = 9,7134 - 0,0310x ; R^2 = 81,3
C1 L1 S1	2199 (1928)	2653 (1928)	2138 (1928)	2849 (1928)	1752 (1928)	1548 (1928)	1028 (1928)	ln Y = 7,5643
C1 L1 S2	2016 (2149)	2845 (2599)	2336 (2449)	1910 (2081)	1714 (1596)	1102 (1104)	685 (688)	ln Y = 3,7613 + 0,1314x - 0,001052x^2 ; R^2 = 98,4
C1 L1 S3	1949 (1960)	2478 (2375)	1823 (1928)	1469 (1445)	1092 (1097)	942 (925)	942 (950)	ln Y = 9,1925 + 0,7366x -0,01025x^2 + 0,000045x^3; R^2 = 99,4
C1 L1 S4	2492 (3253)	2287 (1936)	1589 (1494)	1244 (1152)	1428 (889)	467 (686)	467 (529)	ln Y = 9,9033 - 0,0371x ; R^2 = 82,5
C1 L2 S1	2324 (2712)	1844 (1929)	1776 (1627)	1878 (1373)	1330 (1158)	758 (977)	758 (825)	ln Y = 9,0964 - 0,0243x ; R^2 = 82,0
C1 L2 S2	2773 (3210)	2365 (2391)	2455 (2063)	1945 (1780)	1813 (1537)	1077 (1326)	1077 (1144)	ln Y = 9,1055 - 0,0210x ; R^3 = 85,0
C1 L2 S3	2935 (4059)	2914 (2482)	2516 (1941)	1825 (1518)	1307 (1187)	681 (928)	681 (726)	ln Y = 9,3095 - 0,0246x ; R^2 = 85,0
C1 L2 S4	3412 (3309)	2180 (2345)	2211 (1974)	1580 (1662)	1381 (1399)	1043 (1178)	1113 (991)	ln Y = 10,0296 - 0,0351x ; R^2 = 95,4
C2 (Control)	2530 (3337)	2728 (2331)	2113 (1948)	2103 (1628)	1591 (1360)	885 (1137)	841 (950)	ln Y = 9,3690 - 0,0256x ; R^2 = 80,3
C2 L1 S1	2090 (2061)	2401 (2416)	2207 (2391)	2377 (2230)	2103 (1958)	1505 (1621)	1280 (1263)	ln Y = 5,1958 + 0,0796x -0,00061x^2 ; R^2 = 93,9
C2 L1 S2	2186 (1977)	2563 (1977)	2264 (1977)	3024 (1977)	2248 (1977)	1182 (1977)	1159 (1977)	ln Y = 7,5894
C2 L1 S3	2654 (1846)	2162 (1846)	1740 (1846)	2145 (1846)	1984 (1846)	1251 (1846)	1377 (1846)	ln Y = 7,5211
C2 L1 S4	3070 (4031)	3443 (2657)	2205 (2158)	2193 (1752)	1389 (1423)	1049 (1155)	840 (938)	ln Y = 9,7593 - 0,0279x R^2 = 87,6
C2 L2 S1	2665 (3388)	2728 (2394)	2837 (2013)	1434 (1692)	1450 (1423)	1347 (1196)	820 (1005)	ln Y = 9,3426 - 0,0248x R^2 = 79,2
C2 L2 S2	3140 (3590)	2525 (2633)	3245 (2254)	1672 (1931)	1707 (1653)	1503 (1416)	1095 (1212)	ln Y = 9,2713 - 0,0222x R^2 = 81,1
C2 L2 S3	2889 (3812)	2751 (2457)	2804 (1973)	1832 (1584)	1054 (1272)	936 (1021)	775 (820)	ln Y = 9,7825 - 0,0314x R^2 = 85,7
C2 L2 S4	2651 (3589)	3134 (2356)	1758 (1909)	1879 (1546)	1577 (1253)	997 (1095)	606 (822)	ln Y = 9,6588 - 0,0301x R^2 = 80,9

[1] Treatment code: C1 Teebus

C2 Bonus

L levels of light intensity: L1 70% shading, L2 reflectors.

S time of application of light intensity treatments

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Table 5.13 The effect of level of light intensity and times of appli-
cation on the number of nodes per plant of two dry bean
cultivars, Potchefstroom 1980/81 (see Appendix 59)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 18,50		
Teebus (C1)	S1 (V1-V6f)	24,33	18,33	21,33
	S2 (V6f-R1)	18,40	21,13	19,77
	S3 (R1-R5)	13,67	18,73	16,20
	S4 (R5-R9)	18,40	18,93	18,67
Mean		18,70	19,28	18,99
		Co 23,37		
Bonus (C2)	S1 (V1-V6f)	22,93	21,87	22,40
	S2 (V6f-R1)	25,13	24,00	21,23
	S3 (R1-R5)	24,93	25,60	25,27
	S4 (R5-R9)	20,13	21,00	20,57
Mean		23,28	23,12	22,37
		Co 20,93		
Both cultivars	S1 (V1-V6f)	23,63	20,10	21,87
	S2 (V6f-R1)	21,77	22,57	20,50
	S3 (R1-R5)	19,30	22,17	20,73
	S4 (R5-R9)	19,27	19,97	19,62
Mean		20,99	21,20	21,04

CV 15,7%

	SE	LSD 0,05	0,01
Co and L means	± 0,66	NS	NS
Co vs S means	± 0,94	NS	NS
S means	± 0,81	NS	NS
Co and C means	± 0,94	2,66	3,55
Co vs L x S	± 1,33	3,77	NS
L x S	± 1,05	2,98	NS
Co and L x C	± 0,94	NS	NS
Co vs S x C	± 1,33	3,77	NS
S x C	± 1,15	3,26	NS
Co vs L x S x C	± 1,88	NS	NS
L x S x C	± 1,48	NS	NS

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Table 5.14 The effect of level of light intensity and times of appli-
cation on stem mass (g plant^{-1}) of two dry bean cultivars
at different sampling dates, Potchefstroom, 1980/81

Treatment[1]	Development stage at different sampling dates (days after planting)						
	49	63	70	77	84	91	98
C1 (Control)	8,33	8,92	7,72	8,38	7,08	6,63	6,63
C1 L1 S1	4,17	9,89	11,41	10,70	7,73	7,23	8,31
C1 L1 S2	5,17	9,10	8,13	6,20	6,29	5,39	7,73
C1 L1 S3	5,25	7,20	5,29	5,27	5,67	5,59	5,59
C1 L1 S4	7,75	9,11	6,87	6,69	7,85	5,61	5,61
C1 L2 S1	5,75	9,26	8,92	7,34	5,97	6,13	6,13
C1 L2 S2	8,00	10,92	10,56	7,09	9,61	7,73	7,73
C1 L2 S3	7,41	11,07	8,19	7,65	7,83	7,20	7,20
C1 L2 S4	8,72	9,34	8,89	7,87	7,77	7,77	7,77
C2 (Control)	7,17	10,63	10,82	10,77	10,35	8,77	10,06
C2 L1 S1	5,05	9,47	9,33	11,79	11,63	11,54	11,24
C2 L1 S2	4,67	6,81	8,96	13,03	11,33	11,39	10,32
C2 L1 S3	6,59	6,77	8,11	10,11	9,71	8,81	10,32
C2 L1 S4	9,80	11,95	10,21	9,61	10,05	9,60	8,32
C2 L2 S1	8,12	10,33	11,15	8,87	10,45	9,24	9,96
C2 L2 S2	8,87	10,73	13,14	9,65	13,11	11,41	12,17
C2 L2 S3	7,67	10,78	11,87	10,02	9,42	9,76	9,96
C2 L2 S4	7,71	11,85	10,58	11,13	11,75	11,04	8,67

[1] Treatment code: C1 Teebus
C2 Bonus
L levels of light intensity: L1 70% shading,
L2 reflectors.
S time of application of light intensity treatments

Table 5.15 The effect of level light intensity and times of application on the stem mass (g plant^{-1}) of two dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 60)

Cultivars (C)	Times (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 7,64		
Teebus (C1)	S1 (V1-V6f)	8,25	6,68	7,46
	S2 (V6f-R1)	6,05	8,77	7,41
	S3 (R1-R5)	5,11	7,13	6,12
	S4 (R5-R9)	5,60	7,79	6,69
Mean		6,25	7,59	6,92
		Co 9,75		
Bonus (C2)	S1 (V1-V6f)	10,50	9,55	10,02
	S2 (V6f-R1)	11,12	10,70	10,91
	S3 (R1-R5)	10,29	11,65	10,97
	S4 (R5-R9)	8,29	9,60	8,85
Mean		10,05	10,38	10,21
		Co 8,70		
Both cultivars	S1 (V1-V6f)	9,37	8,11	8,74
	S2 (V6f-R1)	8,59	9,74	9,16
	S3 (R1-R5)	7,70	9,39	8,55
	S4 (R5-R9)	6,95	8,69	7,82
Mean		8,15	8,98	8,61

CV	15,4%			

	SE	LSD	
		0,05	0,01
Co and L means	± 0,27	0,77	NS
Co vs S means	± 0,38	NS	NS
S means	± 0,33	NS	NS
Co C means	± 0,38	1,09	1,45
Co vs L x S	± 0,54	1,54	NS
L x S	± 0,43	1,22	NS
Co and L x C	± 0,38	NS	NS
Co vs S x C	± 0,54	NS	NS
S x C	± 0,47	NS	NS
Co vs L x S x C	± 0,77	NS	NS
L x S x C	± 0,61	NS	NS

stem mass at any time. Shading during the seed fill period (S4), however, resulted in a lower (P=0,05) stem mass than that recorded in the control.

5.4.3 Reproductive sink

5.4.3.1 Pod number

The pod number of Teebus and Bonus reacted differently to levels and times of light intensity treatments (Table 5.16). In comparison with the control (Co), treatment L2 had no effect on the number of pods of both cultivars. The shading treatment (L1) gave rise to a reduction (P=0,01) in pod number in Teebus but had no effect on Bonus.

The pod number of Bonus was little influenced by any of the light treatments, except when applied during pod fill (S4) when the mean effect of times showed a significant (P=0,05) reduction in comparison with the control. In the case of Teebus, the main effects exhibited a reduction in pods per plant during the reproductive period (S3 and S4) with the flowering period (S3) being the most sensitive (P=0,01). An inspection of the three factor interaction in Table 5.16, indicates that these differences were due to the effect of shading.

5.4.3.2 Pod mass

The pod masses of the control treatments and those receiving treatment L2, did not differ significantly at any time of treatment application. Shading during the vegetative phase (S1 and S2), had very little influence on pod mass but when applied during the reproductive phase, the pod mass declined significantly between S2 and S3 and between S3 and S4. At S3 and S4 the pod mass of the shaded treatments was significantly lower (P=0,01) than that of the control (Table 5.17). The interaction between cultivars and times of light manipulation indicates that shading reduced (P=0,01) the stem mass of Bonus during the seed fill period (S4) only but in Teebus this response extended over the whole reproductive period (S3 and S4).

Table 5.16 The effect of level of light intensity and times of appli-
cation on the number of pods per plant of two dry bean
cultivars, Potchefstoom, 1980/81 (see Appendix 61)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 26,98		
Teebus (C1)	S1 (V1-V6f)	24,67	25,87	25,27
	S2 (V6f-R1)	21,33	30,27	25,80
	S3 (R1-R5)	11,33	23,67	17,50
	S4 (R5-R9)	21,13	25,93	23,53
Mean		19,62	26,43	23,03
		Co 14,52		
Bonus (C2)	S1 (V1-V6f)	14,00	13,27	13,63
	S2 (V6f-R1)	16,87	14,73	15,80
	S3 (R1-R5)	15,00	15,80	15,40
	S4 (R5-R9)	8,67	11,93	10,30
Mean		13,63	13,93	13,78
		Co 20,75		
Both cultivars	S1 (V1-V6f)	19,33	19,57	19,45
	S2 (V6f-R1)	19,10	22,50	20,80
	S3 (R1-R5)	13,17	19,73	16,45
	S4 (R5-R9)	14,90	18,93	16,92
Mean		16,63	20,81	19,19

CV   15,1%

	SE	LSD 0,05	0,01
Co and L means	± 0,59	1,68	2,34
Co vs S means	± 0,84	2,38	3,17
S means	± 0,73	2,06	2,74
Co and C means	± 0,84	2,38	NS
Co vs L x S	± 1,18	NS	NS
L x S	± 0,94	NS	NS
Co and L x C	± 0,84	2,38	3,17
Co vs S x C	± 1,18	3,36	4,48
S x C	± 1,03	2,91	3,88
Co vs L x S x C	± 1,67	NS	NS
L x S x C	± 1,32	NS	NS

Table 5.17 The effect of level of light intensity and times of application on the pod mass (g plant^{-1}) of two dry bean cultivars, Potchefstroom 1980/81 (see Appendix 62)

Cultivars	Time	Levels of light intensity		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 37,07		
Teebus (C1)	S1 (V1-V6f)	33,90	34,19	34,05
	S2 (V6f-R1)	31,17	40,55	35,86
	S3 (R1-R5)	15,51	32,02	23,76
	S4 (R5-R9)	18,46	37,74	28,44
Mean		24,76	36,13	30,44
		Co 32,18		
Bonus (C2)	S1 (V1-V6f)	31,25	33,22	32,23
	S2 (V6f-R1)	31,84	35,33	33,59
	S3 (R1-R5)	34,67	40,77	37,70
	S4 (R5-R9)	15,03	28,30	21,67
Mean		28,20	34,41	31,30
		Co 34,63		
Both cultivars	S1 (V1-V6f)	32,57	33,71	33,14
	S2 (V6f-R1)	31,50	37,94	34,72
	S3 (R1-R5)	25,09	36,39	30,73
	S4 (R5-R9)	16,75	33,02	24,88
Mean		26,48	35,27	32,12

CV 15,4%

	SE	LSD 0,05	0,01
Co and L means	± 1,01	2,86	3,81
Co vs S means	± 1,43	4,05	5,40
S means	± 1,24	3,51	4,67
Co and C means	± 1,43	NS	NS
Co vs L x S	± 1,02	5,73	7,63
L x S	± 1,60	4,53	6,03
Co and L x C	± 1,43	NS	NS
Co vs S x C	± 2,02	5,73	7,63
S x C	± 1,75	4,96	6,61
Co vs L x S x C	± 2,85	NS	NS
L x S x C	± 2,26	NS	NS

5.4.3.3   Seeds per pod

The pods of Teebus contained more seeds (P=0,01) than those of Bonus at
all times and levels of light intensity. Plants receiving treatment L2 at
any time produced more seeds per pod than the controls but the differen-
ces were not statistically significant.   There was a tendency for the pods
of shaded plants to contain fewer seeds in the period prior to the onset
of seed fill but again the differences were not statistically significant.
However, shading during the seed fill period (S4) resulted in a highly
significant reduction in the number of seeds per pod (Table 5.18).

5.4.3.4   Seed number

The number of seeds per plant of the two cultivars reacted differently to
light intensity and times of application. As would be expected, the re-
sponse pattern was very similar to that recorded for pod number.

When shaded during the vegetative phase (S1 and S2) Teebus produced about
the same number of seeds per plant as the control, but when this treatment
was applied during the reproductive period (S3 and S4), there was a signi-
ficant reduction in seed number. The number of seeds per plant in Bonus
remained about the same in the shading treatments applied between planting
and the onset of seed fill (S1 to S3). During seed fill (S4) shaded
plants of this cultivar produced significantly less seeds than the con-
trol.   Treatment L2 had no influence on seed number of both cultivars at
any time of application (Table 5.19).

5.4.3.5   Hundred seed mass

The hundred seed mass of Bonus was greater (P=0,01) than Teebus in all
treatment combinations.   Levels and times of light intensity did not
effect this parameter significantly (Table 5.20).

Table 5.18 The effect of level of light intensity and times of appli-
cation on the number of seeds per pod of two dry bean cul-
tivars, Potchefstroom, 1980/81 (see Appendix 63)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 4,72		
Teebus (C1)	S1 (V1-V6f)	4,70	4,40	4,55
	S2 (V6f-R1)	4,97	4,77	4,87
	S3 (R1-R5)	3,97	4,47	4,22
	S4 (R5-R9)	2,87	4,93	3,90
Mean		4,13	4,64	4,38
		Co 3,80		
Bonus (C2)	S1 (V1-V6f)	3,97	4,27	4,12
	S2 (V6f-R1)	3,53	4,17	3,85
	S3 (R1-R5)	4,00	4,23	4,12
	S4 (R5-R9)	2,90	4,30	3,60
Mean		3,60	4,24	3,92
		Co 4,26		
Both cultivars	S1 (V1-V6f)	4,33	4,33	4,33
	S2 (V6f-R1)	4,25	4,47	4,36
	S3 (R1-R5)	3,98	4,35	4,17
	S4 (R5-R9)	2,88	4,62	3,75
Mean		3,86	4,44	4,19

CV   9,4%

	SE	LSD 0,05	LSD 0,01
Co and L means	± 0,08	0,23	0,30
Co vs S means	± 0,11	0,32	0,43
S means	± 0,10	0,28	0,37
Co and C means	± 0,11	0,32	0,43
Co vs L x S	± 0,16	0,45	0,61
L x S	± 0,13	0,36	0,48
Co and L x C	± 0,11	NS	NS
Co vs S x C	± 0,16	0,45	NS
S x C	± 0,14	0,39	NS
Co vs L x S x C	± 0,23	NS	NS
L x S x C	± 0,18	NS	NS

Table 5.19 The effect of level of light intensity and times of appli-
cation on the number of seeds per plant of two dry bean
cultivars, Potchefstroom, 1980/81 (see Appendix 64)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 127,57		
Teebus (C1)	S1 (V1-V6f)	115,80	113,67	114,73
	S2 (V6f-R1)	105,60	142,00	123,80
	S3 (R1-R5)	44,93	106,33	75,63
	S4 (R5-R9)	59,20	127,13	93,17
Mean		81,38	122,28	101,83
		Co 55,03		
Bonus (C2)	S1 (V1-V6f)	55,20	56,93	56,07
	S2 (V6f-R1)	59,40	61,80	60,60
	S3 (R1-R5)	60,07	66,61	63,37
	S4 (R5-R9)	25,13	51,80	38,47
Mean		49,95	59,30	54,63
		Co 91,30		
Both cultivars	S1 (V1-V6f)	85,50	85,30	85,40
	S2 (V6f-R1)	82,50	101,90	92,20
	S3 (R1-R5)	52,50	86,50	69,50
	S4 (R5-R9)	42,17	89,47	65,82
Mean		65,67	90,79	82,59

CV   17,1%

	SE	LSD	
		0,05	0,01
Co and L means	± 2,88	8,18	10,90
Co vs S means	± 4,08	11,57	15,42
S means	± 3,53	10,02	13,35
Co and C means	± 4,08	11,57	15,42
Co vs L x S	± 5,77	16,37	21,81
L x S	± 4,56	12,94	17,24
Co and L x C	± 4,08	11,57	15,42
Co vs S x C	± 5,77	16,37	21,81
S x C	± 4,99	14,17	18,89
Co vs L x S x C	± 8,16	23,15	NS
L x S x C	± 6,45	18,30	NS

Table 5.20 The effect of level of light intensity and times of appli-
cation on the 100 seed mass (g) of two dry bean cultivars,
Potchefstroom, 1980/81 (see Appendix 65)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 23,78		
Teebus (C1)	S1 (V1-V6f)	23,20	23,67	23,43
	S2 (V6f-R1)	24,07	23,30	23,68
	S3 (R1-R5)	28,70	24,67	26,68
	S4 (R5-R9)	24,03	24,30	24,17
Mean		25,00	23,98	24,49
		Co 46,21		
Bonus (C2)	S1 (V1-V6f)	42,67	46,93	44,80
	S2 (V6f-R1)	41,03	45,17	43,10
	S3 (R1-R5)	46,03	48,47	47,25
	S4 (R5-R9)	46,33	43,03	44,68
Mean		44,02	45,90	34,96
		Co 35,00		
Both cultivars	S1 (V1-V6f)	32,93	35,30	34,12
	S2 (V6f-R1)	32,55	34,23	33,39
	S3 (R1-R5)	37,37	36,57	36,97
	S4 (R5-R9)	35,18	33,67	34,43
Mean		34,51	34,94	44,82

CV   9,2%

	SE	LSD	
		0,05	0,01
Co and L means	± 0,65	NS	NS
Co vs S means	± 0,92	2,62	NS
S means	± 0,80	2,28	NS
Co and C means	± 0,92	2,62	3,49
Co vs L x S	± 1,30	NS	NS
L x S	± 1,03	NS	NS
Co and L x C	± 0,92	NS	NS
Co vs S x C	± 1,30	NS	NS
S x C	± 1,13	NS	NS
Co vs L x S x C	± 1,84	NS	NS
L x S x C	± 1,46	NS	NS

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5.4.3.6   Seed yield

There was no significant difference between the seed yield of plants re-
ceiving treatment L2 and the control at any development stage. Shading,
however, resulted in significantly (P=0,01) lower seed yields than the
control during the reproductive phase (S3 and S4) but not during the vege-
tative period (S1 and S2) (Table 5.21). In terms of interactions between
cultivars and time of treatment, this effect was only significant (P=0,01)
for Bonus at S4 and for Teebus at both S3 and S4.

5.4.4   Total dry mass

The fitted values of TDM (Table 5.22) sampled between 49 and 98 days from
planting and the NAR (Table 5.23) and CGR (Table 5.24) values derived from
them show very clear differences in the effects of both light intensity
and time of application.

In both cultivars shading during the vegetative period gave lower yields
of TDM than the control when sampling took place during the subsequent
flowering period. Towards physiological maturity the differences were much
smaller. This was associated with a high NAR during the flowering period
(49 to 63 days) and a high CGR during the seed fill period (77 to 98
days). Shading during the seed fill period (S4) reduced TDM accumulation
in both cultivars to such an extent that their fitted TDM remained con-
stant between 49 and 98 days. This is reflected in an absence of growth as
expressed in the zero values of NAR and CGR.

The TDM yields of the controls of both cultivars showed a linear increase
throughout their reproductive periods (Table 5.22). This was associated
with similar increases in NAR and CGR. The TDM of Bonus reacted in a
similar way to reflected light at all times of application and gave lower
yields than the control. The associated NAR values (Table 5.23) were
markedly lower in treatments after the onset of flower bud initiation (S2,
S3 and S4) and similar reactions were observed in the CGR (Table 2.24) in

Table 5.21 The effect of level of light intensity and times of application on the seed yield (g plant^{-1}) of two dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 66)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 30,25		
Teebus (C1)	S1 (V1-V6f)	26,97	26,98	26,97
	S2 (V6f-R1)	25,39	33,05	29,22
	S3 (R1-R5)	12,93	26,09	19,51
	S4 (R5-R9)	14,36	30,75	22,55
Mean		19,91	29,22	24,56
		Co 25,41		
Bonus (C2)	S1 (V1-V6f)	23,89	26,39	25,14
	S2 (V6f-R1)	24,31	27,88	26,09
	S3 (R1-R5)	27,15	32,41	29,78
	S4 (R5-R9)	11,69	22,19	16,94
Mean		21,76	27,22	24,49
		Co 27,85		
Both cultivars	S1 (V1-V6f)	25,43	26,69	26,06
	S2 (V6f-R1)	24,85	30,46	27,66
	S3 (R1-R5)	20,04	29,25	24,65
	S4 (R5-R9)	13,02	26,47	19,75
Mean		20,84	28,22	25,63

CV   16,0%

	SE	LSD	
		0,05	0,01
Co and L means	± 0,84	2,38	3,17
Co vs S means	± 1,18	3,37	4,49
S means	± 1,03	2,92	3,89
Co and C means	± 1,19	3,37	NS
Co vs L x S	± 1,68	4,76	6,35
L x S	± 1,33	3,77	5,02
Co and L x C	± 1,19	NS	NS
Co vs S x C	± 1,68	4,76	6,35
S x C	± 1,45	4,13	5,50
Co vs L x S x C	± 2,37	NS	NS
L x S x C	± 1,88	NS	NS

Table 5.22 The effect of level of light intensity and times of application on the TDM (g plant^{-1}) of two dry bean cultivars at different sampling dates, Potchefstroom, 1980/81. Fitted values are given in brackets

Treatment[1]	Days after planting							Regression equations and R^2 values: fitted vs observed data
	49	63	70	77	84	91	98	
C1 (Control)	16,3 (18,2)	22,2 (22,7)	25,8 (25,8)	37,3 (28,8)	31,1 (31,4)	34,2 (35,1)	34,2 (39,1)	ln Y = 2,1376 + 0,0156x ; R^2 = 79,0
C1 L1 S1	10,7 (13,4)	23,9 (18,1)	21,5 (21,1)	27,8 (24,6)	26,9 (28,6)	29,0 (33,3)	38,8 (38,7)	ln Y = 1,5333 + 0,0217x ; R^2 = 82,9
C1 L1 S2	10,3 (11,8)	19,8 (16,4)	20,9 (19,3)	21,3 (22,7)	26,5 (26,7)	27,5 (31,4)	39,4 (37,0)	ln Y = 1,3268 + 0,0233x ; R^2 = 91,4
C1 L1 S3	10,2 (12,0)	20,2 (15,3)	16,3 (17,2)	18,7 (20,0)	22,7 (21,9)	25,5 (24,7)	25,5 (27,8)	ln Y = 1,6498 + 0,0171x ; R^2 = 80,7
C1 L1 S4	14,8 (20,9)	22,6 (20,9)	20,4 (20,9)	22,3 (20,9)	26,6 (20,9)	20,4 (20,9)	20,4 (20,9)	ln Y = 3,0381
C1 L2 S1	10,7 (10,7)	19,9 (21,3)	28,7 (26,6)	34,9 (30,9)	28,4 (33,1)	31,7 (32,8)	31,7 (30,1)	ln Y = -2,4848 + 0,1383x - 0,0008x^2 ; R^2 = 94,9
C1 L2 S2	16,0 (15,9)	25,3 (26,9)	35,5 (32,2)	35,2 (36,6)	39,5 (39,4)	39,4 (40,2)	39,4 (38,9)	ln Y = -0,7646 + 0,0990x - 0,00055x^2 ; R^2 = 97,8
C1 L2 S3	14,9 (15,3)	26,9 (24,5)	26,8 (28,9)	33,4 (32,6)	34,1 (35,1)	36,0 (36,1)	36,0 (35,4)	ln Y = 0,3819 + 0,0866x - 0,00047x^2 ; R^2 = 97,2
C1 L2 S4	17,4 (19,3)	23,4 (24,2)	30,0 (27,2)	39,5 (30,4)	30,7 (34,1)	35,8 (38,2)	40,8 (42,9)	ln Y = 2,1621 + 0,0163x ; R^2 = 80,8
C2 (Control)	14,2 (15,1)	20,8 (20,3)	23,8 (23,5)	32,3 (27,3)	30,4 (31,7)	31,5 (36,7)	44,8 (42,6)	ln Y = 1,6803 + 0,0211x ; R^2 = 92,7
C2 L1 S1	10,3 (11,0)	20,2 (15,7)	16,5 (18,8)	21,9 (22,5)	25,6 (46,9)	30,0 (32,1)	42,2 (38,4)	ln Y = 1,1514 + 0,0255x ; R^2 = 91,7
C2 L1 S2	9,8 (11,9)	18,7 (16,1)	21,1 (18,8)	23,9 (21,9)	25,4 (25,2)	26,7 (29,7)	33,1 (34,7)	ln Y = 1,4041 + 0,0219x ; R^2 = 89,7
C2 L1 S3	13,3 (12,1)	15,1 (15,5)	15,1 (17,6)	20,0 (19,9)	24,8 (22,6)	22,2 (25,6)	32,9 (29,0)	ln Y = 1,6127 + 0,0179x ; R^2 = 87,5
C2 L1 S4	18,6 (22,1)	24,8 (22,1)	19,9 (22,1)	25,0 (22,1)	23,7 (22,1)	23,0 (22,1)	20,3 (22,1)	ln Y = 3,0936
C2 L2 S1	15,9 (16,1)	22,3 (20,9)	25,8 (23,8)	22,3 (27,2)	30,3 (31,0)	38,3 (35,3)	40,4 (40,2)	ln Y = 1,8637 + 0,0187x ; R^2 = 91,3
C2 L2 S2	17,0 (16,7)	19,4 (21,7)	27,4 (24,7)	20,8 (28,7)	31,3 (31,9)	43,7 (36,3)	41,9 (41,3)	ln Y = 1,9139 + 0,0184x ; R^2 = 78,0
C2 L2 S3	15,6 (16,4)	22,1 (20,5)	25,9 (22,9)	25,3 (25,6)	23,1 (28,7)	30,3 (32,0)	41,0 (35,8)	ln Y = 2,0140 + 0,0160x ; R^2 = 82,7
C2 L2 S4	15,3 (16,4)	24,4 (20,4)	19,7 (22,8)	26,2 (25,4)	27,8 (28,4)	36,6 (31,7)	31,5 (35,3)	ln Y = 2,0324 + 0,0156x ; R^2 = 81,7

Treatment code: C1 Teebus

C2 Bonus

L levels of light intensity: L1 70% shading,

L2 reflectors.

S time of application of light intensity treatments

Table 5.23 The effect of the level of light intensity and times of application on the esitmated NAR (g m^{-2} day^{-1}) of two dry bean cultivars at different sampling dates, Potchefstroom, 1980/81

Treatment[1]	Development stage at different sampling dates (days after planting)							
	49	63	70	77	84	91	98	Mean
C1 (Control)	0,79	1,51	2,09	2,90	4,02	5,57	7,71	3,51
C1 L1 S1	1,50	2,04	2,37	2,76	3,21	3,74	4,35	2,80
C1 L1 S2	1,28	1,47	1,83	2,54	3,89	6,63	12,50	4,31
C1 L1 S3	1,05	1,10	1,53	2,30	3,41	2,56	5,01	2,42
C1 L1 S4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C1 L2 S1	2,37	4,16	4,36	3,48	1,23	-2,30	-6,56	0,96
C1 L2 S2	2,24	3,35	3,45	2,96	1,72	-0,30	-2,94	1,35
C1 L2 S3	1,52	2,67	3,05	2,98	2,15	0,25	-2,91	1,39
C1 L2 S4	0,95	1,68	2,24	2,98	3,97	5,29	7,04	3,45
C2 (Control)	0,97	1,84	2,55	3,54	4,91	6,81	9,45	4,30
C2 L1 S1	1,36	1,66	2,00	2,57	3,50	5,05	7,74	3,41
C2 L1 S2	1,31	1,78	2,08	2,42	2,82	3,29	3,83	2,50
C2 L1 S3	1,17	1,50	1,70	1,93	2,19	2,48	2,81	1,97
C2 L1 S4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C2 L2 S1	0,87	1,63	2,21	3,00	4,06	5,50	7,46	3,53
C2 L2 S2	0,89	1,51	2,01	2,68	3,56	4,73	6,29	3,10
C2 L2 S3	0,69	1,33	1,85	2,58	3,60	5,01	6,98	3,15
C2 L2 S4	0,72	1,36	1,87	2,57	3,54	4,87	6,71	3,09

[1] Treatment code: C1 Teebus
C2 Bonus
L levels of light intensity: L1 70% shading,
L2 reflectors.
S time of application of light intensity treatments

Table 5.24 The effect of level of light intensity and times of appli-
cation on the estimated CGR (g m^{-2} day^{-1}) of two dry bean
cultivars at different sampling dates, Potchefstroom,
1980/81

Treatment[1]	Development stage at different sampling dates (days after planting)							
	49	63	70	77	84	91	98	Mean
C1 (Control)	5,05	6,28	7,01	7,82	8,72	9,72	10,85	7,92
C1 L1 S1	5,16	6,98	8,12	9,46	11,00	12,80	14,90	9,77
C1 L1 S2	4,89	6,77	7,97	9,38	11,05	13,00	15,31	9,77
C1 L1 S3	3,66	4,65	5,24	5,91	6,66	7,51	8,46	6,01
C1 L1 S4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C1 L2 S1	11,44	14,28	12,61	8,49	2,54	-3,99	-9,62	5,11
C1 L2 S2	12,76	14,22	12,64	9,36	4,70	-0,70	-0,60	7,48
C1 L2 S3	10,95	11,79	10,53	8,04	4,53	0,42	-3,75	6,07
C1 L2 S4	5,58	7,02	7,86	8,81	9,88	10,07	12,41	8,80
C2 (Control)	5,67	7,63	8,84	10,25	11,88	13,77	15,97	10,57
C2 L1 S1	4,99	7,13	8,52	10,19	12,18	14,56	17,40	10,71
C2 L1 S2	4,61	6,27	7,30	8,51	9,14	11,55	13,46	8,69
C2 L1 S3	3,84	4,94	5,60	6,34	7,19	8,15	9,24	6,47
C2 L1 S4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C2 L2 S1	5,34	6,94	7,91	9,02	10,28	11,71	13,34	9,22
C2 L2 S2	5,49	7,12	8,09	9,20	10,47	11,92	13,56	9,41
C2 L2 S3	4,65	5,82	6,50	7,27	8,13	9,10	10,17	7,38
C2 L2 S4	4,56	5,68	6,33	7,07	7,89	8,80	9,82	7,16

[1] Treatment code: C1 Teebus

C2 Bonus

L levels of light intensity: L1 70% shading,
L2 reflectors.

S time of application of light intensity treatments

treatments after the onset of flowering (S3 and S4). In the case of Teebus reflected light (L2) applied before R1 (S1 and S2) increased the TDM as well as the NAR and CGR during the subsequent flowering and early seed growth periods (49 to 77 days) while a sharp drop in NAR and CGR was recorded towards physiological maturity. A similar but less marked tendency was observed as a result of this treatment during the flowering period (S3) of Teebus while it had no effect during the seed fill period (S4).

With regard the yield of TDM at maturity (Table 5.25) there was a significant interaction between the level and time of light intensity treatments. Treatment L2 had no effect on TDM at any time. Shading during the vegetative period (S1 and S2) reduced TDM only slightly but this became significant during the reproductive period (S3 and S4). In Bonus the interaction between cultivars and time of light intensity was significant (P=0,01) during the seed fill period (S4).

5.4.5   Harvest index

Teebus had a significantly higher (P=0,01) HI than Bonus. The HI of plants receiving additional light did not differ significantly from that of the control. Although the shaded plants tended to give lower HI than the control at all times of application, the differences only attained significance (P=0,01) at the S4 stage (Table 5.26).

5.4.6   Correlation matrix

Stem mass and node number were positively correlated (P=0,01) with each other. Parameters relating to economic yield (pod number, seed number and seed yield) were positively (P=0,01) correlated with each other. Pod number, seed number and seeds per pod were positively (P=0,01) correlated with each other and with seed yield while the 100 seed mass was negatively (P=0,01) correlated with pod number, seed number and seeds per pod (Table 5.27).

Table 5.25 The effect of level of light intensity and times of application on the total dry mass (g plant^{-1}) of two dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 67)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 49,59		
Teebus (C1)	S1 (V1-V6f)	46,37	44,01	45,19
	S2 (V6f-R1)	41,77	55,01	48,39
	S3 (R1-R5)	24,72	43,85	34,24
	S4 (R5-R9)	30,56	51,29	40,92
Mean		35,86	48,54	42,19
		Co 46,41		
Bonus (C2)	S1 (V1-V6f)	45,78	44,82	45,30
	S2 (V6f-R1)	47,44	51,03	49,24
	S3 (R1-R5)	49,42	56,79	53,10
	S4 (R5-R9)	28,13	41,57	34,35
Mean		42,69	48,55	45,62
		Co 48,00		
Both cultivars	S1 (V1-V6f)	46,08	44,41	45,23
	S2 (V6f-R1)	44,61	53,02	48,31
	S3 (R1-R5)	37,07	50,32	43,70
	S4 (R5-R9)	29,34	46,43	37,34
Mean		39,27	48,55	45,27

CV   15,3%

	SE	LSD	
		0,05	0,01
Co and L means	+ 1,41	4,01	5,34
Co vs S means	+ 1,64	4,66	6,21
S means	+ 1,73	4,91	6,54
Co C means	+ 1,64	NS	NS
Co vs L x S	+ 2,82	8,01	NS
L x S	+ 2,23	6,33	NS
Co and L x C	+ 1,64	NS	NS
Co vs S x C	+ 2,82	8,01	10,68
S x C	+ 2,44	6,93	9,23
Co vs L x S x C	+ 3,99	NS	NS
L x S x C	+ 3,16	NS	NS

Table 5.26 The effect of level of light intensity and times of application on the harvest index (%) of two dry bean cultivars, Potchefstroom, 1980/81 (see Appendix 68)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 57,45		
Teebus (C1)	S1 (V1-V6f)	54,37	57,97	56,17
	S2 (V6f-R1)	56,27	55,97	56,12
	S3 (R1-R5)	47,13	54,80	50,97
	S4 (R5-R9)	41,37	55,93	48,65
Mean		49,78	56,17	52,98
		Co 51,65		
Bonus (C2)	S1 (V1-V6f)	48,43	57,43	52,93
	S2 (V6f-R1)	48,03	50,77	49,40
	S3 (R1-R5)	51,20	54,23	52,72
	S4 (R5-R9)	37,03	50,80	43,92
Mean		46,18	53,31	49,74
		Co 54,55		
Both cultivars	S1 (V1-V6f)	51,40	57,70	54,55
	S2 (V6f-R1)	52,15	53,67	52,75
	S3 (R1-R5)	49,17	54,52	51,34
	S4 (R5-R9)	39,20	53,37	46,23
Mean		47,98	54,74	52,42

CV	9,1%

	SE	LSD 0,05	LSD 0,01
Co and L means	± 0,97	2,76	3,68
Co vs S means	± 1,38	3,91	5,21
S means	± 1,19	3,38	4,51
Co and C means	± 1,38	3,91	5,21
Co vs L x S	± 1,95	5,53	NS
L x S	± 1,54	4,37	NS
Co and L x C	± 1,38	NS	NS
Co vs S x C	± 1,95	NS	NS
S x C	± 1,69	NS	NS
Co vs L x S x C	± 2,75	NS	NS
L x S x C	± 1,38	NS	NS

Table 5.27 Correlation matrix (r values and tests of significance) of
         the components of the vegetative and reproductive sink at
         harvest, Potchefstroom, 1980/81

	Seed yield	Seed number	Pod number	100 seed mass	Node number	Seeds per pod
Stem mass	0,39	-0,23	-0,21	0,67**	0,81**	-0,18
Seed yield		0,69**	0,63**	-0,70**	0,33	0,62**
Seed number			0,95**	-0,76**	-0,17	0,75**
Pod number				-0,76**	-0,14	0,52**
100 seed mass					0,53**	-0,50*
Node number						-0,15

5.5   Results, 1981/82

5.5.1   Vegetative sink

5.5.1.1   Node number

Teebus produced fewer nodes than Bonus in all treatment combinations.
Levels of light intensity and times of application, had no significant
effect on node number (Table 5.28).

5.5.1.2   Stem mass

Teebus had a significantly ($P=0,01$) lower stem mass than Bonus. Shading
during the vegetative phase (S1 and S2) resulted in significantly higher
stem masses than the same treatment applied during the flowering period
(S3). Reflected light during flower bud initiation and flowering (S2 and
S3) increased the stem mass significantly above that of the same treatment
during the early vegetative period (S1) but none of these treatments dif-
fered significantly from the control (Table 5.29).

5.5.2   Reproductive sink

5.5.2.1   Pod number

When shaded (L1) after flowering (S3 and S4), Teebus and Bonus produced
fewer pods per plant than the control. In the case of Teebus, this treat-
ment resulted in significantly less pods than shading during the vegeta-
tive period (S1 and S2) while no such difference was observed in Bonus.
Bonus produced significantly less pods than Teebus at all times of light
treatment (Table 5.30).

Table 5.28 The effect of level of light intensity and times of appli-
cation on the number of nodes per plant of two dry bean
cultivars, Potchefstroom, 1981/82 (see Appendix 69)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 21,40		
Teebus (C1)	S1 (V1-V6f)	23,73	19,87	21,80
	S2 (V6f-R1)	21,87	22,27	22,07
	S3 (R1-R5)	17,33	22,00	19,67
	S4 (R5-R9)	20,00	21,60	20,80
Mean		20,73	21,43	21,08
		Co 28,07		
Bonus (C2)	S1 (V1-V6f)	24,33	27,73	26,03
	S2 (V6f-R1)	26,93	31,07	29,00
	S3 (R1-R5)	26,40	26,93	26,67
	S4 (R5-R9)	27,73	27,27	27,50
Mean		26,35	28,25	27,30
		Co 24,73		
Both cultivars	S1 (V1-V6f)	24,03	23,80	23,92
	S2 (V6f-R1)	24,40	26,67	25,53
	S3 (R1-R5)	21,87	24,47	23,17
	S4 (R5-R9)	23,87	24,43	24,15
Mean		23,54	24,84	24,37

CV   11,4%

	SE	LSD 0,05	LSD 0,01
Co and L means	± 0,57	NS	NS
Co vs S means	± 0,80	NS	NS
S means	± 0,69	NS	NS
Co and C means	± 0,80	2,27	3,03
Co vs L x S	± 0,42	NS	NS
L x S	± 0,89	NS	NS
Co and L x C	± 0,80	NS	NS
Co vs S x C	± 1,13	NS	NS
S x C	± 0,97	NS	NS
Co vs L x S x C	± 1,60	NS	NS
L x S x C	± 1,27	NS	NS

Table 5.29 The effect of level of light intensity and times of application on the stem mass (g plant^{-1}) of two dry bean cultivars, Potchefstroom, 1981/82 (see Appendix 70)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 6,41		
Teebus (C1)	S1 (V1-V6f)	7,47	6,52	7,99
	S2 (V6f-R1)	5,63	6,97	6,30
	S3 (R1-R5)	5,39	7,17	6,28
	S4 (R5-R9)	5,79	6,70	6,24
Mean		6,07	6,84	6,45
		Co 12,67		
Bonus (C2)	S1 (V1-V6f)	13,55	10,74	12,15
	S2 (V6f-R1)	15,11	13,85	14,48
	S3 (R1-R5)	10,55	12,87	11,71
	S4 (R5-R9)	12,51	12,75	12,63
Mean		12,93	12,55	12,74
		Co 9,54		
Both cultivars	S1 (V1-V6f)	10,51	8,63	9,57
	S2 (V6f-R1)	10,37	10,41	10,39
	S3 (R1-R5)	7,97	10,02	9,00
	S4 (R5-R9)	9,15	9,72	9,44
Mean		9,50	9,70	9,58

CV   15,5%

	SE	LSD	
		0,05	0,01
Co and L means	± 0,30	NS	NS
Co vs S means	± 0,43	NS	NS
S means	± 0,37	NS	NS
Co and C means	± 0,43	1,22	1,62
Co vs L x S	± 0,61	1,74	NS
L x S	± 0,48	1,36	NS
Co and L x C	± 0,43	NS	NS
Co vs S x C	± 0,61	NS	NS
S x C	± 0,52	NS	NS
Co vs L x S x C	± 0,86	NS	NS
L x S x C	± 0,68	NS	NS

Table 5.30 The effect of level of light intensity and times of appli-
cation on the number of pods per plant of two dry bean
cultivars, Potchefstroom, 1981/82 (see Appendix 71)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 27,42		
Teebus (C1)	S1 (V1-V6f)	27,47	27,73	27,60
	S2 (V6f-R1)	30,40	24,80	27,60
	S3 (R1-R5)	15,13	28,13	21,63
	S4 (R5-R9)	20,33	24,33	22,33
Mean		23,33	26,25	24,79
		Co 18,80		
Bonus (C2)	S1 (V1-V6f)	15,87	15,07	15,47
	S2 (V6f-R1)	16,53	19,27	17,90
	S3 (R1-R5)	11,73	19,20	15,47
	S4 (R5-R9)	11,80	17,67	14,73
Mean		13,98	17,80	15,89
		Co 23,11		
	S1 (V1-V6f)	21,67	21,40	21,53
	S2 (V6f-R1)	23,41	22,03	22,75
	S3 (R1-R5)	13,43	23,67	18,55
	S4 (R5-R9)	16,07	21,00	18,53
Mean		18,66	22,03	21,26

CV   14,0%

	SE	LSD 0,05	0,01
Co and L means	± 0,61	1,72	2,29
Co vs S means	± 0,86	2,44	3,24
S means	± 0,74	2,11	2,81
Co and C means	± 0,86	2,44	3,24
Co vs L x S	± 1,21	3,44	4,59
L x S	± 0,96	2,72	3,63
Co and L x C	± 0,86	NS	NS
Co vs S x C	± 1,21	NS	NS
S x C	± 1,05	NS	NS
Co vs L x S x C	± 1,72	4,87	NS
L x S x C	± 1,36	3,85	NS

5.5.2.2   Pod mass

Teebus had a significantly (P=0,01) lower pod mass than Bonus. The shading treatment (L1) did not effect pod mass significantly when applied during the vegetative phase. During the reproductive period (S3 and S4), however, shading resulted in a significantly lower pod mass than that of the control. Treatment L2 did not affect pod mass significantly in any of the treatment combinations (Table 5.31).

5.5.2.3   Seeds per pod

Teebus had significantly more seeds per pod than Bonus. Prior to the seed fill (S1 to S3), shading had no significant influence on the number of seeds per pod compared to that of the control. During seed fill (S4), however, shading reduced the number of seeds per pod significantly (P=0,05). Additional light had no significant effect on the number of seeds per pod at any time (Table 5.32).

5.5.2.4   Seed number

Bonus produced fewer (P=0,01) seeds per plant than Teebus and shading reduced seed number of both cultivars significantly (P=0,01). With regard to differences between times of shading, reduction in seed number arising from this treatment, was most pronounced when applied during the reproductive period (S3 and S4). The difference between the vegetative and reproductive phases was significant at 0,01 probability. Reflected light had no effect on seed number (Table 5.33).

5.5.2.5   Hundred seed mass

The 100 seed mass of Teebus was significantly lower than that of Bonus. No significant effect of level or time of light intensity treatment was recorded (Table 5.34).

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Table 4.31 The effect of level of light intensity and times of appli-
cation on the pod mass (g plant^{-1}) of two dry bean culti-
vars, Potchefstroom, 1981/82 (see Appendix 72)

Cultivars (C)	Time (S)	Levels of light intensity (L)V		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 35,08		
Teebus (C1)	S1 (V1-V6f)	31,39	33,35	32,37
	S2 (V6f-R1)	35,15	35,48	35,30
	S3 (R1-R5)	24,07	38,01	31,04
	S4 (R5-R9)	21,03	32,50	26,77
Mean		27,91	34,83	31,37
		Co 42,08		
Bonus (C2)	S1 (V1-V6f)	37,32	38,11	37,72
	S2 (V6f-R1)	38,47	48,18	43,32
	S3 (R1-R5)	31,37	47,65	39,51
	S4 (R5-R9)	21,94	43,67	32,81
Mean		32,28	44,40	38,34
		Co 38,58		
Both cultivars	S1 (V1-V6f)	34,36	35,73	35,05
	S2 (V6f-R1)	36,81	41,81	39,31
	S3 (R1-R5)	27,72	42,83	35,28
	S4 (R5-R9)	21,49	38,09	29,79
Mean		30,09	39,62	36,10

CV   18,2%

	SE	LSD 0,05	0,01
Co and L means	± 1,34	3,81	5,08
Co vs S means	± 1,90	5,39	7,18
S means	± 1,64	4,67	6,22
Co and C means	± 1,90	5,38	7,18
Co vs L x S	± 2,68	7,62	NS
L x S	± 2,12	6,02	NS
Co and L x C	± 1,90	NS	NS
Co vs S x C	± 2,88	NS	NS
S x C	± 2,33	NS	NS
Co vs L x S x C	± 3,80	NS	NS
L x S x C	± 3,00	NS	NS

Table 5.32 The effect of level of light intensity and times of appli-
cation on the number of seeds per pod of two dry bean
cultivars, Potchefstroom, 1981/82 (see Appendix 73)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 4,15		
Teebus (C1)	S1 (V1-V6f)	4,17	3,93	4,05
	S2 (V6f-R1)	3,87	4,97	4,42
	S3 (R1-R5)	5,10	4,37	4,73
	S4 (R5-R9)	3,27	4,97	4,12
Mean		4,10	4,56	4,33
		Co 4,01		
Bonus (C2)	S1 (V1-V6f)	4,07	4,40	4,23
	S2 (V6f-R1)	3,60	4,53	4,07
	S3 (R1-R5)	4,27	4,27	4,27
	S4 (R5-R9)	3,50	4,40	3,95
Mean		3,86	4,40	4,13
		Co 4,26		
Both cultivars	S1 (V1-V6f)	4,12	4,17	4,14
	S2 (V6f-R1)	3,73	4,75	4,24
	S3 (R1-R5)	4,68	4,32	4,50
	S4 (R5-R9)	3,38	4,68	4,03
Mean		3,40	4,48	4,24

CV   11,2%

	SE	LSD	
		0,05	0,01
Co and L means	± 0,10	0,27	0,37
Co vs S means	± 0,14	NS	NS
S means	± 0,12	NS	NS
Co C means	± 0,14	0,39	NS
Co vs L x S	± 0,19	0,55	0,73
L x S	± 0,15	0,43	0,58
Co and L x C	± 0,14	NS	NS
Co vs S x C	± 0,19	NS	NS
S x C	± 0,02	NS	NS
Co vs L x S x C	± 0,27	NS	NS
L x S x C	± 0,22	NS	NS

Table 5.33 The effect of level of light intensity and times of appli-
cation on the number of seeds per plant of two dry bean
cultivars, Potchefstroom, 1981/82 (see Appendix 74)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 123,67		
Teebus (C1)	S1 (V1-V6f)	113,60	110,27	111,93
	S2 (V6f-R1)	118,73	122,20	120,47
	S3 (R1-R5)	76,80	123,20	100,00
	S4 (R5-R9)	66,27	121,20	93,73
Mean		93,85	119,22	106,53
		Co 79,37		
Bonus (C2)	S1 (V1-V6f)	64,33	66,93	65,63
	S2 (V6f-R1)	59,33	87,33	73,33
	S3 (R1-R5)	50,93	82,07	66,50
	S4 (R5-R9)	37,00	78,07	57,53
Mean		52,90	78,60	65,75
		Co 101,52		
Both cultivars	S1 (V1-V6f)	88,97	88,60	88,78
	S2 (V6f-R1)	89,03	104,77	96,90
	S3 (R1-R5)	63,87	102,63	83,25
	S4 (R5-R9)	51,63	99,63	75,63
Mean		73,38	98,91	91,27

CV   19,2%

	SE	LSD	
		0,05	0,01
Co and L means	± 3,58	10,15	13,52
Co vs S means	± 5,06	14,35	NS
S means	± 4,38	12,43	NS
Co C means	± 5,06	14,35	19,12
Co vs L x S	± 7,15	20,30	27,04
L x S	± 5,65	16,04	21,38
Co and L x C	± 5,06	14,35	19,12
Co vs S x C	± 7,15	NS	NS
S x C	± 6,19	NS	NS
Co vs L x S x C	± 10,11	NS	NS
L x S x C	± 8,00	NS	NS

Table 5.34 The effect of level of light intensity and times of appli-
cation on the 100 seed mass (g) of two dry bean cultivars,
Potchefstroom, 1981/82 (see Appendix 75)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 23,08		
Teebus (C1)	S1 (V1-V6f)	21,93	25,20	23,57
	S2 (V6f-R1)	23,57	23,60	23,58
	S3 (R1-R5)	25,60	21,93	23,77
	S4 (R5-R9)	23,10	21,60	22,35
Mean		23,55	23,08	23,32
		Co 43,38		
Bonus (C2)	S1 (V1-V6f)	45,07	46,67	45,87
	S2 (V6f-R1)	49,73	46,77	48,25
	S3 (R1-R5)	50,77	47,00	48,88
	S4 (R5-R9)	48,73	45,33	47,03
Mean		48,58	46,44	47,51
		Co 33,23		
	S1 (V1-V6f)	33,50	35,93	34,72
	S2 (V6f-R1)	36,65	35,18	35,92
	S3 (R1-R5)	38,18	34,47	36,33
	S4 (R5-R9)	35,92	33,47	34,69
Mean		36,06	34,76	34,69
CV	10,2%			

	SE	LSD	
		0,05	0,01
Co and L means	± 0,72	NS	NS
Co vs S means	± 1,02	NS	NS
S means	± 0,89	NS	NS
Co C means	± 1,02	2,90	3,87
Co vs L x S	± 1,45	NS	NS
L x S	± 1,14	NS	NS
Co and L x C	± 0,32	NS	NS
Co vs S x C	± 1,45	NS	NS
S x C	± 1,25	NS	NS
Co vs L x S x C	± 2,05	NS	NS
L x S x C	± 1,62	NS	NS

5.5.2.6   Seed yield

Teebus gave a significantly lower seed yield than Bonus. Treatment L2 had no effect on seed yield. Shading, however, resulted in a significantly lower yield than the control when applied during the reproductive period (S3 and S4) (Table 5.35).

5.5.3   Total dry mass

Teebus produced a significantly (P=0,01) lower TDM than Bonus (Table 5.36). Shading during the reproductive period (S3 and S4) resulted in a significantly lower TDM than that of the control. The TDM of plants receiving treatment L2 did not differ from that of the controls at any time (Table 5.36).

5.5.4   Harvest index

Shading (L1) of both cultivars resulted in a significantly (P=0,01) lower HI than that of the controls, the effect being most pronounced in the seed fill period (S4). Additional light had no significant effect on HI. Bonus had a lower HI (P=0,01) than Teebus in all treatment combinations (Table 5.37).

5.5.5   Correlation matrix

Stem mass and node number were positively correlated (P=0,01) with each other and with seed yield. Seed yield had no strong correlation with any of the yield components. Hundred seed mass was negatively correlated (P=0,01) with both pod number and seeds per plant (Table 5.38).

Table 5.35 The effect of level of light intensity and times of appli-
cation on the seed yield (g plant^{-1}) of two dry bean culti-
vars, Potchefstroom, 1981/82 (see Appendix 76)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 28,54		
Teebus (C1)	S1 (V1-V6f)	24,93	27,03	25,98
	S2 (V6f-R1)	27,93	28,85	28,39
	S3 (R1-R5)	19,69	30,65	25,17
	S4 (R5-R9)	16,85	26,04	21,45
Mean		22,35	28,15	25,25
		Co 34,05		
Bonus (C2)	S1 (V1-V6f)	29,37	31,07	30,22
	S2 (V6f-R1)	29,64	39,81	34,73
	S3 (R1-R5)	24,92	38,51	31,71
	S4 (R5-R9)	17,97	35,33	26,65
Mean		25,47	36,18	30,83
		Co 31,29		
Both cultivars	S1 (V1-V6f)	27,15	29,05	28,10
	S2 (V6f-R1)	28,78	34,33	31,56
	S3 (R1-R5)	22,30	34,58	28,44
	S4 (R5-R9)	17,41	30,69	24,09
Mean		23,91	32,16	29,12

CV   18,1%

	SE	LSD 0,05	0,01
Co and L means	± 1,08	3,06	4,08
Co vs S means	± 1,53	4,33	NS
S means	± 1,32	3,75	NS
Co and C means	± 1,53	4,33	5,77
Co vs L x S	± 2,16	6,12	NS
L x S	± 1,71	4,84	NS
Co and L x C	± 1,53	NS	NS
Co vs S x C	± 2,16	NS	NS
S x C	± 1,87	NS	NS
Co vs L x S x C	± 3,05	NS	NS
L x S x C	± 2,41	NS	NS

Table 5.36 The effect of level of light intensity and times of appli-
cation on the total dry mass (g plant^{-1}) of two dry bean
cultivars, Potchefstroom, 1981/82 (see Appendix 77)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 45,92		
Teebus (C1)	S1 (V1-V6f)	44,59	43,11	43,85
	S2 (V6f-R1)	45,89	45,97	45,93
	S3 (R1-R5)	35,56	49,39	42,47
	S4 (R5-R9)	30,32	44,16	37,24
Mean		39,09	45,66	42,37
		Co 63,47		
Bonus (C2)	S1 (V1-V6f)	58,14	55,32	56,73
	S2 (V6f-R1)	50,65	70,80	60,73
	S3 (R1-R5)	50,56	68,27	59,41
	S4 (R5-R9)	44,89	65,19	55,04
Mean		51,06	64,89	57,98
		Co 54,69		
Both cultivars	S1 (V1-V6f)	51,37	49,21	50,29
	S2 (V6f-R1)	48,27	58,38	53,33
	S3 (R1-R5)	43,06	58,83	50,94
	S4 (R5-R9)	37,60	54,67	46,14
Mean		45,08	55,27	51,68

CV   16,0%

	SE	LSD 0,05	0,01
Co and L means	± 1,69	4,79	6,38
Co vs S means	± 2,39	NS	NS
S means	± 2,07	NS	NS
Co and C means	± 2,39	6,77	9,02
Co vs L x S	± 3,37	9,58	NS
L x S	± 2,67	7,57	NS
Co and L x C	± 2,39	NS	NS
Co vs S x C	± 3,37	NS	NS
S x C	± 2,92	NS	NS
Co vs L x S x C	± 4,77	NS	NS
L x S x C	± 3,77	NS	NS

Table 5.37 The effect of level of light intensity and times of appli-
cation on the harvest index (%) of two dry bean cultivars,
Potchefstroom, 1981/82 (see Appendix 78)

Cultivars (C)	Time (S)	Levels of light intensity (L)		Mean
		L1 (70% shading)	L2 (reflectors)	
		Co 62,41		
Teebus (C1)	S1 (V1-V6f)	56,13	62,53	59,33
	S2 (V6f-R1)	61,40	62,93	62,17
	S3 (R1-R5)	55,40	62,13	58,77
	S4 (R5-R9)	55,13	58,80	56,97
Mean		57,02	61,60	59,31
		Co 53,63		
Bonus (C2)	S1 (V1-V6f)	50,23	55,87	53,05
	S2 (V6f-R1)	47,37	56,17	51,77
	S3 (R1-R5)	48,90	56,43	52,67
	S4 (R5-R9)	42,30	53,90	48,10
Mean		47,20	55,59	51,40
		Co 58,02		
Both cultivars	S1 (V1-V6f)	53,18	59,20	56,19
	S2 (V6f-R1)	54,38	59,55	56,97
	S3 (R1-R5)	52,15	59,28	55,72
	S4 (R5-R9)	48,72	56,35	52,53
Mean		52,11	58,60	56,24
CV	5,6%			

	SE	LSD	
		0,05	0,01
Co and L means	± 0,64	1,81	2,41
Co vs S means	± 0,90	2,56	3,41
S means	± 0,07	0,21	0,28
Co C means	± 0,90	2,56	3,41
Co vs L x S	± 1,28	NS	NS
L x S	± 1,01	NS	NS
Co and L x C	± 0,90	2,56	NS
Co vs S x C	± 1,28	NS	NS
S x C	± 1,11	NS	NS
Co vs L x S x C	± 1,81	NS	NS
L x S x C	± 1,43	NS	NS

Table 5.38 Correlation matrix (r values and tests of significance) of
the components of the vegetative and reproductive sink at
harvest, Potchefstroom,1981/82

	Seed yield	Seed number	Pod number	100 seed mass	Node number	Seeds per pod
Stem mass	0,58**	-0,46*	-0,49*	0,87**	0,90**	-0,23
Seed yield		0,32	0,21	-0,32	0,62**	0,24
Seed number			0,90**	-0,75**	-0,23	0,51*
Pod number				-0,73**	-0,26	0,14
100 seed mass					0,68**	-0,32
Node number						-0,13

5.6   Discussion

The results of the 1979/80 trial indicate that shading reduced TDM produc-
tion when applied during and after flower initiation. There was no signi-
ficant difference between the 25% and 50% levels of shading at any deve-
lopment stage (Figure 5.1a). The 75% shading, however, resulted in con-
sistently lower TDM values if the components of TDM are considered sepa-
rately, a different pattern arises. In the case of stem mass, there was a
decrease at each lower light intensity just prior to flowering (V6f to R1)
but not at any other stage. With regard to seed mass shading had an
adverse effect during all development stages after flower initiation (V6f
to R9) (Figure 5.1b). During the seed growth period (R5 to R9) seed mass
declined at each higher level of shading. In the earlier period (V6f to
R4) the response was confined to the 75% level. Thus dry matter produc-
tion in the components of TDM is inversely related to intensity of shading
during certain development stages only. In this case stem and seed mass
responded to light intensity only during development stages during which
these organs received preference in partitioning of the available photo-
synthate.   The reduction of TDM in shaded treatments recorded here is in
accordance with the findings of other researchers (Escalante & Kohashi-
Shibata, 1982; Lopez et al., 1982; Martinez, 1982; Eriksen & Whitney,
1984).   However, the differences in partitioning pattern at different
development stages was not identified by these authors.   The present
studies indicate that level of shading cannot be evaluated independently
of the stage at which it is applied.

Reflected light had no effect on TDM in both seasons. Similarly NAR and
CGR in Bonus showed little deviation from the control. When reflected
light was applied before the seed development stage to Teebus, higher NAR
and CGR were recorded up to 77 days from planting. The sharp decline in
these parameters during the seed development stage is the reverse of that
recorded in the control as well as the shading treatments. It indicates
that additional light stimulated the growth rate of Teebus initially but
this rate was not maintained during the seed development stage and the
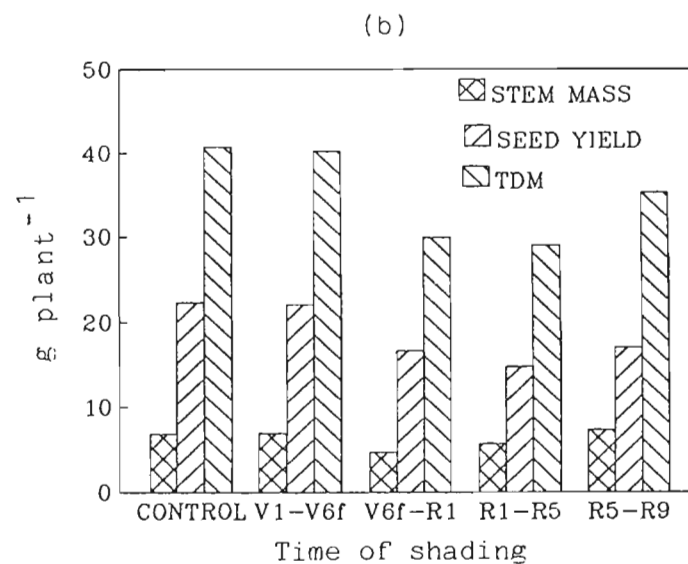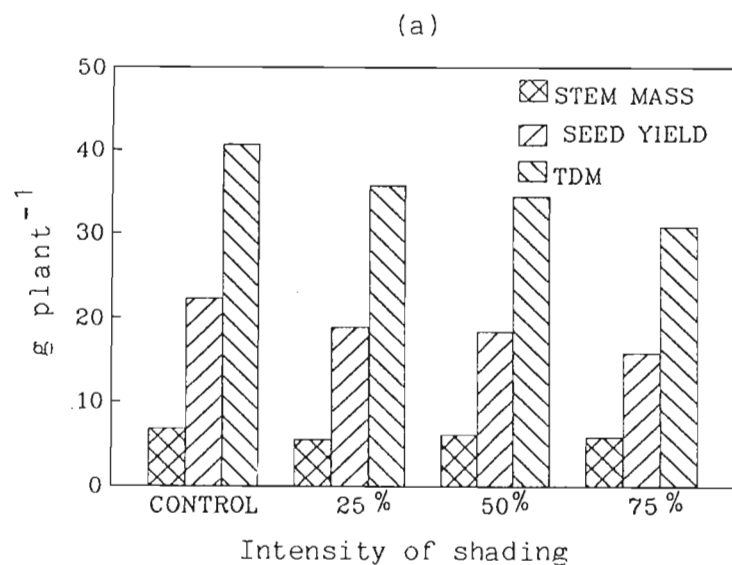
Figure 5.1   The effect of (a) intensities and (b) times of shading on the stem mass, seed yield and TDM of dry beans, Potchefstroom, 1979/80 (tests of significance are presented in Tables 5.1, 5.7 and 5.8)

treatment had no influence on final TDM. Similarly seed yield and its components failed to respond to reflected light.

These results differ from those recorded in soybeans (Johnston *et al.*, 1969; Shou *et al.*, 1978); maize (Pendleton *et al.*, 1967) and groundnuts (Williams, 1978) where increased photosynthesis at lower canopy levels improves seed yield. Additional light will have a positive influence on growth provided (i) mutual shading at the lower canopy levels has a negative influence on photosynthesis or (ii) additional light is no accompanied by other adverse effects (higher temperatures or moisture stress). The lack of response in TDM production to reflected light may have been related to these factors. However, as described previously the reflectors were not entirely effective during the latter development stages and it is not possible to draw firm conclusions.

In 1980/81 shading during the vegetative period reduced maximum leaf area which was attained at the onset of flowering (49 days). This corresponds with the results of Crookston *et al.*, (1975). This treatment also retarded the onset of flowering by 7 days when applied before flower initiation in Teebus and between flower initiation and the onset of flowering, in Bonus. An extended growing season in shaded treatments was also observed by Eriksen & Whithey (1984). Although shading in the vegetative period reduce maximum LA, it prevented the fast decline in LA towards physiological maturity in 1980/81 as indicated by the high LA values of plants shaded before the seed development stage. The high NAR during the flowering period and high CGR during seed growth in this treatment, indicate that the available leaf area was sufficient and very efficient in accumulating dry matter. The extended vegetative period allowed the shaded plants one week of full sunlight before they started flowering as the shades were moved when the controls started flowering.

The reduced maximum leaf area which occurred as a result of shading in the vegetative period, cannot be attributed to variation in leaf number since node numbers were not influenced by shading in both 1980/81 and 1981/82.
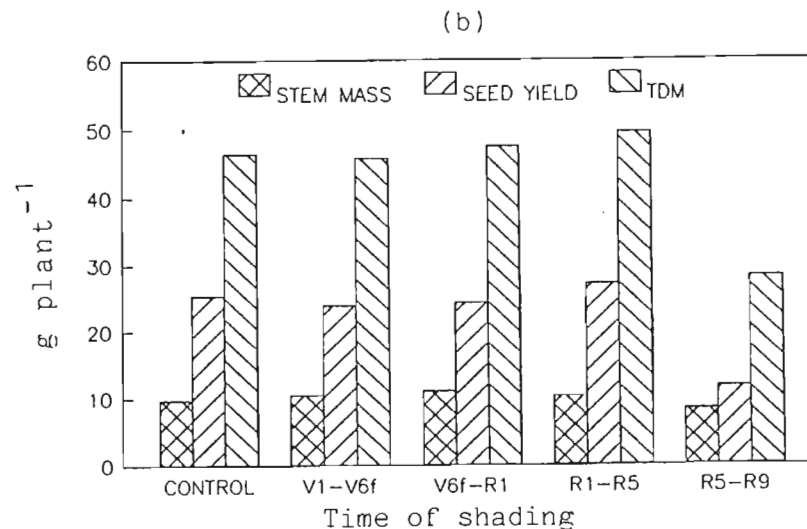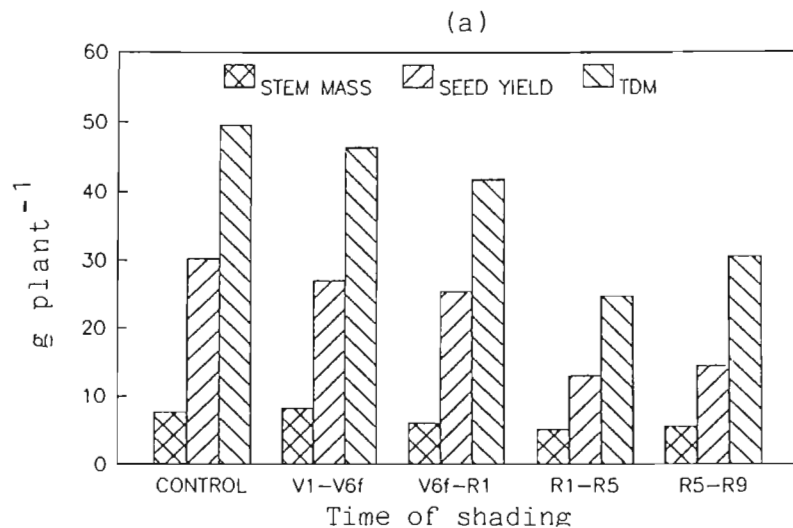
Figure 5.2   The effect of times of 70% shading on the stem mass, seed yield and TDM of cultivars (a) Teebus and (b) Bonus, Potchefstroom, 1980/81 (tests of significance are presented in Tables 5.14, 5.21 and 5.25)
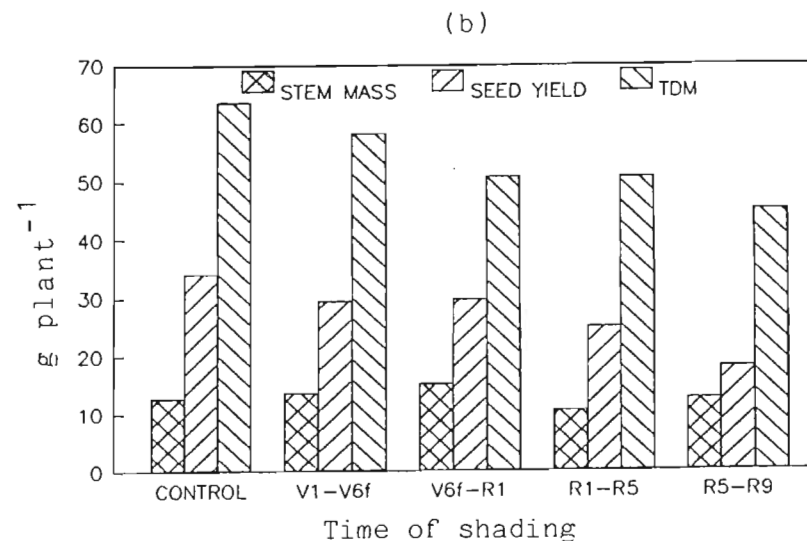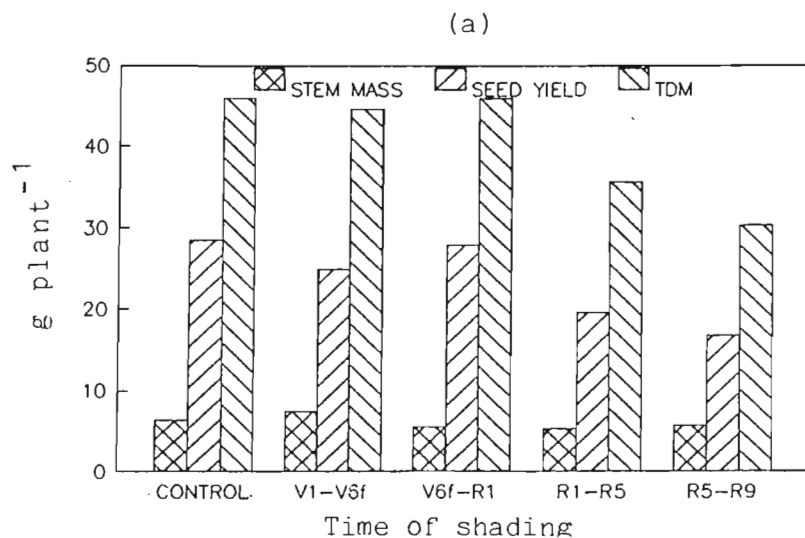
Figure 5.3   The effect of times of 70% shading on the stem mass, seed yield and TDM of cultivars (a) Teebus and (b) Bonus, Potchefstroom, 1981/82 (tests of significance are presented in Tables 5.29, 5.35 and 5.36)

Hence the response was related to change in area of individual leaves. This is in contrast to the results of Crookston *et al.*, (1975) who recorded a reduction in leaf number in shaded treatments.

Shading during the reproductive period resulted in reduced TDM in all three trials (Figures 5.1a, 5.2 and 5.3). The results of the 1980/81 trial indicate that the severity of the negative effect of shading on LA was less pronounced than that recorded in TDM accumulation during the seed growth period. As a result TDM production remained constant and in turn this was associated with zero NAR and CGR values over the whole reproductive period. Thus the TDM values were lower than that of the controls.

The relative importance of shading stress at different development stages on TDM production varied between seasons and cultivars. In all three trials shading before flower initiation had little effect while shading during the seed fill period was very detrimental. The TDM of Teebus was reduced by shading during flower initiation and flowering in 1979/80 (Figure 5.16). Thus the response of TDM to shading immediately before and after the onset of flowering, is inconsistent and varies between seasons and cultivars.

When applied during seed fill, shading at 75% (1979/80) reduced HI indicating that photosynthate production in this treatment was insufficient. In 1980/81 both cultivars reacted in the same way to 70% shading. In the 1981/82 trial the response was recorded in Bonus only. Thus the cultivars differed in the way in which carbohydrate was partitioned during seed fill. Shading during the flower initiation period (V6f to R1) increased the HI in 1979/80 and 1981/82 in the case of Teebus but it had no effect on Bonus. In all cases high HI values were related to a severe reduction in vegetative mass rather than an increase in seed mass. These findings indicate that newly formed photosynthate is partitioned towards the centres of active growth. Any reduction in the photosynthetic rate (as expressed in the CGR and NAR) as a result of shading restricts the development of vegetative organs when induced before flowering (raising the

HI) and reproductive organs, after flowering (reducing the HI). This is in agreement with the description given by Stoy (1969).

In a crop the effect of any stress factor on seed yield is of great importance from the economic point of view. Earlier in the discussion, it was concluded that shading during the reproductive period reduced seed yield in all three trials. Shading during the flower initiation period produced the same response in 1979/80. Similar results were obtained by Martinez (1982), Portez & Silveira (1982), Eriksen & Whitney (1984) and Schepps & Ashley (1985) in non-climbing cultivars.

The two cultivars differed in their reaction to shading. Teebus bore a reduced number of pods per plant as a result of shading during the reproductive period (R1 to R9) in all three trials as well as during the late vegetative period at 75% shading in 1979/80. In the case of Bonus, pod number was reduced by shading during the flowering and late reproductive stage (R6 to R9) in 1980/81 and the flowering period only in 1981/82. In general results are in accordance with those of Portez & Silveira (1982), Eriksen & Whitney (1985) and Schepps & Ashley (1985) but a direct comparison is difficult because these authors did not apply the shading treatment at different development stages.

A marked similarity was found in the effects of treatments on pod number and seed yield indicating a strong relationship between these two parameters. The number of seeds per pod showed little reaction to shading at levels as high as 70%. In 1980/81 and 1981/82 Teebus and Bonus had a reduced number of seeds per pod during the late reproductive stage only. Teebus showed the same tendency, although not significantly, in 1979/80. It appears that this yield component is less responsive to shading and restricted to the period of active seed growth. Seeds per plant showed an even closer relationship with yield than pods per plant in all these trials, indicating a complementary relationship between them. The effect of shading on seed size was very variable. In 1979/80 75% shading during the flowering period in Teebus increased seed size while the same

treatment reduced pod number and seed yield. In 1980/81 shading had no effect on seed size at any stage while in 1981/82 an increase in seed size was recorded in both cultivars at all development stages. It follows from this analysis of yield components that genotypic as well as climatic factors have a significant influence on the way in which a plant reacts to shading.

With regard to yield component compensation, the number of pods per plant showed the largest negative response to shading and this was complemented to some extent by an increase in the number of seeds per pod. Similarly seed size was inclined to increase with decreasing pod number. These results are in agreement with the proposals put forward by Adams (1967) regarding the mechanisms of yield component compensation.

Seed yield was positively correlated with the number of pods per plant during two seasons only (1979/80 and 1980/81). In 1981/82 seed yield showed no strong relationship with any yield component. The number of pods per plant showed a much stronger positive relationship with the number of seeds per plant than with seed yield in all three seasons. This indicates that not only the number of seeds but also the seed size had an influence on yield. Seed number in turn was determined by the number of pods per plant and seeds per pod. This is confirmed by the tendency towards (i) a positive correlation between the number of seeds per pod and seed yield, and (ii) a negative relationship between 100 seed mass and all the yield components except seeds per pod in 1979/80. This clearly indicates that seed size was influenced by the available photosynthate during the seed growth period which in turn depended on the number of seeds amongst which the photosynthate was distributed. It appears therefore that seeds evolve within their genetic potential to a size which has a strong negative correlation with the number of developing seeds per plant. The results also suggest that pod number and seeds per pod, which determine seed number, comprise a unit which must be set early in order to provide a sufficiently long seed growth period for compensation between seed size and seed number to take place.

Shading during the R5 stage onwards reduced the number of seeds per pod and hence, seed abortion may have taken place at this time. In assessing this result it must be taken into account that the development stages are determined by the oldest pods. Thus there were many pods in development stages R2 to R4 when shading was initiated at R5. Thus it is very likely that abortion would have occurred in embryos prior to the R5 stage. This in in accordance with the model for the competition within a nutritional unit proposed by Adams (1967). Thus the source is brought into balance with the sink through seed abortion.

If stored carbohydrate reserves are present in leaves, stems and roots, shading stress may stimulate the plant to draw on these reserves. In growth studies a decline in leaf mass can be related to normal ageing (leaf drop) or to translocation of reserves to reproductive organs. On the other hand variation in stem mass is linked to the latter mechanism only and provides a better measure of mobilized reserves. When applied during the pod set period (R1 to R5) in 1979/81 and 1981/82 and the whole reproductive period in 1981/81, shading caused a large reduction in stem mass. It is not clear why the pod set period was more responsive than the seed fill period in 1979/80 and 1981/82 since a stronger sink would be present in the latter case. Stored reserves may have became more immobile towards the end of the reproductive period or alternatively, normal stem growth was entailed. The remobilization of starch reserves in stems and roots of beans has been reported by Adams et al., (1977). They found a variation between cultivars as well as a decline in starch content during the reproductive period. In 1980/81 the stem mass of Teebus peaked at 63 days (R5 stage) and declined in the following weeks while that of Bonus remained constant indicating (i) cultivar differences in the development of stem mass, and (ii) a drop in the stem mass of Teebus which means that non-structural reserves were redistributed during the development of the cultivar irrespective of the treatment. No indication, therefore, could be found that stored reserves were remobilized as a result of shading stress during any development stage.

Cultivar differences in response to shading were small and inconsistent despite large differences in CGR, NAR and LA. For example, Bonus showed less response to shading than Teebus in 1980/81 but not in 1981/82. Martinez (1982) found that indeterminate climbing cultivars were unaffected by shading before and during flowering, indicating a sink limitation in these cultivars. This would suggest that the indeterminate Bonus may be less responsive to shading than the determinate Teebus, as indicated by the results of 1980/81 in which season Bonus gave a significantly lower yield than Teebus under ambient light intensity. On the other hand both cultivars reacted similarly to shading in 1981/82. In this season Bonus gave a significantly higher yield than Teebus and a sink limitation in the former cultivar was less likely.

5.7   Conclusions

The results of the light manipulation trials can now be applied to the working hypothesis:

(i)   Total dry matter production reacted to levels of shading during certain development stages only. Before flower initiation no level of shading had any effect. Shading after the V6f stage reduced TDM at each higher level. The vegetative sink (stem mass) showed this effect only during its period of active growth (Vnf) while the reproductive sink was affected by the level of shading during the vegetative (Vnf) as well as reproductive (R1-R9) stages.

(ii)   Shading during the vegetative period retarded the onset of reproductive development resulting in a relatively high leaf area during the seed fill period and this had little effect on seed yield. During the reproductive period this treatment reduced seed yield significantly. Thus the shading stress had an effect on the organs which were actively developing during the treatment period. The length of the period of shading was therefore of less importance than the development stage during which is was applied. This

indicates that the rate of current photosynthesis during the reproductive period was the main factor determining reproductive mass.

(iii) Very convincing evidence of yield component compensation was found. The number of pods per plant was the yield component with the largest influence on seed yield as shown by the strong positive relation between these two parameters. In turn, there was a positive correlation between the former parameter and seeds per pod. On the other hand, the correlation between seed size and the other yield components was negative, the effect being most pronounced in the regression incorporating seed number. These results indicate that yield components react to available photosynthate in a way which permits a balance in source and sink size at a particular development stage.

(vi) No evidence of mobilization of stored reserve carbohydrates was found in any of the shaded treatments. It appears therefore, that the reproductive sinks in beans rely mainly on current photosynthesis.

(v) The observed cultivar differences in CGR, NAR and LA appear to be related to the size of the developing reproductive organs. There were indications that the limited response of Bonus to shading was associated with a smaller reproductive sink.

CHAPTER 6

REMOVAL OF REPRODUCTIVE ORGANS

6.1   Introduction

The only practical way to limit the storage capacity of a crop is to re-
move the storage organs. In the case of beans, this can be attained by
removing flowers and/or pods during various stages of development between
flowering and physiological maturity. In this way the source organs stay
unaltered while the drain on the photosynthate is reduced. The plant can
react in one or more of the following ways: (i) produce more vegetative
organs; (ii) set pods from later formed flowers; (iii) compensate for lost
pods by later formed yield components (more seeds per pod and/or larger
seeds), or (iv) fail to respond when none of these options are available.

The aim of the studies reported in this chapter has been to determine
whether (i) the effect on vegetative and reproductive organs is in propor-
tion to the intensity of the removal of reproductive structures; (ii) the
effect of flower and pod removal varies according to the stage during
which it was done; (iii) there are any critical stages during which sink
size is fixed permanently; (iv) yield component compensation takes place;
(v) non-structural reserves are stored; (vi) photosynthesis is influenced
by the size of the storage organs; (vii) cultivars differ in reaction to a
sink restriction.

6.2   Materials and methods

6.2.1   General information

The experiments were conducted in 1981/82 and 1985/86.   Meteorological
data and details of irrigation applied are given in Appendix 1.3 (1981/82)
and Appendix 1.4 (1985/86). Chemical analyses of the soil and fertilizer
applications are set out in Appendix 2.

6.2.2   Pod removal trial, 1981/82

The treatments were as follows:

Control

Co   no pods or flowers were removed.

Levels of flower and pod removal

The pods were removed by hand at the following intensities:

L1   all the pods except five were picked as well as all the open
       flowers,

L2   all the pods except ten were picked as well as all the open
       flowers.

The oldest pods were selected to remain on the plants in these two treat-
ments.

Times of pod removal

Pods were removed once at the following times:

S1   (R2) oldest pods about 10 mm long,

S2   (R3-4) oldest pods 25 to 50 mm long,

S3   (R5) seeds discernible in oldest pods,

S4   (R6-7) seeds 6 mm long to fully developed,

S5   (R8) oldest pods fully developed and just prior to physiological
       maturity.

The cultivar Teebus was planted on 1981/12/22 in a factorially arranged randomized block design in four replications. The treatment combinations consisted of a 2 x 5 factorial arrangement with an added control which was repeated five times in each of the four replications. This provided an extra four degrees of freedom for error. A spacing of 900 mm between rows and 75 mm in the row was adopted (148100 plants ha^{-1}). The plots consisted of three rows of 2 m each with the treatments induced on the centre row.

All the plants in a plot were harvested (26 plants) and the measurements done as described in paragraph 3.2.2. In addition, the harvested pods in each sample were divided into those with and without seeds and the numbers recorded. In order to obtain a consolidated figure for vegetative material, the masses of stem, leaf and pod wall fractions were summed in this trial and named non-reproductive mass (NRM). Thus in the computation of results, vegetative sink size is expressed in terms of NRM rather than leaf and stem mass, separately.

6.2.3   Pod removal trial, 1985/86

An additional two cultivars were included in the 1985/86 trial and depodding was reduced to a single level. In the latter treatment all pods excepting the 10 oldest pods on each plant were removed on five occasions.

Cultivars

The treatments were as follows:

C1   Teebus,
C2   NEP 2,
C3   Bonus.

Time of pod removal

Pods were removed at the following times:

S0   control (no pods removed),

S1   (R2) oldest pods about 10 mm long,

S2   (R3-4) oldest pods 25 to 50 mm long,

S3   (R5) seeds discernible in oldest pods,

S4   (R6-7) seeds 6 mm long to fully developed,

S5   (R8) oldest pods fully developed and just prior to physiological maturity.

The trial was hand planted on 1985-12-23 with a spacing of 750 mm between rows and 75 mm in the row (177700 plants ha^{-1}). The plots consisted of two 5 m rows. Treatments were induced on all the plants in a 2 m section within each row. The trial consisted of a 3 x 6 factorial arrangement with four replications (blocks).

At maturity a sample of 18 plants per plot was harvested and the measurements done as described in par. 6.2.1.

6.2.4   Correlation matrix

Simple correlations were calculated between all measured parameters in each experiment and expressed in terms of a correlation matrix.

6.2.5   Statistical analysis

The statistical analyses of the 1981/82 trial was done on a Burroughs B7900 computer using a Genstat V Mark 4.04B Release package system. The

1985/86 trial was analysed on a Hewlett Packard 9826 computer using the manufacturers package system.

6.3 Results, 1981/82

6.3.1 Days to physiological maturity

In comparisons with the control, pod removal increased the number of days to physiological maturity at all times up to the onset of seed growth (S1, S2 and S3). At the highest depodding level (L1), the growing period was extended by 13 days. At the L2 level the effect was less striking: 13, four and three days for S1, S2 and S3, respectively (Table 6.1).

6.3.2 Vegetative sink

6.3.2.1 Non-reproductive mass

Depodding at the lower level (L2) increased the NRM significantly (P=0,05) at times S3 and S4 (R5-R7). At the higher level (L1) depodding increased NRM significantly (P=0,05) at all times except S5 (just prior to physiological maturity) (Table 6.2).

6.3.3 Reproductive sink

6.3.3.1 Number of empty pods

The highest level of depodding (L1) induced more empty pods (P=0,05) than both the lower level (L2) and the control (Co). In comparisons with the control, there was a significant (P=0,01) increase in empty pods as a result of depodding at S3, while depodding at the end of the seed development stage (S5) reduced the number of empty pods significantly (Table 6.3).

Table 6.1 Phenological data recorded in the pod removal
trial, Potchefstroom, 1981/82

Treatment[1] combination	Days after planting	
	Time of treatment application	Physiological maturity
Co	$-^2$	88
L1 S1 (R2)	49	101
L1 S2 (R3-4)	52	101
L1 S3 (R5)	59	101
L1 S4 (R6-7)	72	90
L1 S5 (R8)	78	86
L2 S1 (R2)	49	101
L2 S2 (R3-4)	52	93
L2 S3 (R5)	59	91
L2 S4 (R6-7)	72	90
L2 S5 (R8)	78	89

[1] Treatment code: Co   control

L   levels of depodding

S   time of depodding

[2] R1 (50% flowering): 45 days after planting

Table 6.2 The effect of the time and level of pod removal on the non-
         reproductive mass (g plant^{-1}) of dry beans (cv. Teebus),
         Potchefstroom, 1981/82 (see Appendix 79)

| Time   of pod removal (S) | Level of pod removal (L) | | Mean |
	L1 (leave 5 pods)	L2 (leave 10 pods)	
	Co 13,32		
S1 (R2)	18,92	16,47	17,70
S2 (R3-4)	20,23	14,24	17,23
S3 (R5)	17,71	18,50	18,10
S4 (R6-7)	19,26	21,67	20,46
S5 (R8)	13,20	13,73	13,47
Mean	17,86	16,92	16,03
CV	16,9%		

| | SE | LSD | |
		0,05	0,01
Co and L means	± 0,61	NS	NS
Co vs S means	± 0,96	2,72	3,63
S means	± 0,80	2,28	3,04
Co vs L x S	± 1,35	3,85	NS
L x S	± 1,05	2,98	NS

Table 6.3 The effect of the time and level of pod removal on the number of empty pods per dry bean plant (cv. Teebus), Potchefstroom, 1981/82 (see Appendix 80)

Time of pod removal (S)	Level of pod removal (L)		Mean
	L1 (leave 5 pods)	L2 (leave 10 pods)	
	Co 1,95		
S1 (R2)	3,35	1,46	2,40
S2 (R3-4)	3,34	0,63	1,98
S3 (R5)	6,42	3,80	5,66
S4 (R6-7)	4,88	0,88	2,34
S5 (R8)	0,44	0,39	0,41
Level means	3,69	1,43	2,36

CV   55,5%

	SE	LSD 0,05	0,01
Co and L means	± 0,92	0,83	1,11
Co vs S means	± 0,46	1,32	1,76
S means	± 0,39	1,10	1,47
Co vs L x S	± 0,65	NS	NS
L x S	± 0,51	NS	NS

6.3.3.2   Number of pods containing seed

The values for this parameter were significantly lower than those of the
control plants at both levels (L1 and L2) of pod removal and at all times
of treatment except S1 at L2. The number of pods declined with each
successive later time of pod removal. The two levels of pod removal reac-
ted similarly at different times of treatment except at S4 when L2 pro-
duced significantly more pods with seeds (Table 6.4).

6.3.3.3   Pod mass

The effect of both levels of pod removal on pod mass was similar. Pod mass
at both levels of pod removal did not differ significantly from that of
the control (Co) when the pods were removed during the pod set period (S1
and S2). At each later time (S3 to S5) of pod removal, there was a pro-
gressive decline in the pod mass which differed significantly (P=0,01)
from the control in all comparisons (Table 6.5).

6.3.3.4   Seeds per pod

This parameter was not affected by treatments apart from two marked excep-
tions: in the S2 L2 treatment, there were significantly more seeds per
pod than the control (Co) while in S3 L1 the value was much lower (P=0,01)
than the control and all the other times at the same level (Table 6.6).

6.3.3.5   Seed number

The L1 treatment gave a significantly (P=0,05) greater reduction in seed
number than L2.   Depodding reduced the number of seeds significantly
(P=0,05) below that of the control at S1. The differences were signifi-
cant (P=0,01) at the four later times of depodding (Table 6.7).

6.3.3.6   Hundred seed mass

The 100 seed mass of the two levels of pod removal did not differ from
each other.   Pod removal increased the 100 seed mass significantly

Table 6.4 The effect of the time and level of pod removal on the
number of pods containing seeds per dry bean plant (cv.
Teebus), Potchefstroom, 1981/82 (see Appendix 81)

| Time of pod removal (S) | Level of pod removal (L) | | Mean |
	L1 (leave 5 pods)	L2 (leave 10 pods)	
	Co 27,23		
S1 (R2)	24,80	23,23	24,02
S2 (R3-4)	21,34	18,38	19,86
S3 (R5)	13,44	12,63	13,03
S4 (R6-7)	5,87	10,08	7,97
S5 (R8)	6,04	9,83	7,93
Mean	14,30	14,83	18,79
CV	15,0%		

| | SE | LSD | |
		0,05	0,01
Co and L means	+ 0,63	NS	NS
Co vs S means	+ 1,00	2,84	3,79
S means	+ 0,84	2,38	3,17
Co vs L x S	+ 1,41	4,02	NS
L x S	+ 1,09	3,11	NS

Table 6.5 The effect of the time and level of pod removal on the pod
          mass (g plant^{-1}) of dry beans (cv. Teebus), Potchefstroom,
          1981/82 (see Appendix 82)

| Time of pod removal (S) | Level of pod removal (L) | | Mean |
	L1 (leave 5 pods)	L2 (leave 10 pods)	
	Co 33,27		
S1 (R2)	36,88	36,37	36,62
S2 (R3-4)	34,20	31,47	32,84
S3 (R5)	17,10	20,50	18,80
S4 (R6-7)	10,68	17,61	14,15
S5 (R8)	7,84	12,06	9,95
Mean	21,34	23,60	26,22
CV	14,6%		

| | SE | LSD | |
		0,05	0,01
Co and L means	$\pm$ 0,85	NS	NS
Co vs S means	$\pm$ 1,35	3,84	5,13
S means	$\pm$ 1,13	3,21	4,29
Co vs L x S	$\pm$ 1,91	NS	NS
L x S	$\pm$ 1,48	NS	NS

Table 6.6 The effect of the time and level of pod removal on the
          number of seeds per pod of dry beans (cv. Teebus), Potchef-
          stroom, 1981/82 (see Appendix 83)

| Time of pod removal (S) | Level of pod removal (L) | | Mean |
	L1 (leave 5 pods)	L2 (leave 10 pods)	
	Co 4,43		
S1 (R2)	4,36	4,51	4,44
S2 (R3-4)	4,35	5,40	4,87
S3 (R5)	3,19	4,46	3,82
S4 (R6-7)	4,50	4,68	4,59
S5 (R8)	4,30	4,12	4,21
Level means	4,14	4,63	4,40
CV	10,3%		

| | SE | LSD | |
		0,05	0,01
Co and L means	± 0,10	0,29	0,39
Co vs S means	± 0,16	0,46	0,61
S means	± 0,13	0,38	0,51
Co vs L x S	± 0,24	0,65	0,86
L x S	± 0,18	0,50	0,67

Table 6.7 The effect of the time and level of pod removal on the number of seeds per plant of dry beans (cv. Teebus), Potchefstroom, 1981/82 (see Appendix 84)

Time of pod removal (S)	Level of pod removal (L)		Mean
	L1 (leave 5 pods)	L2 (leave 10 pods)	
	Co 120,01		
S1 (R2)	107,29	108,25	107,77
S2 (R3-4)	91,96	98,37	95,16
S3 (R5)	41,73	55,05	48,39
S4 (R6-7)	26,79	47,19	36,99
S5 (R8)	25,88	40,58	33,23
Mean	58,73	68,89	82,54
CV	14,0%		

	SE	LSD 0,05	LSD 0,01
Co and L means	± 2,58	7,34	9,80
Co vs S means	± 4,08	11,60	15,49
S means	± 3,41	9,71	12,96
Co vs L x S	± 5,76	NS	NS
L x S	± 4,47	NS	NS

(P=0,01) above that of the control at all times except at S5 (late seed fill). Each later time of depodding between S1 and S3 resulted in a highly significant increase in 100 seed mass. During early seed fill (S3, S4) depodding resulted in significantly larger (P=0,01) 100 seed masses than at any other time (Table 6.8).

6.3.3.7   Seed yield

The response of seed yield (Table 6.9) to treatments was virtually the same as that of pod mass (Table 6.5) except that the seed yield in the L2 treatment was significantly higher than L1 (P=0,05). In the case of pod mass, the differences were not significant.

6.3.4   Total dry mass

Both levels of pod removal (L1 and L2) tended to increase TDM but the differences were statistically significant at the L1 level only. At each of the later times of pod removal, a lower TDM was recorded. In the S3 treatment (beginning of seed growth) both L1 and L2 gave significantly lower yields of TDM than the control. This tendency was maintained during the seed development stages (S4 and S5). The highest level of pod removal (L1) showed the fastest rate of decline in TDM and differed significantly (P=0,01) from the control at S4 while both L1 and L2 did so at S5 (Table 6.10).

6.3.5   Harvest index

Both levels of pod removal resulted in a lower HI than that of the control and the values tended to decline with each later time of treatment. At the highest depodding level (L1) this difference became significant at S2 and highly significant during the seed growth period (S3 to S5). The HI was reduced significantly (P=0,01) by all times of depodding except S2 where little reduction was observed. Depodding reduced the HI more at L1 than at L2 and the difference increased with later depodding times. At S1 this difference was not significant but became significant (P=0,05) at S2

Table 6.8 The effect of time and level of pod removal on the hundred seed mass of dry beans (cv. Teebus), Potchefstroom, 1981/82 (see Appendix 85)

Time of pod removal (S)	Level of pod removal (L)		Mean
	L1 (leave 5 pods)	L2 (leave 10 pods)	
	Co 24,23		
S1 (R2)	27,75	29,15	28,45
S2 (R3-4)	32,53	29,78	31,09
S3 (R5)	33,53	32,65	33,09
S4 (R6-7)	34,13	31,85	32,99
S5 (R8)	25,78	25,05	25,41
Mean	30,74	29,70	28,22
CV	6,2%		

	SE	LSD	
		0,05	0,01
Co and L means	± 0,28	NS	NS
Co vs S means	± 0,44	1,24	1,66
S means	± 0,28	0,78	1,06
Co vs L x S	± 0,62	NS	NS
L x S	± 0,28	NS	NS

Table 6.9 The effect of the time and level of pod removal on the seed yield (g plant^{-1}) of dry beans (cv. Teebus), Potchefstroom, 1981/82 (see Appendix 86)

Time of pod removal (S)	Level of pod removal (L)		Mean
	L1 (leave 5 pods)	L2 (leave 10 pods)	
	Co 27,10		
S1 (R2)	29,20	29,18	29,19
S2 (R3-4)	25,46	25,59	25,63
S3 (R5)	11,64	15,84	13,74
S4 (R6-7)	8,12	14,16	11,14
S5 (R8)	6,38	9,73	8,05
Mean	16,16	18,90	20,72
CV	15,4%		

	SE	LSD	
		0,05	0,01
Co and L means	+_ 0,72	2,04	2,72
Co vs S means	+_ 1,13	3,22	4,30
S means	+_ 0,95	2,69	3,60
Co vs L x S	+_ 1,60	NS	NS
L x S	+_ 1,24	NS	NS

Table 6.10 The effect of the time and level of pod removal on the total dry mass (g plant^{-1}) of dry beans (cv. Teebus), Potchefstroom, 1981/82 (see Appendix 87)

Time of pod removal (S)	Level of pod removal (L)		Mean
	L1 (leave 5 pods)	L2 (leave 10 pods)	
Co 47,04			
S1 (R2)	55,80	52,84	54,32
S2 (R3-4)	53,34	45,71	49,52
S3 (R5)	35,19	38,99	37,09
S4 (R6-7)	29,94	39,27	34,61
S5 (R8)	21,05	25,79	23,42
Mean	39,06	40,52	42,21
CV	11,8%		

	SE	LSD 0,05	0,01
Co and L means	± 1,11	3,17	4,23
Co vs S means	± 1,76	NS	NS
S means	± 1,47	4,20	5,60
Co vs L x S	± 2,49	7,09	NS
L x S	± 1,93	5,49	NS

and highly significant (P=0,01) during the seed growth period (S3 to S5) (Table 6.11).

6.3.6 Correlation matrix

There were positive correlations between NRM and 100 seed mass (P=0,01). The correlations between number of pods containing seed, seed number and seed yield were particularly strong (r=0,92). In turn those parameters all tended to have a negative correlation with 100 seed mass and NRM and a positive correlation with seeds per pod. Three of the yield components: pod number, seeds per pod and 100 seed mass did not show any relationship (Table 6.12).

6.4 Results, 1985/86

6.4.1 Days to physiological maturity

The three cultivars differed in the number of days to physiological maturity. Teebus was the earliest cultivar (87 days), followed by NEP 2 (92 days) and then Bonus (102 days). The time of pod removal had no influence on the length of the growing season (Table 6.13). This is in contrast to the 1981/82 trial when pod removal extended the growing period in treatments S1, S2 and S3.

6.4.2 Vegetative sink

6.4.2.1 Node number

Pod removal had no statistically significant influence on the number of nodes per plant in any of the cultivars. However, there was a tendency for this treatment, at all times and especially during early flowering

Table 6.11 The effect of time and level of pod removal on the harvest
index (%) of dry beans (cv. Teebus), Potchefstroom, 1981/82
(see Appendix 88)

Time of pod removal (S)	Level of pod removal (L)		Mean
	L1 (leave 5 pods)	L2 (leave 10 pods)	
	Co 57,50		
S1 (R2)	52,33	45,95	49,14
S2 (R3-4)	47,90	53,78	50,84
S3 (R5)	28,50	41,10	34,80
S4 (R6-7)	25,60	36,18	30,89
S5 (R8)	26,88	37,80	32,34
Level means	36,24	42,96	45,57
CV	13,4%		

	SE	LSD	
		0,05	0,01
Co and L means	± 1,31	3,74	4,99
Co vs S means	± 2,07	5,91	7,88
S means	± 1,74	4,94	6,60
Co vs L x S	± 2,93	8,35	11,15
L x S	± 2,27	6,47	8,64

Table 6.12 Correlation matrix (r values and tests of significance) of the components of the vegetative and reproductive sink of dry beans at harvest, 1981/82

	Seed number	Seed yield	Pod number	Seeds per pod	100 seed mass	Non-reproductive mass
Empty pods	-0,15	-0,09	0,02	-0,47	0,48	0,22
Seed number		0,95**	0,95**	0,28	-0,51	-0,27
Seed yield			0,92**	0,25	-0,32	-0,11
Pod number				-0,01	-0,45	-0,23
Seeds per pod					-0,21	-0,13
100 seed mass						0,70**

Table 6.13 Phenological data recorded in the pod removal trial,
Potchefstroom, 1985/86

Treatment[1] combination	Days after planting at	
	Time of treatment application	Physiological maturity
C1 S0 (Control)	-[2]	87
C1 S1 (R2)	53	87
C1 S2 (R3-4)	60	87
C1 S3 (R5)	70	87
C1 S4 (R6-7)	74	87
C1 -S5 (R8)	78	87
C2 S0 (Control)	-	92
C2 S1 (R2)	56	92
C2 S2 (R3-4)	60	92
C2 S3 (R5)	70	92
C2 S4 (R6-7)	74	92
C2 S5 (R8)	78	92
C3 S0 (Control)	-	102
C3 S1 (R2)	56	102
C3 S2 (R3-4)	60	102
C3 S3 (R5)	70	102
C3 S4 (R6-7)	74	102
C3 S5 (R8)	78	102

[1] Treatment code: C   cultivar

L   levels of depodding

S   time of depodding

[2] R1 (50% flowering): Teebus (C1) 49 days after planting,

NEP 2 (C2) 51 days after planting,

Bonus (C3) 51 days after planting.

(S1), to give rise to more nodes (indicating leaves) per plant than the control (S0) (Table 6.14).

NEP 2 (C2) produced the most nodes of the three cultivars. This was significantly (P=0,01) more than that of Teebus (C1). Bonus (C3) did not differ from the other two cultivars (Table 6.14).

6.4.2.2   Non-reproductive mass

The NRM of Teebus (C1) was significantly lower (P=0,05) than that of the other two cultivars which did not differ in terms of this parameter. The time of pod removal had no statistically significant influence on NRM. However, there was a tendency for NRM to increase with each successive depodding treatment except in the case of Teebus which showed an opposite trend at S5 (Table 6.15). This response is similar to that recorded in the 1981/82 trial (Table 6.2).

6.4.3   Reproductive sink

6.4.3.1   Pod number

All three cultivars produced fewer pods at each successive time of pod removal. In the case of Bonus (C3), however, the differences were not significant in comparisons with the control (S0). Teebus (C1) and NEP 2 (C2) reacted in a similar way; a fairly constant decline in the number of pods per plant at each later time of pod removal. Teebus produced fewer pods than the control in treatment S1 (P=0,05) and in the later treatments (P=0,01). The effect of pod removal was most severe during active seed growth (S3 to S5). NEP 2 had significantly (P=0,01) less pods than the control (S0) in S2 and all following treatments. The largest reductions occurred in the S4 and S5 treatments (Table 6.16).

6.4.3.2   Pod mass

The pod mass of the three cultivars reacted in a similar way to pod removal. NEP 2 had the lowest pod mass and Bonus the highest. There was a

Table 6.14 The effect of time of pod removal on the number of nodes per plant of three dry bean cultivars, Potchefstroom, 1985/86 (see Appendix 89)

Time of pod removal (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	L3 (Bonus)	
S0 (Control)	18,11	20,00	19,78	19,30
S1 (R2)	19,83	22,59	21,93	20,78
S2 (R3-4)	17,24	21,80	22,13	20,39
S3 (R5)	19,83	18,80	20,39	19,67
S4 (R6-7)	18,13	23,82	18,11	20,02
S5 (R8)	16,15	25,11	18,94	20,07
Mean	18,22	21,69	20,21	20,04
CV	17,2%			

	SE	LSD 0,05	0,01
Cultivars (C)	+ 0,81	2,34	3,15
Times (S)	+ 1,15	NS	NS
C x S	+ 1,98	NS	NS

Table 6.15 The effect of time of pod removal on the non-reproductive mass (g plant^{-1}) of three dry bean cultivars, Potchefstroom, 1985/86 (see Appendix 90)

Time of pod removal (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	L3 (Bonus)	
S0 (Control)	10,19	17,04	18,89	15,37
S1 (R2)	10,56	21,11	19,63	17,10
S2 (R3-4)	9,44	21,85	22,41	17,90
S3 (R5)	10,93	19,82	19,07	16,61
S4 (R6-7)	12,96	21,67	19,63	18,09
S5 (R8)	9,44	23,70	21,48	19,21
Mean	10,59	20,84	20,19	17,21
CV	20,4%			

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 0,83	2,40	3,23
Times (S)	± 1,17	NS	NS
C x S	± 2,03	NS	NS

Table 6.16 The effect of the time of pod removal on the number of pods
per plant of three dry bean cultivars, Potchefstroom,
1985/86 (see Appendix 91)

Time of pod Removal (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	24,50	24,13	12,83	20,49
S1 (R2)	20,37	24,19	11,39	18,32
S2 (R3-4)	17,02	19,09	10,33	15,49
S3 (R5)	12,43	19,32	10,85	14,20
S4 (R6-7)	14,02	13,82	10,91	12,91
S5 (R8)	11,02	12,93	10,67	11,54
Mean	16,56	18,74	11,16	15,49
CV	15,3%			

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 0,56	1,61	2,17
Times (S)	± 0,79	2,28	3,07
C X S	± 1,37	3,95	5,32

significant (P=0,01) difference between NEP 2 and Teebus while the latter differed significantly from Bonus (Table 6.17).

All times of pod removal resulted in a lower pod mass than that of the control but the differences were not significant when the treatment was applied during the flowering and pod set periods (S1 and S2). Pod removal during the seed fill stage (S3 to S5) resulted in a significantly (P=0,01) lower pod mass per plant than that of the control (S0). This value decreased with each later time of the treatment (Table 6.17).

6.4.3.3   Seeds per pod

Teebus (C1) produced significantly (P=0,01) more seeds per pod than Bonus (C3) and NEP 2 (C2) which did not differ from each other in this respect (Table 6.18). No statistically significant differences in the number of seeds per pod were observed as a result of pod removal. There was, however, a very marked tendency for pods in the S2 treatment to contain more seeds than the control. This was particularly noticeable in Teebus (C1) (Table 6.18).

6.4.3.4   Seed number

The number of seeds per plant of the three cultivars reacted to the time of pod removal in a similar way to number of pods.

In the control treatments Bonus (C3) gave a smaller number of seeds per plant than the other two cultivars. There was a slight but not significant, decline with each later time of pod removal. Teebus (C1) tended to have more seeds than NEP 2 (C2) but the difference was not statistically significant in any of the treatments. The seed number of both cultivars showed a successive decline at each time of defoliation. In Teebus the decline during S1 and S2 was not significant in comparisons with the control (S0). NEP 2 (C2) showed an early decline (P=0,05) in the number of seeds per plant in comparisons between the control (S0) and S1 and S2. This difference became highly significant (P=0,01) at S3 (Table 6.19).

Table 6.17 The effect of time of pod removal on the pod mass (g plant^{-1}) of three dry bean cultivars, Potchefstroom, 1985/86 (see Appendix 92)

Time of pod removal (S)	Cultivars (C) C1 (Teebus)	C2 (NEP 2)	L3 (control)	Mean
S0 (Contol)	25,56	20,93	25,00	23,83
S1 (R2)	23,70	19,07	21,11	21,30
S2 (R3-4)	22,78	19,63	22,22	21,54
S3 (R5)	15,19	17,41	20,56	17,72
S4 (R6-7)	16,48	12,22	19,63	16,11
S5 (R8)	10,93	12,04	20,56	14,51
Mean	19,11	16,88	21,51	19,17
CV	17,0%			

	SE	LSD 0,05	0,01
Cultivars (C)	± 0,77	2,22	2,99
Times (S)	± 1,09	3,14	4,23
C x S	± 1,88	NS	NS

Table 6.18 The effect of the time of pod removal on the number of seeds per pod of three dry bean cultivars, Potchefstroom, 1985/86 (see Appendix 93)

Time of pod removal (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	3,70	3,60	3,57	3,62
S1 (R2)	4,00	3,17	3,37	3,51
S2 (R3-4)	4,53	3,73	3,83	4,03
S3 (R5)	4,10	3,30	3,53	3,64
S4 (R6-7)	4,30	3,37	3,30	3,66
S5 (R8)	4,03	3,63	3,53	3,73
Mean	4,11	3,47	3,52	3,70
CV	11,5%			

	SE	LSD	
		0,05	0,01
Cultivars (C)	+ 0,10	0,29	0,39
Times (S)	+ 0,14	NS	NS
C X S	+ 0,25	NS	NS

Table 6.19 The effect of the time of pod removal on the number of seeds per plant of three dry bean cultivars, Potchefstroom, 1985/86 (see Appendix 94)

Time of pod removal (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	91,52	86,37	45,70	74,53
S1 (R2)	81,00	72,28	38,82	64,03
S2 (R3-4)	77,37	70,59	39,70	62,56
S3 (R5)	51,06	63,57	37,39	50,67
S4 (R6-7)	58,32	46,80	35,98	47,03
S5 (R8)	44,30	46,13	37,65	42,69
Mean	67,26	64,29	39,21	56,92
CV	16,7%			

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 2,24	6,45	8,69
Times (S)	± 3,16	9,13	12,29
C X S	± 5,47	15,81	21,29

6.4.3.5   Hundred seed mass

As a result of large differences in seed size, the 100 seed mass data was
not normally distributed and a ln transformation was performed on the
data.

The 100 seed mass of each of the three cultivars differed significantly
(P=0,01).   Bonus (C3) had the largest values and NEP 2 the smallest
(Table 6.20).

The 100 seed mass of the three cultivars showed a similar response to the
treatments.   In the S2 treatment (pod set) pod removal resulted in a
higher (P=0,01) 100 seed mass than the control (S0) (Table 6.20).   There
was a similar tendency in S1 and S3 but the differences were not signifi-
cant.

6.4.3.6   Seed yield

The seed yield of the three cultivars reacted in a similar way to pod
removal at different times. NEP 2 (C2) gave a significantly (P=0,01)
lower seed yield than Teebus (C1) and Bonus (C3). The latter two did not
differ significantly (Table 6.21).

The response of seed yield to pod removal was virtually identical to that
of pod mass, as may be seen in a comparison of the data in Table 6.16 (pod
mass) and Table 6.21 (seed yield).

6.4.4   Total dry mass

There were significant differences (P=0,05) in TDM between each of the
three cultivars, the relevant values being Teebus 29,7 g plant^{-1};   NEP 2
37,7 g plant^{-1} and Bonus 41,7 g plant^{-1}.

The total dry mass of the three cultivars was influenced in a similar way
by the different times of pod removal. Pod removal during the flowering
and pod set periods (S1 and S2) had no effect on the TDM compared with

Table 6.20 The effect of the time of pod removal on the hundred seed mass (g)
(ln transformation) of three dry bean cultivars, Potchefstroom,
1985/86 (see Appendix 95)

Time of pod removal (S)	Cultivars (C)			Mean	
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)		
S0 (Control)	3,09* (21,97)	2,80* (16,40)	3,69* (39,97)	3,19* (26,11)	
S1 (R2)	3,13 (22,93)	2,88 (17,90)	3,66 (38,93)	3,23 (26,59)	
S2 (R3-4)	3,14 (23,13)	2,99 (20,00)	3,73 (41,77)	3,29 (28,30)	
S3 (R5)	3,14 (23,07)	2,93 (18,70)	3,69 (39,97)	3,25 (27,24)	
S4 (R6-7)	3,06 (21,33)	2,86 (17,53)	3,71 (40,73)	3,21 (26,53)	
S5 (R8)	3,06 (21,30)	2,88 (17,77)	3,70 (40,53)	3,21 (26,53)	
Mean	3,10 (22,29)	2,89 (18,05)	3,70 (40,32)	3,23 (26,89)	
CV	1,7%				

	SE*	LSD*	
		0,05	0,01
Cultivars (C)	± 0,01	0,04	0,05
Times (S)	± 0,02	0,05	0,07
C X S	± 0,03	NS	NS

* Transformated data of 100 seed mass (g 100^{-1} seeds)

Table 6.21 The effect of the time of pod removal on the seed yield (g plant^{-1}) of three dry bean cultivars, Potchefstroom, 1985/86 (see Appendix 96)

Time of pod removal (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	20,09	14,22	18,26	17,53
S1 (R2)	18,50	12,96	15,26	15,57
S2 (R3-4)	17,83	14,15	16,57	16,19
S3 (R5)	11,67	11,83	14,94	12,82
S4 (R6-7)	12,41	8,17	14,69	11,75
S5 (R8)	9,46	8,20	15,24	10,97
Mean	14,99	11,59	15,83	14,14
CV	18,3%			

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 0,61	1,76	2,37
Times (S)	± 0,86	2,48	3,35
C X S	± 1,49	NS	NS

that of the control (S1) but the same comparison during the seed fill stage (S3 to S5) indicated significantly lower TDM values in the treated plants (Table 6.22).

6.4.5   Harvest index

The HI of the three cultivars differed significantly (P=0,01) from each other. Teebus (C1) had the highest HI and NEP 2 (C2) the lowest (Table 6.23).

Pod removal resulted in a reduction in the HI values compared to those of the control (S0). This difference was not significant during the flowering and pod set period (S1 and S2). It was, however, highly significant (P=0,01) during the seed fill stages (S3 to S5) (Table 6.23).

6.4.6   Correlation matrix

The number of seeds per pod correlated positively (P=0,01) with NRM. Seed yield and seeds per plant were positively (P=0,05) correlated. Pod and seed number showed a negative (P=0,01) correlation with 100 seed mass. There was no relationship between the yield components: pod number, seeds per pod and 100 seed mass except for a negative (P=0,01) correlation between pod number and 100 seed mass (Table 6.24).

6.5   Discussion

The results in 1981/82 indicated that each increase in intensity of depodding during the pod set period (R2 to R4) tended to give an increase in TDM (Figure 6.1a). This was accompanied by an extension of the growing period, the effect being more pronounced at the most severe depodding level. A similar response has been reported in beans (Wien, Sandstead & Wallace, 1973; Olufajo et al., 1981) and soybeans (Hicks & Pendleton, 1969). Thus the higher yields of TDM in the treatments depodded during the pod set period are most likely related to an extended growing period.

Table 6.22 The effect of time of pod removal on the total dry mass (g plant^{-1}) of three dry bean cultivars, Potchefstroom, 1985/86 (see Appendix 97)

Time of pod removal (S)	Level of pod removal (L)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	35,74	37,96	43,89	39,20
S1 (R2)	34,26	40,19	40,74	38,40
S2 (R3-4)	32,22	41,48	44,63	39,44
S3 (R5)	26,11	37,22	39,63	34,32
S4 (R6-7)	29,44	33,89	39,26	34,20
S5 (R8)	20,37	35,74	42,04	32,72
Mean	29,69	37,75	41,70	32,72

CV   15,0%

	SE	LSD	
		0,05	0,01
Cultivars (C)	± 1,16	3,34	4,51
Times (S)	± 1,64	4,73	6,37
C x S	± 2,84	NS	NS

Table 6.23 The effect of the time of pod removal on the harvest index
(%) of three dry bean cultivars, Potchefstroom, 1985/86
(see Appendix 98)

Time of pod removal (S)	Cultivars (C)			Mean
	C1 (Teebus)	C2 (NEP 2)	C3 (Bonus)	
S0 (Control)	56,00	37,33	41,67	45,00
S1 (R2)	54,00	33,00	36,33	41,11
S2 (R3-4)	55,33	34,33	37,67	42,44
S3 (R5)	45,00	32,00	38,00	38,33
S4 (R6-7)	41,67	24,00	37,33	34,33
S5 (R8)	46,67	23,00	36,33	35,33
Mean	49,78	30,61	37,89	39,42
CV	11,9%			

	SE	LSD 0,05	0,01
Cultivars (C)	± 1,10	3,19	4,30
Times (S)	± 1,56	4,51	6,07
C X S	± 2,71	NS	NS

Table 6.24 Correlation matrix (r values and tests of significance) of the
components of the vegetative and reproductive sink at harvest,
1985/86

	Pod number	Seed number	Seed yield	Seeds per pod	100 seed mass	Non-reproductive mass
Node number	-0,09	-0,15	-0,18	-0,14	-0,03	0,30
Pod number		0,90**	0,36	-0,10	-0,59**	-0,14
Seed number			0,49*	0,32	-0,59**	-0,35
Seed yield				0,27	0,38	-0,19
Seeds per pod					-0,15	-0,53**
100 seed mass						0,24
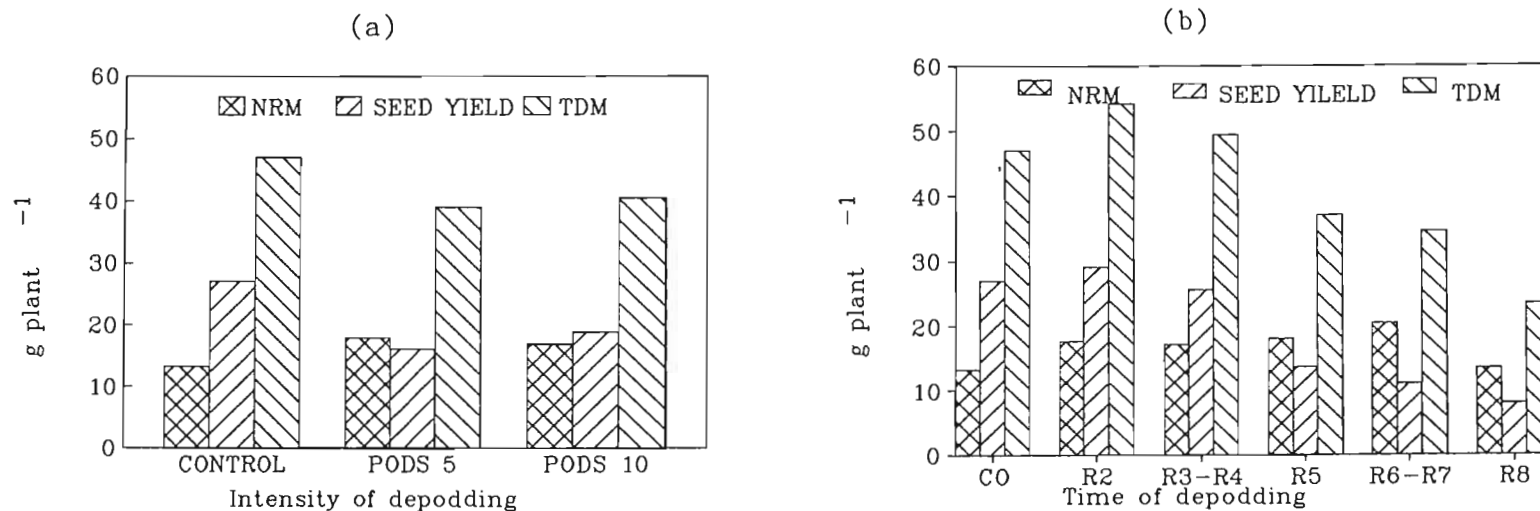
Figure 6.1 The effect of (a) intensities and (b) times of depodding on the NRM, seed yield and TDM of dry beans, Potchefstroom, 1979/80 (tests of significance are presented in Tables 6.2, 6.9 and 6.10)
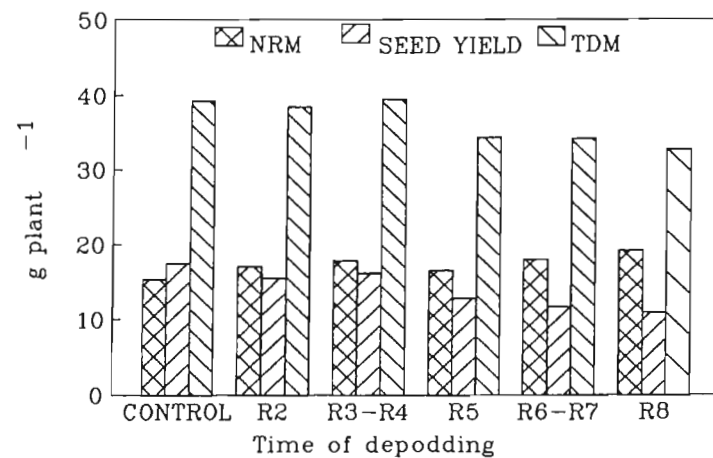
Figure 6.2 The effect of time of depodding on the NRM, seed yield and TDM of dry beans, Potchefstroom, 1985/86 (tests of significance are presented in Tables 6.15, 6.21 and 6.22)

Depodding after the onset of seed growth (R5) in 1981/82 produced an oppo-
site response to that observed prior to R5. There was a negative rela-
tionship between TDM and intensity of depodding and the treatments had no
effect on the length of the growing period. Plaut & Mayoral (1984) repor-
ted that depodding during the later development stages reduced leaf photo-
synthesis and this is probably the reason for the negative relationship
observed in the present study.

In 1985/86 unlike 1981/82, depodding prior to R5 had no effect on TDM
production and the length of the growing period. Thus TDM production is
increased only when the growing season is extended.

Immediately after the partial removal of reproductive storage organs the
plant has a surplus source of potential photosynthate as the leaf area
remains constant. This photosynthate can be partitioned to different sink
organs: vegetative (leaves and stems) or reproductive (new or existing
flowers and pods). If neither is possible or very limited, a decline in
the dry matter production can be expected. Several authors have reported
a reduced photosynthetic rate under conditions of prolonged depodding.
Normally this is accompanied by an increase in the non-structural reserves
(mainly starch) in the leaves and petioles of beans (Ciha & Brun, 1978;
Plaut & Mayoral, 1984) and soybeans (Wittenbach, 1982; Wittenbach, 1983).
In this study the response pattern differed in the two seasons. In
1981/82 vegetative growth took place as a result of depodding. The NRM
increased with depodding until the R7 development stage (Figure 6.1b) and
thus leaf and stem mass continued to increase despite a decrease in seed
yield as a result of depodding at R5 and later. In 1985/86 there was no
response in vegetative growth in any cultivar and NRM (Figure 6.2) and
node number remained unchanged in all the depodding treatments. The
reason for the difference between the two seasons may be related to clima-
tic factors but the precise cause is not known.

During both seasons a similar pattern of partitioning was observed. The
HI decreased very slightly as a result of depodding during the R2 to R4
development stages. This indicates that the balance between source and
sink organs was not seriously disturbed by this treatment and the plants

were still able to set pods from later formed flowers. This corresponds with the results of Binnie & Clifford (1981) and Santos (1984). The pattern of partitioning changed when depodding was applied during the seed fill period. Seed yield declined significantly between the R4 and R5 stages as well as between R5 and R8 while the NRM increased (1981/82) (Figure 6.1b) or remained constant (1985/86) (Figure 6.2). This resulted in a highly significant drop in the HI during these periods. Clearly the potential sink size was determined prior to the R5 stage (R1 to R4). In the case of Teebus the pod set period (R1 to R4) continued about seven to 10 days after the onset of flowering in 1980/81 and 11 to 15 days in 1985/86. In NEP 2 and Bonus in 1985/86 the corresponding time span was nine to 13 days. These results are in agreement with those of Olufajo et al. (1981) except that they found no yield reduction until about 24 days after the onset of flowering. In their experiments the oldest immature edible pods were picked while in this study the oldest pods were left on the plants. This may account for the divergence in results. The pods left on the plants in the studies of Olufajo et al. (1981) were in the R4 or earlier development stages which corresponds in this study to depodding treatments before onset of seed growth.

It follows therefore that the factor which determines whether additional pods will set or not, is related to fast growing seeds. In their assessment of this process, Subhadrabandhu et al. (1978) and Binnie & Clifford (1981) were not able to answer the question of which mechanism is responsible for growing seeds receiving preference in the translocation of available photosynthate. They postulated that it is implemented by means of a hormone which inhibits pod set (associated with the number of pods or seed size) or competition for the available photosynthate. Evidence of flower shedding induced by substances produced by fertilized soybean ovaries was found by Huff & Dybing (1980). From the present trials it is, however, clear that the inhibition of pod set was not directly associated with the number of pods per plant. It was more dependent on the development stage of the plant since after the onset of seed growth (R5 stage), no further pod set occurred in the case of Teebus and Bonus, while NEP 2 continued to set pods at R5, at a depodding level of 10 pods per plant. In the case of more severe depodding (five pods left per plant) Teebus

also set pods during the R5 development stage in 1981/82. After the R6 development stage no further pod set was recorded even if only five pods were left per plant. The significant increase in the number of empty pods at the higher level of depodding at R5 and R6 in 1981/82 could indicate that these treatments stimulated later formed flowers to set pods but that they failed to form seeds due to growth substances preventing seed enlargement or a lack of photosynthate. It is unlikely that a limited source could prevent the seed from developing as the depodding treatments would have caused an excess source.

From the above discussion it may be concluded that the bean plant is very tolerant to depodding when it occurs before the onset of seed enlargement, or in some cases, at the onset of seed enlargement. When there is a severe restriction in reproductive structures, the plant will extend it's flowering and growing period as shown in 1981/82. After the R5 stage the yield loss is to a large extent permanent and in proportion to sink size at the onset of this period. It seems therefore that the potential sink size is fixed at the R5 development stage irrespective of the size of source.

Data relating seed yield to it's components may provide information regarding the way in which bean plants react to an excess source during different development stages. The number of pods per plant is the first formed yield component (Adams, 1967) and has the predominant influence on the yield of beans (Chung & Goulden, 1971; Duarte & Adams, 1972; Westermann & Crothers, 1977). In this study pod number was not directly related to seed yield. These two parameters differed in their reaction to depodding during the R2 to R4 development stages. Where 10 pods per plant were left on the plant, depodding resulted in a reduction in the number of pods per plant in Teebus (both seasons) and NEP 2 (1985/86) but had no effect in Bonus. Seed yield, however, did not show these differences: the seed yield of all the cultivars was not affected by depodding before the R5 development stage. Thus the other two yield components (seeds per pod and seed size) compensated for the loss in pod number in Bonus. In the case of Bonus in 1985/86 pod number in the depodded treatments was very near to the potential (12,83 pods plant^{-1}) attained in the control. Clearly in

this treatment the sink deficiency was very small and there was no signi-
ficant reduction in the number of pods per plant.

The number of seeds per pod, which is the second yield component to be
determined (Adams, 1967), tended to increase with pod removal in the R3 to
R4 development stages. In 1985/86 this increase was not statistically
significant in any of the cultivars but in 1981/82 the same treatment
resulted in a significant increase in the number of seeds per pod in
Teebus. This compensated to some extent for the loss in number of seeds
per plant (the product of pods per plant and seeds per pod). Since seed
size is the last yield component to be formed (Adams, 1967), it would be
expected to react to any excess photosynthate during the reproductive
period. During both seasons depodding gave an increase in seed size. In
1981/82 this effect occurred at all reproductive stages except R8. In
1985/86 the response was significant (all cultivars) at the R3 to R4
stages only. Thus seed size reacts to excess source early in the repro-
ductive period (R2 to R4 (both seasons)) as well as later (R5 to R8
(1985/86)). It can be concluded that the increase in the number of seeds
per pod was not sufficient to compensate for the reduced sink size due to
depodding. The increase in seed size was related to the initiation of
balancing mechanisms between source and sink sizes. These results agree
with those of Olufajo et al. (1982) who found that an increase in seed
size, rather than an increase in the number of seeds per pod, was the most
common way of yield component compensation following depodding.

When the correlations between seed yield and yield components in the two
seasons are assessed in conjunction (Tables 6.12 and 6.24), several con-
sistent relationships are apparent. The number of seeds per pod had no
relationship with seed yield or any of its components. The number of pods
per plant showed a consistent negative relationship with seed size. This
means that depodding did not change the number of seeds per pod but
increased seed size, which is in accordance with the findings of Olufajo
et al. (1981). The number of seeds per plant had a similar relationship
with seed size. The positive relationship between seed yield and the
number of pods agrees with the findings of Chung & Goulden, 1971; Duarte &

Adams, 1972; Westermann & Crothers, 1977. The relationship between seed yield and seed size was inconsistent: in 1981/82 it was negative and in 1985/86 positive. This indicates that there may be a seasonal variation in the relationship between seed size and seed yield.

From the above discussion it may be concluded that before the onset of rapid seed growth, the plants were able to bring their sink in balance with the excess source which occurred as a result of depodding. This was accomplished by (i) replacement of lost reproductive structures by pods set from later formed flowers and (ii) yield component compensation. The capacity of the plant to set more seeds per pod seemed to be limited, whereas in the case of seed size, this limitation was not so apparent. After the onset of the rapid seed development stage, the plant's capacity to replace lost reproductive organs (pods) was absent and this loss was no longer compensated for by the production of more seeds per pod.

The results also indicate that seed size in both seasons was determined before the onset of rapid seed growth, as shown by an increase in seed size due to depodding during this period. Egli, Fraser, Leggett & Poneleit (1981) found that differences in seed size between soybean cultivars is determined by the number of cells in the cotyledons. It is not clear in the present study whether changes in seed size as a result of a limited sink, are related to the same factor. Depodding during the cell division period (i.e. before the rapid seed growth period associated with cell expansion) produced larger seeds and this may indicate a connection between cell division and seed size. The fact that depodding at the R5 or later development stages resulted in larger seed in 1981/82 suggests that an excess source could permit the formation of larger cells in the seeds.

Cultivar differences in yield component compensation were associated with the size of the differences between the number of pods in the control and in the depodded plants. In the case of Bonus where this relationship was not pronounced, little imbalance in source-sink relationships was experienced, resulting in a minor effect on the number of pods per plant.

Total dry matter production declined when depodding took place during the rapid seed development stage, while leaf area remained constant. This provides evidence that photosynthesis was suppressed by this treatment.

6.6   Conclusions

The result of the depodding trials support the following aspects of the working hypothesis.

(i)   Depodding prior to the onset of seed growth tended to increase the TDM in proportion to the intensity of the treatment when this was accompanied by an increase in the length of the growing season (1981/82). The opposite reaction was observed for seed yield and the dominant yield component: pods per plant. Thus depodding had an influence in both the vegetative and the reproductive periods, the effect being proportional to the intensity of the treatment in both seasons.

(ii)   Depodding varied in its effect according to the reproductive stage at which it was applied. It had little effect on the TDM or seed yield in the pod set period (R2 to R4). During the rapid seed development stage there was a marked reduction in reproductive sink size and this effect increased with each later stage of depodding. This is reflected in reduced seed yield, pod mass and HI. Thus the reproductive period before the onset of rapid seed growth, is of critical importance in balancing the sink and the source.

(iii)   There was no direct relationship between the length of the period of restricted sink size and vegetative or reproductive yield. The main factors affecting yield was whether the treatment was induced before (little influence) or during (large yield reduction) rapid seed growth.

(iv)   Evidence of yield component compensation was found when depodding was induced during pod set (R2 to R4). Larger seeds were formed when the number of seeds per plant was reduced, mainly as a result

of a reduced number of pods per plant. During all reproductive
stages, the capacity of plants to produce more seeds per pod to
compensate for a reduced number of pods, was very limited. Seed
size was the only yield component which reacted to depodding during
rapid seed growth.

(v)   By means of yield component compensation, a balance between source
        and sink sizes developed in plants treated before the onset of
        rapid seed growth but not afterwards, mainly because no new pods
        were set.

(vi)   No convincing evidence of mobilization of stored non-structural
        reserves was found. The tendency for NRM to increase in the
        absence of a longer growing period may indicate a limited amount of
        stored reserves. On the other hand, reduced TDM production as a
        result of depodding during rapid seed growth, does suggest a re-
        duced photosynthetic rate since LA was not affected by depodding.

(vii)   Cultivars did differ in their reaction to depodding. The differen-
        ces which occurred were related to the intensity of the stress,
        induced by the treatment, in a particular cultivar. This was rela-
        ted to the potential number of pods per cultivar which implies that
        a particular intensity of depodding resulted in different levels of
        stress in different cultivars.

CHAPTER 7

REVIEW OF RESULTS AND FINAL CONCLUSIONS

The effect of induced source and sink related stresses on dry matter pro-
duction depended on the type and intensity of the stress as well as the
development stage(s) of the plant at the time of treatment. Ultimately it
was the partitioning of dry matter during each development stage which
determined economic yield and the relative size of yield components.

A summary of the effects of the treatments on vegetative and reproductive
mass at maturity is given in Table 7.1. The major trends in response
patterns to treatments applied at various development stages, are outlined
below.

Vegetative phase When a source related stress was of such a nature that
the plant could recover during later development, no permanent detrimental
effect on vegetative or reproductive organs was recorded. The defoliation
and shading treatments showed this reaction when applied during the vege-
tative phase (V1-V6f). The thinning studies showed that when the source
was increased during this period by reducing interplant competition early
(before V4), plants did not show any effect of interplant competition.

Flower initiation Flower initiation was identified as the most sensitive
period to induced source related stresses. Treatments applied at this
time were associated with reduced vegetative development. The effect of
defoliation was in proportion to the intensity of the treatment. On the
other hand, the reduction in LA and vegetative mass was not directly pro-
portional to intensity of shading. This treatment extended the growing
period. The cultivars Teebus and Bonus differed in sensitivity to shading
but both maintained a sufficiently high NAR to prevent loss of economic
yield. This suggests that when ambient light intensity was reinstated,
the supply of photosynthate to reproductive organs was at the same level
as in the unshaded treatments. Unlike shading, defoliation which reduced

Table 7.1 Summary of effects of manipulation of source-sink system at various development stages on mature vegetative and reproductive mass of dry beans, Potchefstroom, (1979/80, 1980/81, 1981/82 and 1985/86)

Parameter	Source stress			Sink stress
	Increased		Reduced [1]	Increased
	Defoliation	Shading	Thinning	Depodding
Vegetative phase (V1-V5)				
Vegetative mass	unaffected	unaffected	unaffected	-
Reproductive mass	unaffected	unaffected	unaffected	-
Flower initiation (Vnf)				
Vegetative mass	reduced	reduced	increased	-
Reproductive mass	reduced	unaffected	increased	-
Flowering and pod set (R1-R4)				
Vegetative mass	unaffected	unaffected	unaffected	variable
Reproductive mass	reduced	reduced	increased	unaffected
Seed fill (R5-R9)				
Vegetative mass	unaffected	unaffected	unaffected	unaffected
Reproductive mass	reduced	reduced	unaffected	reduced
Economic yield components				
Pods per plant	reduced	reduced	increased	reduced
Seeds per pod	increased	reduced	increased	increased
Seed size	unaffected	variable	unaffected	increased
Cultivar interaction				
Teebus	sensitive	sensitive	sensitive	sensitive
NEP 2	insensitive	- [2]	sensitive	sensitive
Bonus	sensitive after R5	sensitive after R5	sensitive	sensitive

1) Data relating to reflected light are not included since there were practical limitations in the application of this treatment (par. 5.6).

2) NEP 2 was not included in the light manipulation trials.

LA permanently, resulted in a reduction in economic yield. Enlargement of the source by reducing interplant competition gave an increase in vegetative mass, and more branches and leaves were formed which represented a larger potential source. This in turn gave rise to a larger reproductive sink.

Flowering A source stress during the flowering period (R1-R4) reduced TDM production by restricting the partitioning of photosynthate to the reproductive organs. Thus lower seed yields and HI values were recorded. The effect of a loss of LA and shading at this stage was as detrimental to economic yield as during the flower initiation period. The partitioning pattern, however, differed. This was indicated by the HI values which increased with stress before flowering (Vnf) and decreased with stress during flowering.

Cultivar differences in response to reduced source were observed. NEP 2 did not respond to defoliation and Bonus was less responsive to shading than Teebus. Reduced interplant competition favoured the partitioning of photosynthate to the reproductive organs, increasing the HI values. The direct relationship between reduced or increased source and economic yield indicates that source size during flowering is a dominant factor affecting economic yield. This relationship is confirmed by the absence of a yield response to partial depodding during flowering. The lack of a yield response of certain cultivars (Bonus and NEP 2) to a source limitation may indicate that sink size in these cultivars was smaller than the potential set by the source.

Seed filling During the seed filling period (R5-R8), the source related stresses had no effect on vegetative mass but they did have an adverse effect on the partitioning of photosynthate to the reproductive organs in certain cultivars. Bonus was more sensitive to defoliation than Teebus while NEP 2 was insensitive. Bonus was less sensitive to shading than Teebus. Thus in certain cultivars the level of current photosynthesis has a significant effect on seed yield throughout seed filling. As stated

previously the lack of a yield response in certain cultivars may indicate a sink limitation. This could be related to differences between the cultivars in adaptation to climatic conditions particularly temperature: for example, reduced pod set at high temperatures has been recorded in Bonus and NEP 2 in the National Dry Bean Cultivar Trials (Liebenberg & Joubert, 1983, Liebenberg & Joubert, 1987). The lack of a yield response in all cultivars to thinning at R5 and later, indicates that the potential sink size was set before R5. This is confirmed by the inability of all the cultivars to set new pods when depodded during this period.

The results of the present study support the concepts of yield component compensation put forward by Adams (1967). Pod number was the yield component most seriously affected by source reducing treatments (defoliation or shading) applied between development stages V6f and R4. The potential sink was determined mainly through the number of pods per plant. The size of this sink was in balance with the source unless some stress factor was present which had an influence on the number of pods. When source size was increased by reducing interplant competition (thinning), all cultivars produced more pods. The number of seeds per pod did not always react in the same way to an increased or reduced source. When there was a permanent reduction in source size (defoliation), seeds per pod increased, an opposite response to that recorded for pod number. This indicates that the sink size, determined by pods set earlier, was insufficient. Shading during the seed growth period resulted in a reduced number of seeds per pod though pod number was not influenced by shading at this time. An increased source induced by thinning or a reduced sink (depodding) increased the number of seeds per pod. The number of seeds per plant, the product of pods per plant and seeds per pod, appears to function as a unit and represents the main yield component providing a balance between source and sink.

Seed size was the least responsive yield component. It was not affected by defoliation or thinning and had a variable response to shading. However, in the case of a serious sink limitation (depodding) seed size

increased during all reproductive stages. In all the data there was a
negative relationship between seed size and pods per plant.

With regard to the practical implications of the results of this study,
stress associated with shading by weeds, partial defoliation by insects or
hail, is not likely to cause a reduction in vegetative or reproductive
mass at maturity, provided it occurs before flower initiation. From this
stage onwards these stress factors and those related to foliar diseases,
will be detrimental to yield. In the case of shading, the effect was less
severe when this treatment was discontinued during flowering and suggests
that weeding at this time will be beneficial.

Under field conditions lodging and branching in certain cultivars reduce
light transmission into the lower canopy. The beneficial effects of
improved light penetration obtained in this study indicated that breeding
programmes should be orientated towards developing genotypes with short
lateral branches and good standability. The results showed distinct
evidence of genotypic sink limitations which emphasizes the need to iden-
tify the factors associated with this effect and to select for example,
for heat and drought tolerance in the progeny of crosses.

Since the presence of growing seeds tends to reduce pod set, extending the
length of flowering period may permit the establishment of a larger sink
or at least one that is in balance with the full potential of the source.

Better resistance to leaf diseases which normally affect the plant during
the flowering period, would help to preserve the largest possible source.
Normally selection for adaptation is done at harvest, when symptoms of
leaf diseases have disappeared and often it is not possible to identify
resistant material. The results of this study indicate that disease in-
fected plants can be removed from a segregating population at any time
after the R3 stage without seriously affecting the yield of the remaining
plants. Selection for yield potential and adaptation may then take place
in the remaining plants at maturity.

SUMMARY

Following a review of the relevant literature, a hypothesis regarding source-sink relationships in dry beans (*Phaseolus vulgaris* L.) was developed, as follows: (i) the effect of stress on the sink is in proportion to its intensity, (ii) organs having preference to partitioned photosynthate at a particular development stage will be more harmed by applied stress or benefit from its relief, (iii) non-structural reserves can be mobilized when source becomes the limiting factor, (iv) source and sink sizes will tend to balance by means of yield component compensation during the reproductive stage, and (v) there is a similarity between the effects of different types of stress via its effect on photosynthesis.

This hypothesis was tested in a series of field experiments at Potchefstroom Research Station. The treatments consisted of intensities and times of application of source or sink related stresses, namely defoliation, thinning, light intensity (shades and reflectors) and removal of reproductive organs. In the initial experiments a single cultivar (Teebus (determinate bush)) and a wide range of intensities of stress were incorporated. In subsequent experiments, two additional cultivars: NEP 2 (indeterminate bush) and Bonus (indeterminate short runner), were included and intensities of stress were reduced to two levels.

Plant development in all experiments was divided into four main periods: vegetative (V1-V6f), flower initiation (V6f-R1), flowering (R1-R5) and seed filling (R5-R9). Times of treatment application and measurement of response patterns in terms of growth analysis, were related to these periods.

No permanent detrimental effect on vegetative or reproductive organs was observed when source related stress (defoliation and shading) was applied during the vegetative period, since the plants were able to recover during later development. Plants did not respond to an increased source as a result of less interplant competition, when thinning took place before V4.

Flower initiation was identified as the period most sensitive to defoliation, a permanent source related stress. The reduced vegetative growth and loss of economic yield was in proportion to the intensity of the treatment. On the other hand, the reduction in leaf area and vegetative mass was not directly proportional to the intensity of a non-permanent stress (shading) during flower initiation. This treatment extended the growing period. When ambient light intensity was reinstated, a sufficiently high net assimilation rate prevented a loss of economic yield. Increasing the source by thinning during flower initiation, improved the vegetative mass and leaf area. This in turn gave rise to a larger reproductive sink.

A source stress during the flowering period reduced total dry matter production by restricting partitioning to the reproductive organs. Lower seed yields and harvest index values were recorded due to a loss of leaf area or reduced photosynthesis through shading. The partitioning pattern differed from that during the vegetative stages in that harvest index values increased with stress before flowering and decreased with stress during and after flowering. Reduced interplant competition during flowering favoured partitioning to the reproductive organs thus raising the harvest index values. The direct relationship between reduced or increased source and economic yield during this period indicates that the size of the source is the dominant factor determining economic yield. This result is confirmed by the absence of a yield response to partial depodding during flowering. The lack of a negative yield response to 66% defoliation in NEP 2 and 70% shading in Bonus, may indicate that sink size in these two cultivars, was smaller than the potential set by the source.

During the seed filling period the source related stresses had no effect on vegetative mass, but they did have an adverse effect on the partitioning of photosynthate to the reproductive organs in certain cultivars. Bonus was more sensitive to defoliation than Teebus while NEP 2 was insensitive. Bonus was less sensitive to shading than Teebus. Thus in certain cultivars the level of current photosynthesis has a significant effect on

seed yield throughout seed filling. The lack of a yield response in all cultivars to thinning during seed filling indicates that the potential sink size was set before R5 and thereafter economic yield was limited by sink size. This is confirmed by the inability of all cultivars to set new pods when depodded during seed fill.

The results in all trials indicated that the potential economic sink was set during the flowering period. The size of this sink depended on the size of the available source during that period which in turn was determined by the absence or presence of source related stresses during the flower initiation period.

The results provided strong evidence supporting the concepts of yield component compensation in dry beans. Pod number was the yield component most seriously affected by source reducing treatments (defoliation or shading) during flower initiation and flowering. The potential sink was determined mainly through the number of pods per plant. The size of this sink was in balance with the source unless some stress factor was present which had an influence on the number of pods. When source size was increased by reducing interplant competition (thinning), all cultivars produced more pods. The number of seeds per pod did not always react in the same way to an increased or reduced source. When there was a permanent reduction in source size (defoliation), seeds per pod increased, an opposite response to that recorded for pod number. This indicates that the sink size, determined by pods set earlier, was insufficient. Shading during the seed filling period resulted in a reduced number of seeds per pod though pod number was not influenced by shading at this time. An increased source induced by thinning or a reduced sink (depodding), increased the number of seeds per pod. The number of seeds per plant, the product of pods per plant and seeds per pod, appeared to function as a unit and represented the main yield component providing a balance between source and sink. Seed size was the least responsive yield component. It was not affected by defoliation or thinning and had a variable response to shading. However, in the case of a serious sink limitation (depodding),

seed size increased during all reproductive stages. In all the data there
was a negative relationship between seed size and pods per plant.

There was no indication in the data that source limiting factors initiated
mobilization of stored carbohydrate reserves in the above ground vegeta-
tive organs. All cultivars appeared to rely on current photosynthesis to
fill their sinks.

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Appendix 1 Selected climatic data recorded and irrigation applied in
the field experiments, Potchefstroom Research Station

1.1 1979/80

	1979		1980		
	November	December	January	February	March
Mean maximum temp. (°C)	26,8	28,7	28,7	27,2	27,8
Mean minimum temp. (°C)	14,0	15,3	15,4	15,7	13,8
Total rainfall (mm)	81,8	62,0	125,8	112,4	17,9
Total irrigation (mm)	0,0	34,0	30,0	25,0	0,0
Mean PET (mm)	6,3	7,7	8,1	6,2	6,1
Mean minimum RH (%)	36,6	36,0	35,5	42,3	33,9
Mean sunshine (hours)	9,0	9,7	9,2	8,1	8,4

1.2 1980/81

	1980		1981		
	November	December	January	February	March
Mean maximum temp. (°C)	27,2	28,5	28,7	26,6	24,6
Mean minimum temp. (°C)	13,4	14,9	16,5	15,5	12,3
Total rainfall (mm)	149,7	91,1	166,2	144,1	75,6
Total irrigation (mm)	40,0	0,0	30,0	0,0	0,0
Mean PET (mm)	8,0	7,0	6,3	5,9	4,2
Mean minimum RH (%)	35,0	37,0	41,0	42,7	42,3
Mean sunshine (hours)	8,3	10,0	8,1	8,0	7,4

1.3 1981/82

	1981		1982		
	November	December	January	February	March
Mean maximum temp. (°C)	29,8	29,0	30,0	29,8	27,7
Mean minimum temp. (°C)	14,7	15,3	16,1	15,9	13,0
Total rainfall (mm)	69,7	76,8	73,3	55,5	41,6
Total irrigation (mm)	0,o	0,0	0,0	0,0	0,0
Mean PET (mm)	7,3	6,9	7,1	6,8	5,4
Mean minimum RH (%)	28,5	32,3	32,9	32,2	30,1
Mean sunshine (hours)	8,9	8,7	9,0	8,9	8,9

1.4 1985/86

	1985		1986		
	November	December	January	February	March
Mean maximum temp. (°C)	27,3	29,7	28,4	27,3	25,4
Mean minimum temp. (°C)	14,7	16,2	14,3	13,6	10,9
Total rainfall (mm)	103,3	112,1	45,3	80,6	28,6
Total irrigation (mm)	0,0	40,0	30,0	0,0	0,0
Mean PET (mm)	8,6	7,7	7,1	6,4	5,2
Mean minimum RH (%)	34,9	32,5	32,4	33,1	32,4
Mean sunshine (hours)	8,9	9,0	8,9	8,2	7,5

Appendix 2   Soil fertility data and applied fertilizer for the expe-
              rimental sites, (1979/80, 1980/81,1981/82 and 1985/86)

Growing season	Soil analysis			Fertilizer applied (kg ha^{-1})		
	pH (H$_2$O)	P ppm (Bray 2)	K ppm	N	P	K
1979/80	6,5	25	125	42	25	0
1980/81	7,1	8	59	67	54	25
1981/82	6,6	25	94	60	30	0
1985/86	6,7	33	148	50	45	0

Appendix 3   Analysis of variance: effect of levels and times of defo-
              liation on the leaf area (m^2 x 10^{-4} plant^{-1}) of dry beans
              at the R1, R5 stages, 1979/80

Source of variation	DF	MS	F	MS	F
		R1		R5	
Replication	3	3067862		631272	
Control	1	6182145	**	3097071	**
Levels of defoliation	1	7915552	**	3130787	**
Times of defoliation	6	3048055	**	1319990	**
Levels x times	6	216051	NS	271654	*
Error	46	126313		103591	
Total	63				

Appendix 4   Analysis of variance: effect of levels and times of defo-
              liation on the leaf dry mass (g plant^{-1}) of dry beans   at
              the R1, R5 stages, 1979/80

Source of variation	DF	MS	F	MS	F
		R1		R5	
Replication	3	19,032		5,391	
Control	1	77,722	**	43,314	**
Levels of defoliation	1	74,060	**	56,200	**
Times of defoliation	6	36,985	**	13,410	**
Levels x times	6	2,163	NS	2,416	NS
Error	46	1,329		2,046	
Total	63				

Appendix 5   Analysis of variance: effect of levels and times of defo-
              liation on the number of leaves per plant of dry beans at
              the R5 stage, 1979/80

Source of variation	DF	MS	F
Replication	3	103,63	
Control	1	57,14	NS
Levels of defoliation	1	171,50	**
Times of defoliation	6	68,14	**
Levels x times	6	26,67	NS
Error	46	20,12	
Total	63		

Appendix 6   Analysis of variance: effect of levels and times of defo-
              liation on the number of nodes per plant of dry beans at
              the R5 stage, 1979/80

Source of variation	DF	MS	F
Replication	3	158,46	
Control	1	57,14	NS
Levels of defoliation	1	147,88	*
Times of defoliation	6	60,39	*
Levels x times	6	27,25	NS
Error	46	22,15	
Total	63		

Appendix 7   Analysis of variance: effect of levels and times of defo-
              liation on the stem mass (g plant^{-1}) of dry beans at the
              R1, R5 and R9 stages, 1979/80

Source of variation	DF	MS	F	MS	F	MS	F
		R1		R5		R9	
Replication	3	43,436		22,369		4,127	
Control	1	27,107	**	17,522	*	26,911	**
Levels of defoliation	1	34,102	**	17,944	*	32,163	**
Times of defoliation	6	9,938	**	9,981		6,338	
Levels x times	6	2,876	NS	3,667	NS	4,796	NS
Error	46	1,903		3,517		2,971	
Total	63						

Appendix 8   Analysis of variance: effect of levels and times of defo-
              liation on the number of racemes per plant of dry beans
              at the R5 stage, 1979/80

Source of variation	DF	MS	F
Replication	3	77,35	
Control	1	25,08	NS
Levels of defoliation	1	1,45	NS
Times of defoliation	6	41,23	NS
Levels x times	6	22,15	NS
Error	46	31,39	
Total	63		

Appendix 9   Analysis of variance: effect of levels and times of defo-
              liation on the number of pods per plant of dry beans at
              the R5, R9 stages, 1979/80

Source of variation	DF	MS	F	MS	
		R5		R9	
Replication	3	12,00		32,840	
Control	1	66,04		122,281	**
Levels of defoliation	1	135,16	**	45,943	**
Times of defoliation	6	27,99	NS	9,869	NS
Levels x times	6	13,49	NS	8,506	NS
Error	46	17,77		4,871	
Total	63				

Appendix 10 Analysis of variance: effect of levels and times of defo-
liation on the pod mass (g plant^{-1}) of dry beans at the
R5, R9 stages, 1979/80

Source of variation	DF	MS	F	MS	F
		R5		R9	
Replication	3	34,67		15,361	
Control	1	68,05	*	135,740	**
Levels of defoliation	1	78,50		136,938	**
Times of defoliation	6	7,70	NS	19,312	*
Levels x times	6	4,58	NS	8,891	NS
Error	46	10,08		6,249	
Total	63				

Appendix 11 Analysis of variance: effect of levels and times of defo-
liation on the number of seeds per pod of dry beans at
the R9 stage, 1979/80

Source of variation	DF	MS	F
Replication	3	4,0968	
Control	1	0,8540	NS
Levels of defoliation	1	1,1863	NS
Times of defoliation	6	1,2816	*
Levels x times	6	0,5400	NS
Error	46	0,4087	
Total	63		

Appendix 12   Analysis of variance: effect of levels and times of defo-
             liation on the number of seeds per plant of dry beans   at
             the R9 stage, 1979/80

Source of variation	DF	MS	F
Replication	3	196,92	
Control	1	1506,80	**
Levels of defoliation	1	1365,77	**
Times of defoliation	6	234,04	**
Levels x times	6	76,62	NS
Error	46	60,39	
Total	63		

Appendix 13   Analysis of variance: effect of levels and times of defo-
             liation on the 100 seed mass (g) of dry beans at the R9
             stage, 1979/80

Source of variation	DF	MS	F
Replication	3	1,0793	
Control	1	0,7313	NS
Levels of defoliation	1	3,9645	*
Times of defoliation	6	1,4952	NS
Levels x times	6	1,3845	NS
Error	46	0,8340	
Total	63		

Appendix 14   Analysis of variance: effect of levels and times of defo-
liation on the seed yield (g plant^{-1}) of dry beans at the
R9 stage, 1979/80

Source of variation	DF	MS	F
Replication	3	11,398	
Control	1	78,223	**
Levels of defoliation	1	83,326	**
Times of defoliation	6	11,498	*
Levels x times	6	5,552	NS
Error	46	4,067	
Total	63		

Appendix 15   Analysis of variance: effect of levels and times of defo-
liation on the total dry mass (g plant^{-1}) of dry beans at
the R1, R5 and R9 stages, 1979/80

Source of variation	DF	MS	F	MS	F	MS	F
		R1		R5		R9	
Replication	3	23,935		25,77		27,46	
Control	1	196,360	**	360,54	**	290,90	**
Levels of defoliation	1	208,672	**	448,05	**	324,24	**
Times of defoliation	6	74,639	**	37,09	NS	43,21	*
Levels x times	6	7,520	NS	16,34	NS	23,79	NS
Error	46	5,524		40,06		15,15	
Total	63						

Appendix 16 Analysis of variance: effect of levels and times of defo-
liation on the harvest index (%) of dry beans at the R9
stage, 1979/80

Source of variation	DF	MS	F
Replication	3	20,555	
Control	1	0,881	NS
Levels of defoliation	1	2,817	NS
Times of defoliation	6	28,820	**
Levels x times	6	4,738	NS
Error	46	3,858	
Total	63		

Appendix 17 Analysis of variance: effect of time of defoliation on
the number of nodes per plant of three dry bean culti-
vars, 1980/81

Source of variation	DF	MS	F
Replication	2	46,043	
Cultivars	2	66,807	**
Time of defoliation	11	4,326	NS
Cultivars x times	22	7,938	NS
Error	70	5,973	
Total	107		

Appendix 18 Analysis of variance: effect of time of defoliation on
the stem mass (g plant^{-1}) of three dry bean cultivars,
1980/81

Source of variation	DF	MS	F
Replication	2	,680	
Cultivars	2	114,202	**
Time of defoliation	11	7,504	**
Cultivars x times	22	1,573	NS
Error	70	1,683	
Total	107		

Appendix 19 Analysis of variance: effect of time of defoliation on
the number of racemes per plant of three dry bean culti-
vars, 1980/81

Source of variation	DF	MS	F
Replication	2	2,807	
Cultivars	2	15,018	**
Time of defoliation	11	2,432	NS
Cultivars x times	22	2,754	NS
Error	70	1,798	
Total	107		

Appendix 20   Analysis   of variance: effect of time of   defoliation   on
              the   pod   number per plant of three dry   bean   cultivars,
              1980/81

Source of variation	DF	MS	F
Replication	2	7,692	
Cultivars	2	1155,048	**
Time of defoliation	11	44,095	**
Cultivars x times	22	17,356	NS
Error	70	13,737	
Total	107		

Appendix 21   Analysis   of variance: effect of time of   defoliation   on
              the   pod   mass (g plant^{-1}) of three dry   bean   cultivars,
              1980/81

Source of variation	DF	MS	F
Replication	2	24,767	
Cultivars	2	216,572	**
Time of defoliation	11	127,375	**
Cultivars x times	22	55,180	*
Error	70	28,257	
Total	107		

Appendix 22 Analysis of variance: effect of time of defoliation on the number of seeds per pod of three dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replication	2	0,064	
Cultivars	2	17,976	**
Time of defoliation	11	1,229	**
Cultivars x times	22	0,397	NS
Error	70	0,298	
Total	107		

Appendix 23 Analysis of variance: effect of time of defoliation on the number of seeds per plant of three dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replication	2	217,711	
Cultivars	2	44144,903	**
Time of defoliation	11	1036,409	**
Cultivars x times	22	490,139	**
Error	70	226,904	
Total	107		

Appendix 24 Analysis of variance: effect of time of defoliation on the 100 seed mass (g) of three dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replication	2	40,028	
Cultivars	2	7835,353	**
Time of defoliation	11	16,889	NS
Cultivars x times	22	6,575	NS
Error	70	11,453	
Total	107		

Appendix 25 Analysis of variance: effect of time of defoliation on the seed yield (g plant^{-1}) of three dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replication	2	27,390	
Cultivars	2	177,333	**
Time of defoliation	11	83,899	**
Cultivars x times	22	34,658	*
Error	70	19,368	
Total	107		

Appendix 26 Analysis of variance: effect of time of defoliation on the total dry mass (g plant^{-1}) of three dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replication	2	34,464	
Cultivars	2	345,169	**
Time of defoliation	11	144,688	**
Cultivars x times	22	71,948	*
Error	70	40,301	
Total	107		

Appendix 27 Analysis of variance: effect of time of defoliation on the harvest index (%) of three dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replication	2	36,063	
Cultivars	2	615,014	**
Time of defoliation	11	84,307	**
Cultivars x times	22	9,411	NS
Error	70	8,733	
Total	107		

Appendix 28   Analysis of variance: effect of times and levels of thinning on the leaf mass (g plant^{-1}) of dry beans, 1979/80

Source of variation	DF	MS	F
Replications	3	15,13	
Control	1	38,07	**
Levels of thinning	2	24,11	**
Times of thinning	3	11,75	NS
Levels x times	6	4,26	NS
Error	48	2,79	
Total	63		

Appendix 29   Analysis of variance: effect of times and levels of thinning on the stem mass (g plant^{-1}) of dry beans, 1979/80

Source of variation	DF	MS	F
Replications	3	2,31	
Control	1	42,83	**
Levels of thinning	2	35,96	**
Times of thinning	3	58,88	**
Levels x times	6	2,66	NS
Error	48	2,38	
Total	63		

Appendix 30   Analysis   of   variance: effect of times   and   levels   of thinning   on the number of pods per plant of   dry   beans, 1979/80

Source of variation	DF	MS	F
Replications	3	8,03	
Control	1	519,56	**
Levels of thinning	2	325,48	**
Times of thinning	3	344,10	**
Levels x times	6	21,15	NS
Error	48	12,38	
Total	63		

Appendix 31   Analysis   of   variance: effect of times   and   levels   of thinning   on   the   pod mass (g   plant^{-1})   of   dry   beans, 1979/80

Source of variation	DF	MS	F
Replications	3	51,84	
Control	1	1343,66	**
Levels of thinning	2	676,75	**
Times of thinning	3	865,66	**
Levels x times	6	56,01	NS
Error	48	24,67	
Total	63		

Appendix 32   Analysis of variance: effect of times and levels of thin-
ning on the number of seeds per pod of dry beans, 1979/80

Source of variation	DF	MS	F
Replications	3	0,224	
Control	1	0,109	**
Levels of thinning	2	0,287	**
Times of thinning	3	0,539	*
Levels x times	6	0,080	NS
Error	48	0,158	
Total	63		

Appendix 33   Analysis of variance: effect of times and levels of thin-
ning on the number of seeds per plant of dry beans,
1979/80

Source of variation	DF	MS	F
Replications	3	684,44	
Control	1	13170,30	**
Levels of thinning	2	6702,90	**
Times of thinning	3	9081,00	**
Levels x times	6	679,30	NS
Error	48	274,20	
Total	63		

Appendix 34   Analysis of variance: effect of times and levels of thin-
ning on the 100 seed mass (g) of dry beans, 1979/80

Source of variation	DF	MS	F
Replications	3	1,36	
Control	1	1,25	NS
Levels of thinning	2	1,11	NS
Times of thinning	3	2,78	*
Levels x times	6	1,29	NS
Error	48	0,90	
Total	63		

Appendix 35   Analysis of variance: effect of times and levels of thin-
ning on the seed yield (g plant^{-1}) of dry beans, 1979/80

Source of variation	DF	MS	F
Replications	3	32,87	
Control	1	805,65	**
Levels of thinning	2	389,69	**
Times of thinning	3	566,73	**
Levels x times	6	36,78	*
Error	48	15,35	
Total	63		

Appendix 36 Analysis of variance: effect of times and levels of thin-
ning on the total dry mass (g plant^{-1}) of dry beans,
1979/80

Source of variation	DF	MS	F
Replications	3	155,79	
Control	1	2391,65	**
Levels of thinning	2	1334,75	**
Times of thinning	3	1600,27	**
Levels x times	6	99,67	NS
Error	48	49,51	
Total	63		

Appendix 37 Analysis of variance: effect of times and levels of thin-
ning on the harvest index (%) of dry beans, 1979/80

Source of variation	DF	MS	F
Replications	3	12,75	
Control	1	9,49	NS
Levels of thinning	2	7,70	NS
Times of thinning	3	45,58	**
Levels x times	6	2,45	NS
Error	48	3,84	
Total	63		

Appendix 38 Analysis of variance: effect of times of thinning on the leaf mass (g plant^{-1}) of three dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replications	2	2,282	
Cultivars	2	34,595	NS
Times of thinning	11	77,920	NS
Cultivars x times	22	10,287	NS
Error	70	12,545	
Total	107		

Appendix 39 Analysis of variance: effect of times of thinning on the number of nodes per plant of three dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replications	2	13,587	
Cultivars	2	151,227	**
Times of thinning	11	82,221	**
Cultivars x times	22	10,070	NS
Error	70	9,243	
Total	107		

Appendix 40   Analysis of variance: effect of times of thinning on the
              number of branches per plant of three dry bean cultivars,
              1980/81

Source of variation	DF	MS	F
Replications	2	0,008	
Cultivars	2	4,057	**
Times of thinning	11	1,473	**
Cultivars x times	22	0,188	**
Error	70	0,080	
Total	107		

Appendix 41   Analysis of variance: effect of times of thinning on the
              stem mass (g plant^{-1}) of three dry bean cultivars,
              1980/81

Source of variation	DF	MS	F
Replications	2	2,696	
Cultivars	2	228,443	**
Times of thinning	11	28,923	**
Cultivars x times	22	6,087	**
Error	70	2,405	
Total	107		

Appendix 42 Analysis of variance: effect of times of thinning on the
number of pods per plant of three dry bean cultivars,
1980/81

Source of variation	DF	MS	F
Replications	2	0,035	
Cultivars	2	1891,243	**
Times of thinning	11	237,927	**
Cultivars x times	22	15,113	NS
Error	70	14,708	
Total	107		

Appendix 43 Analysis of variance: effect of times of thinning on the
pod mass (g plant^{-1}) of three dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replications	2	87,283	
Cultivars	2	67,041	NS
Times of thinning	11	731,522	**
Cultivars x times	22	40,522	NS
Error	70	37,341	
Total	107		

Appendix 44 Analysis of variance: effect of times of thinning on the
number of seeds per pod of three dry bean cultivars,
1980/81

Source of variation	DF	MS	F
Replications	2	0,508	
Cultivars	2	17,606	**
Times of thinning	11	0,462	NS
Cultivars x times	22	0,484	NS
Error	70	0,412	
Total	107		

Appendix 45 Analysis of variance: effect of times of thinning on the
number of seeds per plant of three dry bean cultivars,
1980/81

Source of variation	DF	MS	F
Replications	2	904,033	
Cultivars	2	92008,399	**
Times of thinning	11	5367,746	**
Cultivars x times	22	579,831	NS
Error	70	357,525	
Total	107		

Appendix 46   Analysis of variance: effect of times of thinning on   the
               100 seed mass (g) of three dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replications	2	12,317	
Cultivars	2	6736,206	**
Times of thinning	11	17,175	*
Cultivars x times	22	18,544	**
Error	70	7,074	
Total	107		

Appendix 47   Analysis of variance: effect of times of thinning on   the
               seed yield (g plant^{-1}) of three dry bean cultivars,
               1980/81

Source of variation	DF	MS	F
Replications	2	84,254	
Cultivars	2	87,628	NS
Times of thinning	11	516,348	**
Cultivars x times	22	30,170	NS
Error	70	28,366	
Total	107		

Appendix 48 Analysis of variance: effect of times of thinning on the total dry mass (g plant^{-1}) of three dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replications	2	127,923	
Cultivars	2	307,057	**
Times of thinning	11	1058,134	**
Cultivars x times	22	50,929	NS
Error	70	53,920	
Total	107		

Appendix 49 Analysis of variance: effect of times of thinning on the harvest index (%) of dry three bean cultivars, 1980/81

Source of variation	DF	MS	F
Replications	2	8,651	
Cultivars	2	552,311	**
Times of thinning	11	32,650	**
Cultivars x times	22	14,088	**
Error	70	4,867	
Total	107		

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Appendix 50   Analysis of variance: effect of levels and times of sha-
               ding on the stem mass (g plant^{-1}) of dry beans, 1979/80

Source of variation	DF	MS	F
Replicates	3	1,1303	
Control	1	4,5623	**
Levels	2	1,9555	*
Times	3	16,7769	**
Levels x times	6	2,1480	**
Error	44	0,5466	
Total	59		

Appendix 51   Analysis of variance: effect of levels and times of
               shading on the number of pods per plant of dry beans,
               1979/80

Source of variation	DF	MS	F
Replicates	3	6,19	
Control	1	88,40	**
Levels	2	42,69	**
Times	3	115,32	**
Levels x times	6	4,34	NS
Error	44	7,81	
Total	59		

Appendix 52   Analysis   of   variance: effect of levels   and   times   of
              shading   on   the   pod mass (g   plant^{-1})   of   dry   beans,
              1997/80

Source of variation	DF	MS	F
Replicates	3	7,58	
Control	1	340,82	**
Levels	2	60,40	**
Times	3	183,73	**
Levels x times	6	21,25	*
Error	44	9,20	
Total	59		

Appendix 53   Analysis   of   variance: effect of levels   and   times   of
              shading   on   the number of seeds per pod of   dry   beans,
              1979/80

Source of variation	DF	MS	F
Replicates	3	0,14	
Control	1	0,04	NS
Levels	2	0,52	NS
Times	3	0,59	NS
Levels x times	6	0,51	NS
Error	44	0,49	
Total	59		

Appendix 54   Analysis of variance: effect of levels and times of
shading   on the number of seeds per plant of dry   beans,
1979/80

Source of variation	DF	MS	F
Replicates	3	177,40	
Control	1	2816,00	**
Levels	2	1392,30	**
Times	3	3329,10	**
Levels x times	6	303,80	*
Error	44	115,90	
Total	59		

Appendix 55   Analysis of variance: effect of levels and times of
shading on the 100 seed mass (g) of dry beans, 1979/80

Source of variation	DF	MS	F
Replicates	3	3,36	
Control	1	5,58	NS
Levels	2	5,63	NS
Times	3	37,49	**
Levels x times	6	7,27	**
Error	44	2,08	
Total	59		

Appendix 56 Analysis of variance: effect of levels and times of shading on the seed yield (g plant^{-1}) of dry beans, 1979/80

Source of variation	DF	MS	F
Replicates	3	4,06	
Control	1	213,33	**
Levels	2	55,33	**
Times	3	118,44	**
Levels x times	6	18,57	*
Error	44	6,42	
Total	59		

Appendix 57 Analysis of variance: effect of levels and times of shading on the total dry mass (g plant^{-1}) of dry beans, 1979/80

Source of variation	DF	MS	F
Replicates	3	23,63	
Control	1	481,55	**
Levels	2	104,04	**
Times	3	339,46	**
Levels x times	6	38,16	*
Error	44	15,87	
Total	59		

Appendix 58   Analysis of variance: effect of levels and times of
              shading on the harvest index (%) of dry beans, 1979/80

Source of variation	DF	MS	F
Replicates	3	22,95	
Control	1	53,11	*
Levels	2	53,57	**
Times	3	155,42	**
Levels x times	6	60,29	**
Error	44	9,81	
Total	59		

Appendix 59   Analysis of variance: effect of levels of light inten-
              sity and times of application on the number of nodes per
              plant of dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replicates	2	62,37	
Control	1	1,03	NS
Levels	1	13,02	NS
Times	3	10,30	NS
Cultivars	2	139,40	**
Levels x times	3	33,94	*
Levels x cultivars	1	2,52	NS
Times x cultivars	3	43,54	*
Levels x times x cultivars	3	12,07	NS
Error	52	10,57	
Total	71		

Appendix 60 Analysis of variance: effect of levels of light
intensity and times of application on the stem mass (g
plant^{-1}) of dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replicates	2	3,725	
Control	1	0,265	NS
Levels	1	8,317	*
Times	3	3,773	NS
Cultivars	2	78,226	**
Levels x times	3	6,056	*
Levels x cultivars	1	3,091	NS
Times x cultivars	3	4,073	NS
Levels x times x cultivars	3	1,829	NS
Error	52	1,764	
Total	71		

Appendix 61 Analysis of variance: effect of levels of light
intensity and times of application on the number of pods
per plant of dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replicates	2	20,42	
Control	1	88,05	**
Levels	1	151,94	**
Times	3	51,46	**
Cultivars	2	978,70	**
Levels x times	3	20,36	NS
Levels x cultivars	1	127,40	**
Times x cultivars	3	73,23	**
Levels x times x cultivars	3	22,93	NS
Error	52	8,41	
Total	71		

Appendix 62   Analysis   of   variance: effect   of   levels   of   light
             intensity   and times of application on the pod   mass   (g
             plant^{-1}) of dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replicates	2	118,68	
Control	1	226,00	**
Levels	1	927,52	**
Times	3	223,39	**
Cultivars	2	76,07	NS
Levels x times	3	126,58	**
Levels x cultivars	1	79,57	NS
Times x cultivars	3	241,14	**
Levels x times x cultivars	3	18,82	NS
Error	52	24,43	
Total	71		

Appendix 63   Analysis   of   variance: effect   of   levels   of   light
             intensity   and   times of application on   the   number   of
             seeds per pod of dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replicates	2	0,14	
Control	1	0,18	NS
Levels	1	4,03	**
Times	3	0,95	**
Cultivars	2	3,80	**
Levels x times	3	1,84	**
Levels x cultivars	1	0,05	NS
Times x cultivars	3	0,47	*
Levels x times x cultivars	3	0,38	NS
Error	52	0,15	
Total	71		

Appendix 64 Analysis of variance: effect of levels of light intensity and times of application on the number of seeds per plant of dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replicates	2	323,2	
Control	1	2733,5	**
Levels	1	7575,2	**
Times	3	1907,5	**
Cultivars	2	29155,0	**
Levels x times	3	1244,6	**
Levels x cultivars	1	2986,2	**
Times x cultivars	3	1664,1	**
Levels x times x cultivars	3	473,8	*
Error	52	199,6	
Total	71		

Appendix 65 Analysis of variance: effect of levels of light intensity and times of application on the 100 seed mass (g) of dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replicates	2	5,83	
Control	1	1,17	NS
Levels	1	2,25	NS
Times	3	29,05	*
Cultivars	2	4021,95	**
Levels x times	3	10,62	NS
Levels x cultivars	1	25,23	NS
Times x cultivars	3	1,93	NS
Levels x times x cultivars	3	14,84	NS
Error	52	10,20	
Total	71		

Appendix 66 Analysis of variance: effect of levels of light
intensity and times of application on the seed yield (g
plant^{-1}) of dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replicates	2	88,21	
Control	1	176,27	**
Levels	1	654,16	**
Times	3	140,02	**
Cultivars	2	69,39	*
Levels x times	3	80,79	**
Levels x cultivars	1	44,31	NS
Times x cultivars	3	150,08	**
Levels x times x cultivars	3	15,18	NS
Error	52	16,90	
Total	71		

Appendix 67 Analysis of variance: effect of levels of light
intensity and times of application on the total dry mass
(g plant^{-1}) of dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replicates	2	48,33	
Control	1	367,87	*
Levels	1	1031,57	**
Times	3	248,61	**
Cultivars	2	100,72	NS
Levels x times	3	197,21	*
Levels x cultivars	1	139,54	NS
Times x cultivars	3	344,76	**
Levels x times x cultivars	3	25,03	NS
Error	52	47,84	
Total	71		

Appendix 68   Analysis   of   variance: effect   of   levels   of   light
intensity and times of application on the harvest   index
(%) of dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replicates	2	906,97	
Control	1	162,99	**
Levels	1	548,10	**
Times	3	152,54	**
Cultivars	2	163,65	**
Levels x times	3	87,79	*
Levels x cultivars	1	1,69	NS
Times x cultivars	3	39,22	NS
Levels x times x cultivars	3	14,55	NS
Error	52	22,76	
Total	71		

Appendix 69   Analysis   of   variance: effect   of   levels   of   light
intensity   and   times of application on   the   number   of
nodes per plant of dry bean cultivars, 1981/82

Source of variation	DF	MS	F
Replicates	2	55,40	
Control	1	4,69	NS
Levels	1	20,28	NS
Times	3	11,71	NS
Cultivars	2	365,22	**
Levels x times	3	5,51	NS
Levels x cultivars	1	4,32	NS
Times x cultivars	3	5,29	NS
Levels x times x cultivars	3	20,58	NS
Error	52	7,69	
Total	71		

Appendix 70 Analysis of variance: effect of levels of light intensity and times of application on the stem mass (g plant^{-1}) of dry bean cultivars, 1981/82

Source of variation	DF	MS	F
Replicates	2	1,81	
Control	1	0,05	NS
Levels	1	0,46	NS
Times	3	4,07	NS
Cultivars	2	354,63	**
Levels x times	3	7,92	*
Levels x cultivars	1	3,99	NS
Times x cultivars	3	5,61	NS
Levels x times x cultivars	3	1,41	NS
Error	52	2,20	
Total	71		

Appendix 71 Analysis of variance: effect of levels of light intensity and times of application on the number of pods per plant of dry bean cultivars, 1981/82

Source of variation	DF	MS	F
Replicates	2	11,95	
Control	1	122,47	**
Levels	1	136,01	**
Times	3	54,80	**
Cultivars	2	696,00	**
Levels x times	3	85,85	**
Levels x cultivars	1	2,43	NS
Times x cultivars	3	20,26	NS
Levels x times x cultivars	3	25,36	*
Error	52	8,84	
Total	71		

Appendix 72 Analysis of variance: effect of levels of light intensity and times of application on the pod mass (g plant^{-1}) of dry bean cultivars, 1981/82

Source of variation	DF	MS	F
Replicates	2	31,74	
Control	1	221,96	*
Levels	1	1088,14	**
Times	3	183,00	**
Cultivars	2	838,21	**
Levels x times	3	168,02	*
Levels x cultivars	1	81,48	NS
Times x cultivars	3	6,87	NS
Levels x times x cultivars	3	23,04	NS
Error	52	43,25	
Total	71		

Appendix 73 Analysis of variance: effect of levels of light intensity and times of application on the number of seeds per pod of dry bean cultivars, 1981/82

Source of variation	DF	MS	F
Replicates	2	0,07	
Control	1	0,01	NS
Levels	1	3,00	**
Times	3	0,48	NS
Cultivars	2	0,99	*
Levels x times	3	1,86	**
Levels x cultivars	1	0,02	NS
Times x cultivars	3	0,24	NS
Levels x times x cultivars	3	0,37	NS
Error	52	0,22	
Total	71		

Appendix 74 Analysis of variance: effect of levels of light intensity and times of application on the number of seeds per plant of dry bean cultivars, 1980/81

Source of variation	DF	MS	F
Replicates	2	186,5	
Control	1	3782,3	**
Levels	1	7823,4	**
Times	3	966,0	*
Cultivars	2	15867,2	**
Levels x times	3	1446,7	**
Levels x cultivars	1	0,0	NS
Times x cultivars	3	144,8	NS
Levels x times x cultivars	3	265,6	NS
Error	52	306,9	
Total	71		

Appendix 75 Analysis of variance: effect of levels of light intensity and times of application on the 100 seed mass (g) of dry bean cultivars, 1981/82

Source of variation	DF	MS	F
Replicates	2	8,39	
Control	1	76,27	*
Levels	1	20,28	NS
Times	3	8,36	NS
Cultivars	2	4748,71	**
Levels x times	3	21,13	NS
Levels x cultivars	1	8,33	NS
Times x cultivars	3	4,90	NS
Levels x times x cultivars	3	1,07	NS
Error	52	12,57	
Total	71		

Appendix 76 Analysis   of   variance: effect   of   levels   of   light
intensity and times of application on the seed yield (g
plant^{-1}) of dry bean cultivars, 1981/82

Source of variation	DF	MS	F
Replicates	2	30,17	
Control	1	169,26	*
Levels	1	817,08	**
Times	3	113,91	*
Cultivars	2	277,90	**
Levels x times	3	89,05	*
Levels x cultivars	1	72,42	NS
Times x cultivars	3	3,45	NS
Levels x times x cultivars	3	15,72	NS
Error	52	27,92	
Total	71		

Appendix 77 Analysis   of   variance: effect   of   levels   of   light
intensity and times of application on the total dry mass
(g plant^{-1}) of dry bean cultivars, 1981/82

Source of variation	DF	MS	F
Replicates	2	19,20	
Control	1	326,28	*
Levels	1	1248,07	**
Times	3	107,37	NS
Cultivars	2	2384,97	**
Levels x times	3	230,80	*
Levels x cultivars	1	158,56	NS
Times x cultivars	3	14,66	NS
Levels x times x cultivars	3	62,52	NS
Error	52	68,31	
Total	71		

Appendix 78 Analysis   of variance: effect of levels of   light
intensity and times of application on the harvest   index
(%) of dry bean cultivars, 1981/82

Source of variation	DF	MS	F
Replicates	2	33,02	
Control	1	113,60	**
Levels	1	505,05	**
Times	3	45,56	**
Cultivars	2	607,09	**
Levels x times	3	3,70	NS
Levels x cultivars	1	43,51	*
Times x cultivars	3	13,04	NS
Levels x times x cultivars	3	14,74	NS
Error	52	9,78	
Total	71		

Appendix 79 Analysis   of variance: effect of levels and times of   pod
removal   on the non-reproductive mass (g plant^{-1}) of   dry
beans, 1981/82

Source of variation	DF	MS	F
Replications	3	31,26	
Control	1	221,46	**
Levels of pod removal	1	8,87	NS
Times of pod removal	4	50,89	**
Levels x times	4	22,08	*
Error	46	7,32	
Total	59		

Appendix 80 Analysis of variance: effect of levels and times of pod
removal on the number of empty pods per plant of dry
beans, 1981/82

Source of variation	DF	MS	F
Replications	3	5,33	
Control	1	4,89	NS
Levels of pod removal	1	50,82	★★
Times of pod removal	4	29,22	★★
Levels x times	4	3,89	NS
Error	46	1,71	
Total	59		

Appendix 81 Analysis of variance: effect of levels and times of pod
removal on the number of pods containing seeds per dry
bean plant, 1981/82

Source of variation	DF	MS	F
Replications	3	35,96	
Control	1	2138,70	★★
Levels of pod removal	1	2,83	NS
Times of pod removal	4	414,30	★★
Levels x times	4	21,19	★
Error	46	7,89	
Total	59		

Appendix 82   Analysis of variance: effect of levels and times of pod removal on the pod mass (g plant^{-1}) of dry beans, 1981/82

Source of variation	DF	MS	F
Replications	3	51,83	
Control	1	1687,05	**
Levels of pod removal	1	51,12	NS
Times of pod removal	4	1094,40	**
Levels x times	4	29,70	NS
Error	46	14,56	
Total	59		

Appendix 83   Analysis of variance: effect of levels and times of pod removal on the number of seeds per pod of dry beans, 1981/82

Source of variation	DF	MS	F
Replications	3	2,9450	
Control	1	0,0211	NS
Levels of pod removal	1	2,4453	**
Times of pod removal	4	1,2618	**
Levels x times	4	0,7980	**
Error	46	0,2055	
Total	59		

Appendix 84   Analysis of variance: effect of levels and times of pod
removal on the number of seeds per plant of dry beans,
1981/82

Source of variation	DF	MS	F
Replications	3	636,1	
Control	1	42115,2	**
Levels of pod removal	1	1031,1	**
Times of pod removal	4	91886,6	**
Levels x times	4	175,5	NS
Error	46	132,9	
Total	59		

Appendix 85   Analysis of variance: effect of levels and times of pod
removal on the 100 seed mass (g) of dry beans, 1981/82

Source of variation	DF	MS	F
Replications	3	23,394	
Control	1	478,002	**
Levels of pod removal	1	10,920	NS
Times of pod removal	4	85,983	**
Levels x times	4	5,265	NS
Error	46	3,036	
Total	59		

Appendix 86 Analysis of variance: effect of levels and times of pod
removal on the seed yield (g plant^{-1}) of dry beans,
1981/82

Source of variation	DF	MS	F
Replications	3	31,98	
Control	1	1221,07	**
Levels of pod removal	1	690,08	**
Times of pod removal	4	13,95	NS
Levels x times	4	10,21	
Error	46		
Total	59		

Appendix 87 Analysis of variance: effect of levels and times of pod
removal on the total dry mass (g plant^{-1}) of dry beans,
1981/82

Source of variation	DF	MS	F
Replications	3	127,690	
Control	1	699,55	**
Levels of pod removal	1	21,34	NS
Times of pod removal	4	1215,91	**
Levels x times	4	90,24	*
Error	46	24,83	
Total	59		

Appendix 88   Analysis of variance: effect of levels and times of pod removal on the harvest index (%) of dry beans, 1981/82

Source of variation	DF	MS	F
Replications	3	162,41	
Control	1	4269,75	**
Levels of pod removal	1	451,58	**
Times of pod removal	4	737,87	**
Levels x times	4	119,66	**
Error	46	34,43	
Total	59		

Appendix 89 Analysis of variance: effect of times of pod removal on the number of nodes per plant of three dry bean cultivars, 1985/86

Source of variation	DF	MS	F
Replications	2	51,277	
Cultivars	2	54,570	**
Times	5	2,456	NS
Cultivars x times	10	14,371	NS
Error	34	11,810	
Total	59		

Appendix 90   Analysis of variance: effect of times of pod removal   on
              the non-reproductive mass (g plant^{-1}) of three dry bean
              cultivars, 1985/86

Source of variation	DF	MS	F
Replications	2	4,224	
Cultivars	2	594,690	**
Times	5	10,815	NS
Cultivars x times	10	7,845	NS
Error	34	12,388	
Total	59		

Appendix 91   Analysis of variance: effect of times of pod removal   on
              the number of pods per plant of three dry bean cultivars,
              1985/86

Source of variation	DF	MS	F
Replications	2	17,506	
Cultivars	2	274,026	**
Times	5	102,403	**
Cultivars x times	10	21,786	**
Error	34	5,611	
Total	59		

Appendix 92   Analysis of variance: effect of times of pod removal   on
the pod mass (g plant^{-1}) of three dry bean cultivars,
1985/86

Source of variation	DF	MS	F
Replications	2	17,953	
Cultivars	2	96,502	**
Times	5	117,116	**
Cultivars x times	10	18,772	NS
Error	34	10,642	
Total	59		

Appendix 93   Analysis of variance: effect of times of pod removal   on
the number of seeds per pod of three dry bean cultivars,
1985/86

Source of variation	DF	MS	F
Replications	2	0,367	
Cultivars	2	2,296	**
Times	5	0,286	NS
Cultivars x times	10	0,102	NS
Error	34	0,181	
Total	59		

Appendix 94   Analysis   of variance: effect of times of pod removal   on
              the   number   of   seeds   per   plant   of   three   dry   bean
              cultivars, 1985/86

Source of variation	DF	MS	F
Replications	2	652,522	
Cultivars	2	4274,791	**
Times	5	1317,137	**
Cultivars x times	10	252,104	*
Error	34	89,926	
Total	59		

Appendix 95   Analysis   of variance: effect of times of pod removal   on
              the   hundred seed mass (g) (Ln transformation)   of   three
              dry bean cultivars, 1985/86

Source of variation	DF	MS	F
Replications	2	0,0069	
Cultivars	2	3,1363	**
Times	5	0,0110	**
Cultivars x times	10	0,0041	NS
Error	34	0,0029	
Total	59		

Appendix 96   Analysis   of variance: effect of times of pod removal   on the   seed yield (g plant^{-1}) of three dry bean   cultivars, 1985/86

Source of variation	DF	MS	F
Replications	2	15,126	
Cultivars	2	90,725	**
Times	5	63,366	**
Cultivars x times	10	11,076	NS
Error	34	6,661	
Total	59		

Appendix 97   Analysis of variance: effect of times of pod removal   on the total dry mass (g plant^{-1}) three dry bean   cultivars, 1985/86

Source of variation	DF	MS	F
Replications	2	8,665	
Cultivars	2	673,943	**
Times	5	78,871	**
Cultivars x times	10	28,785	NS
Error	34	24,182	
Total	59		

Appendix 98 Analysis of variance: effect of times of pod removal on
the harvest index (%) of three dry bean cultivars,
1985/86

Source of variation	DF	MS	F
Replications	2	68,019	
Cultivars	2	1685,019	**
Times	5	156,419	**
Cultivars x times	10	33,841	NS
Error	34	21,960	
Total	59		