CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

Seed yield is the result of many plant growth processes affecting the yield components of pods per plant, seeds per pod and seed weight. The highest seed yields are realised when all the yield components are maximised (Grafton, Schneiter, & Nagle, 1988). The dry-bean (*Phaseolus vulgaris* L.) crop, like many other legume crops, produces an excess of flowers. One of the reasons advanced for low yield obtained in dry bean is abscission of flowers and immature pods (Subhadrabandhu, Adams & Reicosky, 1978). Numerous factors can induce flower and/or pod drop and ultimately reduce yields. These include both genetic (limited photosynthate supply, susceptibility to disease) and environmental (disease/pest prevalence and climatic influences) factors (Liebenberg, 1989).

Yields of many agricultural crops have been increased by the adoption of improved cultural practices and higher yielding cultivars. Tremendous increases have thus been achieved in the production of cereal crops like maize (*Zea mays* L), wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.). Less success has been achieved with dry-bean. The major improvements in dry-bean have been in disease tolerance and favourable maturity adjustments (Adams, 1973).

Liebenberg (1989) reports that in South Africa dry bean yields have been limited mainly by source related stress factors such as leaf diseases, particularly bean rust (*Uromyces phaseoli*) (Reuben) Wint.), common blight (*Xanthomonas phaseoli* (E.F.S.M) Dows.) and halo blight (*Pseudomonas phaseolicola* (Bunl.) Dows.). This situation has been partially overcome with the introduction of certified seed, improved cultivation practices and better yielding cultivars. As a result the yield potential of dry-bean has been raised and the risk associated with the production of the crop has been minimised, leading to increased grain yield per unit area, thus improving income at farm level.

Major successes have been recorded in the development of resistant cultivars and seed programmes to produce bacterial- and fungal-free seed by use of meristem tissue culture techniques. Little success, however, has been achieved in the development of virus-free seed.

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Viruses are some of the worst seed borne diseases of bean in most areas of production.

A continuous effort is being made to obtain higher production per unit area in order to increase profitability and to meet the ever increasing demand for food, especially vegetable protein (Liebenberg & Van Wyk (eds), 1994). The optimal production of dry bean can only be accomplished by means of problem focussed research, and the development of virus-free seed is one of the technologies that would contribute greatly to increased production and productivity of the crop.

To exploit the genetic yield potential of dry-bean and increase production, virus-free bean seed is being produced using the meristem tissue culture technique (Theron, 1999-personal communication)[1]. Meristem tips of bean seedlings are cultured and plantlets developed from them. These plantlets have been successfully transplanted in the greenhouse and grown to maturity to produce seed. At present seed yield of the greenhouse grown plants are very low hence the need for more work to improve the situation (Theron, 1999-personal communication).[1]

In South Africa field experiments have been done to study the agronomic requirements of the bean crop. Seed multiplication programmes are limited to designated areas (warm and dry conditions) where the prevalence of bean diseases is low (Dry Bean Producers Organization (DPO), 1999). Little attention has been paid to the multiplication of disease-free seed under controlled environmental conditions in greenhouses.

The multiplication of disease-free seed under greenhouse conditions poses challenges. A number of studies need to be undertaken to determine the crop requirements such as spacing, fertilization and other factors that would optimise production.

In an effort to improve greenhouse production, the following objectives were developed.

1. To determine the plant population effect on dry bean seed production.
2. To determine the effect of different nitrogen sources and concentration in a nutrient solution on dry bean seed production under greenhouse conditions.
3. To evaluate the effect of a cytokinin-containing growth regulator on seed production.

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[1] Dr D.J. Theron, Dry Bean Producer . Box 15587, Lynn East, Pretoria

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CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Dry bean (*Phaseolus vulgaris* L.) is a protein rich crop widely used in human diets and hold great promise in meeting the protein needs of societies (Arora, 1983). For 7 000 to 8 000 years the dry bean has evolved from a wild-growing vine on the highlands of central America and the Andes into a major leguminous crop grown worldwide in a broad range of environments and farming systems. According to Gepts & Debouck (1991) this period encompasses the initial domestication phase and subsequent evolution under cultivation during which evolutionary forces have effected some striking changes in shaping the morphological, physiological and genetic characteristics of the present day common bean.

2.2 THE BEAN PLANT

Common bean is a member of the family *Leguminosae*, tribe *Phaseoleae*, and sub-family *Papilinoidea*. The cultivated forms are herbaceous annuals, determinate or indeterminate in growth and bearing papilionaceous flowers in axillary and terminal racemes. Racemes may be one to many-flowered. Flowers are zygomorphic, with a bi-petalled keel, two lateral wing petals and a large outwardly displayed standard petal. Flower colour is genetically independent of seed color, and may be white or purple (also red in *P. coccineus*) (Adams, Coyne, Davies, Graham & Francis, 1985). The flower contains ten stamens and a single multi-ovuled ovary that is normally self-fertilised, developing into a straight or slightly curved fruit, the pod. The pods are usually slender and narrow up to 20cm long and 1.5cm wide. Five to seven seeds per pod are typical, with up to ten seeds in some cultivars. Shapes of the pods vary from glabrous, straight or slightly curved edges to rounded or convex with a prominent beak. The pods are usually yellow or green with or without anthocyanin flecks or bloches. The seeds vary in color, shape and size with an average weight of 200 to 600mg (Smartt, 1976).

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According to Adams *et al*, 1985) close relatives like Tepary (P. *acutifolius* A. Gray) and Scarlet runner (*P. coccineus* L.) beans share many morphological and anatomical characteristics with the common bean. They state that Tepary is better adapted to hot summers and dry soils and Scarlet runner to cool sites, particularly in the uplands of Mexico and Central America, although they are also grown commercially in England, Northern Europe and South Africa.

Determinate types of the common bean have a central axis, or main stem, with five to nine nodes and form two to several branches which arise from the more basal nodes. Indeterminate types have central axes with twelve to fifteen nodes, or even more in climbing vine types.

Germination is epigeal (hypogeal in *P. coccineus* L.) and requires five to seven days at a soil temperature of 16°C. Time to flowering varies with variety, temperature and photoperiod and is usually from 28 to 42 days. Flowering is usually complete in five to six days in type I genotypes or 15 to 30 days in types II, III, and IV according to the CIAT classification (Appendix Table 8.1). As many as two thirds of the flowers produced may abscise, and under temperature or moisture stress young pods and/or developing seeds may also abort. Abscission is greatest in flowers formed on the later nodes and branches, and in later developing flowers on racemes with multiple flowers. Seed filling periods may extend from as few as 23 days to nearly 50 days. Physiological maturity, the stage where no further increase in dry mass of seeds takes place, may be reached in the earliest varieties in only 60 to 65 days from planting. Some type IV genotypes in cooler upland sites may require 150 days.

P. vulgaris, P. lunatus, and *P. acutifolius* are invariably self fertilized, whereas *P. coccineus* is normally cross-fertilized. Interspecific crossing, except for *P. vulgaris* x *P. coccineus,* is rare in nature. Hybridization between *P. vulgaris* x *P. coccineus* is said to be relatively easy and there exists some evidence that inter-crosses occur in nature. In all known cases *P. vulgaris* is the female parent (Polhill & van der Maese, 1985).

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2.3 PLANT GROWTH AND DEVELOPMENT

2.3.1 Germination and seedling emergence

The seed size of *Phaseolus* varies considerably, but most commercial cultivars of common beans have a seed size in the range of 200 to 350mg (Davies, 1997). This variation means that sowing rates need to be adjusted based on the desired plant population, expected germination percentage and seed weight.

Germination of the common beans is epigeal and takes about six to eight days under favourable conditions. Mature seeds do not normally show any dormancy. Water is imbibed through the micropyle, the raphe and the hilum, and uptake through the seed coat is negligible (Korban, Coyne & Weihing, 1981). Hard seeds, which do not imbibe water properly may occur, and this appears to be associated with restriction of the micropyle (Kyle & Randall, 1963).

There are differences among common beans in the rate of early seedling growth that can be associated with seed size. Small seeded cultivars tend to germinate and grow more rapidly than large seeded ones when grown at relatively high temperature (28°C) (Laing, Jones & Davies, 1984; Li, Davies & Shen, 1991). Austin & Maclean (1972) reported that at low temperatures (12°C) large-seeded cultivars tend to germinate more quickly than small seeded ones. This is in agreement with observations that cultivars adapted to cooler climates tend to have larger seeds. On the contrary, Hucl (1993) indicated that genotypes with thinner seeds germinated better than wide-seeded genotypes under low temperature conditions.

The rate of seed germination of *P.vulgaris L* is most rapid at 29-34°C, the exact optimum temperature depending on the cultivar. Below 8°C germination does not occur (White & Montes-R, 1993).Beans do not germinate in cold soils and are highly sensitive to frost. They need to be planted in warm soils, preferably soils warmer than 18°C, after all danger of frost has passed. The minimum frost-free period needed for the different cultivars differ, and can fluctuate between 85 to 120 days (Liebenberg & Van Wyk, 1994).

Beans are susceptible to soaking injury. However, Davies (1997) reports that seeds could be soaked for 16 hours in CO_2 saturated water without any injury occurring. Leaching of sugars does not seem to be the cause of soaking injury. The physiology of this injury is not fully

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understood (Davies, 1997). Salinity adversely affects germination and seedling growth in beans. Cachoro, Ortiz & Cerda (1994) found that adding calcium could reduce this effect.

2.3.2 Vegetative growth

Under optimal conditions the bean plant grows nearly exponentially during the vegetative phase until pod growth begins. Leaf area index (LAI) in common beans increases up to about 40 days after emergence (DAE), depending on the cultivar and then declines during seed filling (50 to 65 DAE) as photosynthates and nitrogen are translocated to the developing seeds. Leaves at the lower nodes senesce first, followed by leaves higher up the main stem and later on the branches (Davies, 1997).

Bush beans develop a rather shallow root system, the bulk of the roots growing in the top 20 to 30cm and a radius of 45 to 70cm. This makes the plants generally susceptible to nutrient or moisture deficiency, even over relatively short periods of time. Modern green bean cultivars have highly concentrated flowering and pod set. This has made the bean crop to have relatively little ability to recover from any setback in growth which may occur (Davies 1997).

2.3.3 Growth habit

Beans are commonly classified into bush, half-runner and pole types. Virtually all green bean production for processing is done with the determinate bush beans. This is mainly because they provide the concentrated pod set required for machine harvesting. Suitable erect indeterminate varieties for commercial dry bean production have been developed (Davies, 1997). According to Adams *et al* (1985) growth habit is said to be elastic, changing with changes in the environment. Changes in temperature, photoperiod and stresses such as drought and poor soil fertility greatly affect vegetative structure. They further indicate that growth habit can be associated with the adaptation of a variety to different cropping systems, population densities and to different stresses.

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2.4 REPRODUCTION IN BEANS

Bees are essential for achieving pod set in large white kidney beans, but not so in the common beans which are by and large self-pollinated. The anthers dehisce in the bud just before it opens, usually at night. Once the pollen reaches the stigma, the pollen tubes grow down the hollow style and fertilize the ovules within 12 hours, the ovules nearest the style being fertilised first (Davies, 1997).

Commercial cultivars of common beans take about 25 days from pollination to the stage at which the green pods are ready for harvesting. This is when the pods are approaching their maximum length and fresh weight. Thereafter the seeds continue to develop for another 20 to 30 days to maturity.

The distribution of pods on the plant depends on the cultivar and its growth habit. Determinate cultivars first form flower primordia on the raceme in the axil of the uppermost leaf of the main stem. Flowering then proceeds downwards to the lower nodes and along the branches (Davies, 1997). By contrast, in indeterminate bush cultivars, the first flowers to open normally arise from nodes 6 or 7 and flowering then proceeds upwards and downwards on the main stem and along the branches (Laing *et al.*, 1984).

Commercially grown cultivars do not have time to develop a large LAI before pod set begins. Evidence suggests that the first formed reproductive structures have a strong competitive advantage for available assimilates. Complete pod set is almost certain for the first-opened flowers, followed by a high rate of abscission of later-formed flowers. Even under optimum conditions about 60 to 70% of the flowers and young pods are shed (Davies, 1997). This tendency to give precedence to the survival of a limited number of pods ensures more uniform pod set and has been selected for in a number of modern cultivars.

2.5 YIELD AND YIELD COMPONENTS

In the bean crop yield is a function of the number of pods per unit area, the number of seeds per pod and the seed mass (seed size or 100 seed mass). The interaction of these three components culminates in the economic yield. Under conditions where either nutrients or metabolic substances or both are limited, the plant adjusts by dropping the most recently set pods. If the stress continues, fertilized ovules in older pods are aborted (Adams, 1967).

The number of pods per plant is the yield component with the predominant influence on the yield of beans since it incorporates the other two yield components (Chung & Goulden, 1971; Duarte & Adams, 1972; Crothers & Westermann, 1976 & Westermann & Crothers, 1977). Similar observations have been made in soybeans (Pandey & Torrie, 1973) and *Vicia faba* v. minor (L.) (Yassin, 1973). 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 *et al.*, 1972).

Pods per plant can be divided into four components: pods per raceme, racemes per node, nodes per branch and branches per plant. This has led to the conclusion that most of the variation in pods per plant induced by plant population stress can be attributed to changes in the number of branches per plant and racemes per node. These two components are said to be negatively correlated to each other while pods per raceme and nodes per branch have little influence on yield (Bennet, Adams & Burga, 1977).

Liebenberg (1989) indicates that the yield components of beans are believed to be genetically independent and that under stress situations, negative correlations arise as induced relationships. Adams (1967) hypothesized that the rate of metabolic input for the formation and development of reproductive structures is relatively invariable and limiting. He indicated that when 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 manner. Component Z (the last in the sequence) may also vary in reaction to X and Y. The preference for photosynthate distribution in young plants is towards the centres of active growth such as developing leaves, root tips or shoot apices (vegetative sinks). Later, much of assimilate transport is diverted to storage organs such as fruits, grains or tubers (reproductive sinks). If the photosynthates are limited, then the 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 photosynthates during the seed fill period (Liebenberg, 1989).

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2.6 CARBOHYDRATE SYNTHESIS

According to Graham (1982) common beans differ in their ability to supply carbohydrates to the roots and nodules. Late maturing cultivars are reported to supply more soluble carbohydrates to roots than the early maturing cultivars. In late maturing cultivars, there is a delay in the onset of competition for photosynthates between the developing pods and the nodules and have a long leaf area duration since they shed their lower leaves late. This enables these cultivars to maintain their active assimilatory surface longer (Mohamed, 1998).

The relationship between photosynthesis, carbohydrate assimilation and crop yield is very complex. This is mainly because 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, canopy structure, dark and light respiration, translocation and partitioning of assimilates (Liebenberg, 1989). Photosynthesis mostly takes place in the leaves hence leaf area is a major component of whole plant yield. Leaf area has then been divided into leaf number and leaf size and photosynthetic production increases with increasing leaf area per unit ground area, referred to as leaf area index (LAI).

2.7. FACTORS AFFECTING PRODUCTION

The extent of senescence and abscission are major determinants of final yield. Failure of fertilization will cause flowers to abort. Davies (1997) reports that only one ovule needs to be fertilised to prevent pod abscission. Older pods may drop if there is inadequate supply of carbon assimilates. The amount of carbohydrates stored in the stem at flowering varies considerably even in the same cultivar. Differences exist between genotypes in both the amount of carbohydrates stored and its mobilization after flowering, which could be related to the incidence of abscission and the ability of the plant to tolerate stress. The occurrence of senescence and abscission appears to depend mainly on the source-sink balance in the plant, such that tissues which are at a competitive disadvantage are eliminated (Davies, 1997). There are likely to be other mechanisms also at play, such as endogenous growth regulators (White & Izquierdo, 1991). Key factors influencing the supply side of the source-sink relationship/balance are photoperiod, light, temperature, water, CO_2 concentration and nitrogen.

2.7.1 Photoperiod

Photoperiod refers to the relative duration of day and night, and responses to photoperiod are found in both plants and animals. The life of a plant is crucially dependent upon timing of events such as germination, flowering, seed filling and maturation. Adaptation and yield under specific agricultural conditions are often affected by photoperiod (Masaya & White, 1991).

The actual duration of the dark period is determined within the plant cell by the pigment phytochrome. The Pr form of phytochrome is the physiologically active form and is transformed to the Pfr form by red light and back to the Pr form by far red light. The Pfr form spontaneously reverts to Pr in the dark (Masaya *et al.*, 1991). Many physiological processes in bean show phytochrome responses. This include the unfolding of the epicotyl during emergence of seedlings, rapid movements of leaves, changes in the plant biochemistry such as synthesis of flavoids and regulation of stomatal conductance. According to them, it is unknown whether the role of phytochrome is only to measure night length or whether it is also important in sensing changes in light intensity such as response to shading. They also state that induction of flowering and subsequent differentiation of flower and fruit tissues, and the response of stem elongation to photoperiod, are the more important physiological effects of phytochrome in determining adaptation of bean cultivars.

There is, however, argument as to whether photoperiod affects the initiation of flower buds in bean (Van Schoonhoven *et al.*, 1991). Wallace (1980; 1985) indicated that there is no effect of photoperiod on the differentiation of the first floral primordium, but rather on the enlargement of the already differentiated floral primordium.

Garner & Allard (1920) first demonstrated that beans have a short day requirement for flowering, implying that a photoperiod-sensitive cultivar will flower only under days with a dark period longer than a critical length. It also means that the number of days from planting to flowering (anthesis) decreases as the day length is shortened below this limit until a minimum number of days to flowering is obtained (Masaya *et al.*, 1991).

The flowering pattern of beans differ depending on the growth habit. The first-opened flower appears in the axil of the upper most node on the main stem of determinate cultivars. On the other hand in indeterminate cultivars, the first opened flower appears on first, second or

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upper axil of main stem (Ojehomon, Zehni, & Morgan, 1973).

Photoperiod has been shown to affect the growth habit of the bean crop. Node and branch formation and the overall balance between reproductive and vegetative growth tend to be affected by photoperiod. Long days promote the elongation of stems early in the development of the plant, while at a later phase stem elongation is promoted by short days (Masaya & White, 1991; Kretchmer, Ozbun, Kaplan, Laing & Wallace, 1977).

White *et al*, (1989) also observed that small seeded genotypes were predominantly day neutral, while medium and large seeded genotypes were predominantly photoperiod sensitive. This is the case in South African cultivars where the large-white kidney bean is more day length sensitive and do not flower in winter (Liebenberg & Van Wyk, 1994).

2.7.2 CO_2 concentration

The concentration of carbon dioxide in the air surrounding the leaves markedly affects photosynthesis and has been found to improve the productivity of most crops. A tenfold increase in CO_2 of the air doubled the photosynthetic rate of some crops such as wheat, rice, soybean, some vegetables and fruits (Hartmann, Kofranek, Rubatzky and Flocker, 1988). Trials conducted to determine the effect of CO_2 indicate an increase in pod set in beans when grown in a CO_2 enriched environment, especially during the flowering stage. Hardman & Brun (1971) observed yield increases in soybeans with CO_2 enrichment. However, the increased CO_2 concentration had no influence on the number of seeds per pod or seed size of beans, but increased the seed size in soybeans.

2.7.3 Temperature

Chapman (1986) stated that beans is a warm season crop with an optimum temperature of about 24° C. It requires a frost-free period of 120 to 130 days. They further indicated that high temperatures between 29°C and 32°C cause dropping of buds and flowers, a phenomenon referred to as flower blasting, resulting in reduced yield. According to Laing *et al.*, (1984) a period of hot weather imposing heat–and/or drought–induced stress during reproductive development usually results in large yield losses. Heat reduces pod and seed set (Stobbe, Ormrod, & Wooley 1966; Dickson & Boettger, 1984; Weaver, Timm, Silbernagel & Burke 1985), and high temperatures during the night is more detrimental than during the day (Gross & Kigel, 1994.).

The common bean is a very sensitive plant specie in which excessive abscission of reproductive organs occur during hot weather. This results in interruption of pod set followed by resumption several days later, resulting in two different sizes of pods during the pod enlargement stage, often referred to as split set (Li, Davies & Shen, 1991). Plants exposed to extreme heat stress produce few or no pods.

Initiation of flowering and podding, and the maintenance thereof, is highly temperature sensitive. White *et al.* (1991) reports that both day-neutral and short day sensitive cultivars of beans respond to temperature change in a similar way, with days to flowering hastened by higher temperatures. They postulated that by changing the rate of flower bud development and presumably of pod growth, temperature affects the duration of flowering and seed filling and thus timing of maturity. Lienbenberg (1995), and Lusse (1996) reported that beans grow optimally at temperatures between 20°C and 24°C. In South Africa, temperatures below 20°C reduce crop growth rate while night / day temperatures of 15°C/20°C after flowering damage tissue, delay maturity and affect pod filling. This results in low seed yield. According to de Villiers (1975) night/day temperatures of 18°C/32°C for a seven day period followed by temperatures of 12°C/24°C during the pre-flowering stage, retarded flowering while exposure during flower-bud or early-flowering stages extended the flowering period, increased the number of flowers per plant and delayed maturity of the first pods. Allen & Smithson (1991); Allen, Dessert, Trutman & Voss (1989); and White *et al.* (1991) observed that mean temperatures between 16 to 24°C during the growth and development stages have bean associated with principal areas of bean production.

2.7.4 Soil fertility and nitrogen requirements

Nitrogen is often the most important factor limiting plant growth even though the atmosphere contains 78% nitrogen. It is the nutrient required in the greatest quantity by most crops. It is also one of the most complex in behaviour, occurring in soil, air and water in inorganic and

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organic forms (Archer, 1988). Chemically inert nitrogen gas can be made available to plants by symbiotic nitrogen fixation, which commonly occurs in nodules formed by R*hizobia* bacteria on the roots of leguminous plants. Plants supply the R*hizobia* with carbohydrates in return for nitrogen fixation by R*hizobia* (Velagaleti & Cline, 1995).

Much of the research regarding nitrogen fixation has focussed on grain and forage legumes. These legumes are able to fix significant amounts of nitrogen and thereby reduce requirements for inorganic nitrogen fertilizer. If the legumes are not harvested, they can be incorporated into the soil as green manure to provide nitrogen to subsequent crops.

High rates of nitrogen fixation can be obtained under appropriate conditions. Field studies using the ^{15}N isotope dilution technique shows maximum rates of nitrogen fixation equivalent to between 64 and 121kg N/ha per growth cycle (Adams *et al.*, 1985).

The fertility status of the soil can affect symbiotic nitrogen fixation directly by affecting initiation and development of nodules, hence influencing the efficiency of the legume-R*hizobium* symbiosis. It therefore plays an important role in the overall plant metabolism and growth (Mohamed, 1998). He further indicates that aluminium and manganese toxicity, soil pH, levels of nitrogen, phosphorus and molybdenum are some of the nutritional factors which can affect the efficiency of symbiosis in tropical soils. Common bean is exceptionally sensitive to very acidic soils, and poor plant growth, delayed nodulation and ultimately poor nitrogen fixation are some of the effects of acidic conditions (Liebenberg & Van Wyk, 1994) .The optimum pH for growth of bean plants and for the nitrogen fixation process is indicated as 5.5 to 6.7 (Graham, 1982)

Nitrogen deficiency usually has an overriding effect on growth and dominates the effects of other elements. Research studies of plant elemental composition with various plants show nitrogen as one of the elements found in large amounts. It has also been reported that the requirement for nitrogen exists through out the development of a plant to maintain growth, as nitrogen is a constituent of both structural (e.g. cell wall) and non-structural (e.g. enzymes, chlorophyll and nucleic acids) components of the cell.

It is generally believed that dry beans are not capable of satisfying all their nitrogen requirements by means of nitrogen fixation (Liebenberg & Van Wyk, 1994). Its nitrogen fixation capabilities are less effective than those of other legumes (Salema, 1987; Nyemba, Munyinda, Tembo, Mwale & Sakala, 1989). Dry beans require a supply of inorganic nitrogen in order to fully exploit its yield potential (Karel *et al.*, 1981)

The amount of nitrogen fixed by the common bean is dependent on the interaction among three factors: the host (bean) plant, the *Rhizobium* strain and the environment (Salema, 1987). Graham & Holliday (1977); Salema (1987) and Nyemba *et al.* (1989) reported that differences do exist among cultivars in their respective abilities to fix nitrogen. Most literature indicate a trend of climbing and late maturing cultivars being superior in fixing nitrogen compared to bush types and early maturing cultivars (Mohamed, 1998). Graham (1982) associates this with differences among the bean types in the duration of photosynthate supply to the roots and the nodules, since carbohydrate is the primary factor limiting nitrogen fixation in legumes.

Mohamed (1998) reports that rates of nitrogen fixation in common bean increases during the vegetative growth period, reaching its peak during flowering and early podding, and decreasing as pod filling progresses. During the reproductive stage more photosynthates are partitioned to developing pods than to the roots (Salema, 1987). Mohamed (1998) further states that in other legumes like soybean and cowpea, flowering occurs late, allowing a longer nitrogen fixation period. This is regarded as the reason why the common bean is inferior in nitrogen fixation compared to other legumes.

2.7.5 Nitrogen source

Nitrogen is absorbed by plants in either nitrate (NO_3^-) or ammonium (NH_4^+) form. However, most uptake at normal soil pH levels for crop production is as nitrate. Archer (1988) indicates that this is because of the rapid conversion of ammonium to nitrate in the soil following application of ammonium fertilizers.

Most nitrogen fertilizers contribute to soil acidity since their reaction in the soil increases the concentration of hydrogen ions in the soil solution. This is true especially with NH_4^+ based fertilizers (Western Fertilizer Handbook, 1985). Braun & Roy (1983) indicated that there is generally no difference in the efficacy of various types of nitrogenous fertilizers, but differences are occasionally observed under certain soil conditions for some crops. Bernardo,

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Clark & Maranville (1984a & b) reported an increase in dry matter yield and nitrogen uptake of sorghum plants fertilized with an NH_4^+ source rather than a NO_3^- source. Similar results were reported for vegetable amaranth. Plants fertilized with NH_4^+ grew taller and were higher in yield and leaf pigments than those receiving their nitrogen in the other forms (Makus, 1984). On the other hand, Mwamba, Rhoden, Ankumah & Khan (1992) and Vavrina & Obreza (1992) found no significant yield differences due to sources of nitrogen used in their studies with vegetable amaranth and Chinese cabbage respectively.

2.7.6 Plant density

Research studies with several annual crop species have shown that yield can be increased by growing appropriate cultivars at extremely high plant densities (Cooper, 1977; Grafton, Schneiter & Nagle (1988). Kwapata & Hall (1990) state that cultivars with different plant morphologies would require different optimum densities to express their full seed yield potential.

Adams (1967) indicates that very productive bean genotypes should have an optimum number of phytometric units (leaf plus pods), efficient source tissue and minimal structural tissues. This alludes to an ideotype with the ability to partition more of the photosynthates to the target sink, the seed, than to other plant parts. While plant density may influence light distribution in plant canopies, partitioning of photosynthates in soybean was barely influenced by density (Kwapata & Hall., 1990). Pilbeam, Hebblethwaite & Clark (1989) indicate that plant density, distance between adjacent rows of plants, or a combination of the two, influence interplant competition for all environmental resources. They further indicated that interplant competition intensifies if the plant density increases and the inter row spacing remain constant, or if the distance between the rows decreases while plant density remains unchanged. Any inter-plant competition may be expected to affect the growth and development of a plant and ultimately its yield.

According to Pilbeam *et al.*, (1989) studies on the effect of row width on the yield of Faba bean (*Vicia faba* L) have shown that seed yield increased as inter-row width decreased. However, these studies have used only conventional indeterminate cultivars. A possibility seems to exists for a dramatic change in inter-plant competition response due to a radical

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change in the morphology of a plant by using determinate cultivars. Grafton *et al.*, (1988) reported a yield increase in a determinate cultivar with increased plant population while row spacing x plant population interaction had no effect on yield for both determinate and indeterminate cultivars. They further indicated the need for more research in the genotype x row spacing interaction to determine potential production at specific row spacings.

2.8 GROWTH REGULATORS IN BEAN PRODUCTION

Premature abscission of reproductive structures in grain legumes results in loss of reproductive sink and is a critical factor determining harvestable yield (Clifford, Pentland & Baylis, 1992). They state that yield fluctuation in *Vicia faba* is primarily due to reproductive failure which can occur as a result of bud abortion, flower shedding, pod or ovule abortion. Flower losses due to premature abortion has been stated to range between 52 - 76% in *Phaseolus vulgaris* L. (Subhadrabandhu, Adams & Reicosky, 1978), 85% in *Vicia faba* (Soper, 1952) and 34% in *Pisum sativum* (Meadley & Milbourn, 1970). In tropical legumes, losses range from 83% in *Glycine max* (Van Schaik & Probst, 1958) to 54% in *Vigna unguiculata* (Ojehomon, 1970). Although Binnie & Clifford (1981) indicate a possibility of direct competition for assimilate or other nutrients being responsible for abscission of especially later formed flowers, they also strongly believe that reproductive yield is under hormonal control. Reduction or prevention of flower and pod abortion is important as it would improve the yield level of grain legumes, dry bean in particular. A means to control abscission is by way of application of exogenous plant growth regulators.

Plant growth regulators are increasingly used in horticulture, agriculture and forest industries to improve the efficiency of crop production. They are used for the control of growth, flowering, fruiting, senescence and dormancy (Luckwill, 1981). According to Keller & Belluci (1983) the main purpose of using growth regulators especially in Faba bean (*Vicia faba* L.) is the improvement in quantity and quality of the grain yield. Favourable influence on yield components such as podset per node, number of nodes with pods on a long part of a stem, grains per pod, single grain weight and uniform development of all pods per node are some of the expected effects of using growth regulators. According to Tamas, Wallace, Ludford & Ozbun (1979) specific literature regarding the regulation of these hormonal changes within a plant and the coordination of flower and pod abortion with overall plant development is scanty. Keller & Belluci (1983) also state that there is no known growth regulator treatment that consistently gives an economic increase in yield under field conditions.

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CHAPTER 3

SEED YIELD AND SEED YIELD COMPONENTS OF DRY BEANS AS AFFECTED BY PLANT DENSITY UNDER GREENHOUSE CONDITIONS

3.1 INTRODUCTION

The need to increase dry bean production emanates from the discrepancy that exists between production and consumption in South Africa and many other sub-Saharan countries. Consumption of dry beans is much higher than production and South Africa depends on importation of especially the red speckled dry bean types from China (Dry bean Producers' Organisation, 1999).

Disease has been one of the major contributors to low productivity and hence production of dry beans in many sub-Saharan countries (Nickel, 1989, Allen *et al.*, 1989) and South Africa in particular (Liebenberg, 1989). Over the years research has been conducted and cultivars which are agronomically more acceptable and offer greater tolerance to disease have been developed (Liebenberg *et al.*, 1994).

Despite the improvement in the past years, grain yield of dry beans remains relatively low and the yield potential of the crop is far from being achieved. To improve the quality of seed on the market, in vitro propagation has been used to develop disease free seed using meristem tissue culture techniques. The low seed yield from transplants in the greenhouse is a serious limitation (Theron, 1999, personal communication)[2]. One way of optimizing greenhouse production is by establishing the crop's response to plant population under such conditions.

Studies with several annual crop species have shown that yield can be increased by growing appropriate cultivars at high plant densities (Cooper, 1977; Grafton *et al.*, 1988). According to Pilbeam *et al.* (1989) plants with different morphologies may exploit the space available to them more or less effectively. Agreeing with the aforesaid, Kwapata & Hall (1990) reported that cultivars with different plant morphologies require different optimum densities to express their full seed yield potential. Achievement of high seed yield at very high plant density requires that a cultivar should efficiently use photosynthetically active radiation and

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[2] Dr D.J. Theron, Dry Bean Producer [illegible]. Box 15587, Lynn East, Pretoria

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effectively partition photosynthates to seed (Kwapata & Hall, 1990). Gifford, & Evans, (1981) indicate that the distribution of photosynthetic assimilate to particular organs depends more on the properties of the sinks themselves than the source. However, Egli, Guffy & Leggert (1985) indicate that the partitioning of dry matter between vegetative and reproductive growth during flowering and pot set (growth stages R1-R6) is relatively insensitive to environmental conditions or growth habit. They further observed constant partitioning coefficients during flowering and pod set, and concluded that variation in pod and seed number may be more closely related to crop growth rate than in the ability of the plant to allocate assimilates to the developing fruit.

Although some information is available on the effect of plant population on growth and yield under field conditions, no published data for greenhouse conditions could be found. The objective of this experiment was to determine the effect of plant population on the seed yield and yield components of dry beans under greenhouse conditions.

3.2 MATERIALS AND METHODS

Experiment 1

Two South African dry bean cultivars, Kranskop and Teebus, were planted in a greenhouse in April 1999 at the University of Pretoria Experimental Farm (Lat. 25° 45'S, Long.28° 16'E, elevation 1372masl). One litre capacity pots were filled with a clay loam soil and planted at a seeding rate of three seeds per pot. These were thinned to one plant per pot a week after emergence. The pots were then arranged in such a way that planting densities of 42 and 29 plants m^{-2} were established by use of two equidistant row x intra row spacing of 15.5 x 15.5 cm and 18.5 x 18.5 cm. Each treatment consisted of four pots (plants) which were arranged as completely randomised design with four replicates. Nitsch nutrient solution (Nitsch, 1972) was applied at a rate of 600 ml per application three times a week. Tap water was supplied on the other days to leach the soil and hence avoid salt accummulation.
Aldicarb (Temik), a systemic insecticide, was used for control of aphids and as a preventive measure against other insects. Furthermore a systemic fungicide, Triforine (Fungitex), was applied. All four plants in each treatment of each of the four replicates were harvested at maturity. . Seed yield (g $plant^{-1}$ and gm^{-2}), number of pods per plant, number of seeds per

pod, and seed size (100 seed mass) were recorded.

The data set was analysed using the General Linear Models (GLM) procedure of the Statistical System (SAS Institute, 1989) computer programme. Differences at the $P< 0.05$ level of significance are reported.

Experiment 2

The second experiment involved cultivar Kranskop at three plant densities. The trial was planted in a greenhouse on 30th October 1999, in 12 crates of size 60 x 55 x 20cm. The crates were filled with a clay loam soil. Planting was done at a seeding rate of two seeds per planting station, thinned to one after emergence. Plant densities of 44, 25 and 16 plants per square metre were established. This was achieved by equidistant row x intra-row spacings of 15 x 15, 20 x 20 and 25x 25 cm. These were designated as high, medium and low plant density treatments respectively. The crates were arranged as a completely randomised design (CRD) with four replicates. Nitsch nutrient solution (Nitsch, 1972) was applied three times a week. Tap water was supplied on the other days to leach the soil and hence avoid salt accumulation. Similar crop protection practices as in experiment 1 were used.

Each crate was considered as a plot and all plants in each crate were harvested at maturity on 7th March, 2000. Seed yield (g plant^{-1} and gm^{-2}), number of pods per plant, number of seeds per pod, seed size (100 seed mass) and harvest index (HI) were recorded.

The data set was analysed using the General Linear Models (GLM) procedure of the Statistical System (SAS Institute, 1989) computer program. Differences at the $P< 0.05$ level of significance are reported.

Experiment 3

In the third experiment, dry bean cultivar Kranskop was used at four very high plant densities. The trial was planted in a greenhouse on 31st August, 2000 in eight crates of size 60 x 55 x 20cm. The crates were filled with a clay loam soil as in experiment 2. Two seeds were planted per planting station and thinned to one after emergence. Plant densities of 200, 139, 100 and 69 plants m^{-2} were established. This was achieved by varying row x intra-row

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spacings of 10 x 5, 12 x 6, 10 x 10 and 12 x 12 cm respectively. The Nitsch nutrient solution (Nitsch, 1972) was applied three times a week. Tap water was supplied on the other days to leach the soil and hence avoid salt accumulation.

Similar crop protection practices as in experiments 1 and 2 were used. In addition, Tetradifon (Red spidercide) was applied once per week for three weeks to contain the red spidermite infection observed. The experimental conditions were favourable and resulted in vigorous growth as can be seen in Figure 3.1.

Each crate was considered as a plot and all plants in each crate were harvested at maturity on 25th November 2000 for all treatments except for the 10 x 10 and 10 x 5 cm spacing treatments which were harvested a week later on 2nd December, 2000. Mean values for seed yield (g plant^{-1} and gm^{-2}), number of pods per plant, number of seeds per pod, seed size (100 seed mass) and harvest index (HI), were recorded.

Due to the fact that only two replicates could be accommodated in the greenhouse, the data was not statistically analysed. Graphical presentation of the results was done to compare the different treatments.

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Figure 3.1 General appearance of the bean crop in the second crate experiment (Experiment 3)

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3.3 RESULTS

Experiment 1

Seed yield per plant did not differ significantly between both cultivars and plant densities (Table 3.1). However, there was a tendency for seed yield per plant decreasing with increasing plant density. The non-significant yield difference between the two cultivars could be attributed to opposite characteristics of two yield components; number of pods per plant and seed size. While cultivar Teebus had a significantly higher number of pods per plant, the 100 seed mass was very low. On the other hand, cultivar Kranskop had a low number of pods per plant (Table 3.3) but the 100 seed mass was high (Table 3.5).

Seed yield per unit area differed significantly, increasing with increasing plant density for both cultivars (Table 3.2). However, no significant difference was observed between the two cultivars, although the yield of cultivar Kranskop (322g m^{-2}) was somewhat higher than that of cultivar Teebus (276.6g m^{-2}).

Plant density did not affect the number of pods per plant for either of the cultivars, but cultivar Teebus produced significantly more pods per plant (9.1) than cultivar Kranskop (4.8) (Table 3.3). The number of seeds per pod did not differ significantly with changes in plant density (Table 3.4). However, cultivar differences were observed in response to plant density as indicated by the statistically significant interaction. While cultivar Teebus showed increase in the number of seeds per pod with increasing density, there was a slight decrease in the case of cultivar Kranskop. Cultivar Teebus produced more seeds per pod than cultivar Kranskop. Cultivar Kranskop seems to have been more sensitive to plant density than cultivar Teebus. This is seen by the reduction in the number of seeds per pod with increasing density (Table 3.4). Cultivar Teebus reacted in the opposite way, increasing the number of seeds per pod with increasing density. Seed size of cultivar Kranskop was much larger than that of cultivar Teebus (57g and 24 g/100 seeds respectively). Plant density did not affect the seed size (Table 3.5).

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Table 3.1 Effect of plant density on seed yield (g/plant) of two dry bean cultivars (ANOVA: Appendix Table 8.2A)

	CULTIVARS (C)		
Plants m^{-2}	Teebus	Kranskop	Mean
29	7.94	9.70	8.82
42	7.72	8.66	8.19
Mean	7.83	9.18	8.51
LSD	Cultivar (C)	ns	
	Density (D)	ns	
	C x D	ns	
SE	±0.53		
CV	16.2%		
R^2	0.30		

Table 3.2 Effect of plant density on seed yield (g m^{-2}) of two dry bean cultivars (ANOVA: Appendix Table 8.2B)

	CULTIVARS (C)		
Plants m^{-2}	Teebus	Kranskop	Mean
29	232.1	283.4	257.8
42	321.2	360.5	340.8
Mean	276.6	322.0	299.3
LSD	Cultivar (C)	ns	
	Density (D)	47.3	
	C x D	ns	
SE	±32.3		
CV	16.2%		
R^2	0.61		

Table 3.3 Effect of plant density on the number of pods per plant of two dry bean cultivars (ANOVA: Appendix Table 8.2C)

	CULTIVARS (C)		
Plants m^{-2}	Teebus	Kranskop	Mean
29	9.67	5.08	7.37
42	8.59	4.58	6.58
Mean	9.1	4.8	6.98
LSD	Cultivar (C)	1.5	
	Density (D)	ns	
	C x D	ns	
SE	±1.86		
CV	19.7 %		
R^2	0.77		

Table 3.4 Effect of plant density on the number of seeds per pod of two dry bean cultivars (ANOVA: Appendix Table 8.2D)

	CULTIVARS (C)		
Plants m^{-2}	Teebus	Kranskop	Mean
29	3.56	3.43	3.50
42	3.78	3.25	3.52
Mean	3.67	3.34	3.51
LSD	Cultivar (C)	0.24	
	Density (D)	ns	
	C x D	0.24	
SE	±0.12		
CV	6.30%		
R^2	0.50		

Table 3.5 Effect of plant density on the hundred seed mass (g) of two dry bean cultivars (ANOVA: Appendix Table 8.2E)

	CULTIVARS (C)		
Plants m^{-2}	Teebus	Kranskop	Mean
29	23.0	56.9	40.0
42	25.0	58.6	41.8
Mean	24.0	57.8	40.9
LSD	Cultivar (C)	2.77	
	Density (D)	ns	
	C x D	ns	
SE	±1.32		
CV	6.21%		
R^2	0.98		

Experiment 2

Seed yield per plant decreased with increasing plant density. The highest seed yield was observed at the lowest plant density and a reduction in seed yield was observed at the medium plant density treatment. No difference in seed yield was observed between the medium and high plant density treatments (Table 3.6). On the other hand, seed yield m^{-2} increased with increasing plant density. The highest seed yield was obtained at the high plant density treatment. No change in seed yield m^{-2} was observed between the low and medium plant density treatments.

The number of pods per plant differed significantly between the medium and high plant densities. However, no difference was observed between the low and medium plant densities. The highest number of pods per plant was observed at the low plant density, followed by the medium plant density treatment. These two treatments produced significantly more pods per plant than the high plant density treatment. Number of seeds per pod did not show any clear trend in its response to increased plant density. The highest number of seeds per pod was observed in the low and high plant density treatments while the medium plant density treatment had significantly less seeds per pod than the other treatments. The 100 seed mass followed a similar but opposite trend as number of seeds per pod. The low and high plant density treatments had smaller seeds than the medium plant density treatment. The lower number of seeds per pod was associated with larger seeds.

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Table 3.6 Effect of plant density on seed yield and seed yield components of dry bean, cultivar Kranskop (ANOVA: Appendix Table 8.3A – 8.3F)

	Seed yield (g/plant)	**Seed yield (gm^{-2})**	**No.pods /plant**	**No.seeds / pod**	**100 seed mass(g)**	**Harvest Index (%)**
Plants m^{-2}						
16	22.1a	354 b	13.1a	4.1a	48.2 b	48.8a
25	15.0 b	376 b	12.2a	3.8 b	52.1a	48.2a
44	13.1 b	581a	8.9 b	4.0a	48.8 b	46.9 b
LSD(p<0.05%)	5.62	136	1.11	0.12	0.54	0.91
C.V (%)	19.4	18.0	5.6	1.83	0.63	1.09

Means within the columns followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

Harvest index decreased with increasing plant density. No difference was observed in harvest index between the low and medium plant density treatments while a reduction in harvest index was observed between the medium and high plant density treatments. The highest harvest index was observed at the lowest plant density treatment. The low harvest index associated with the high plant density reflects a reduction in seed yield per plant with less effect on biomass.

Experiment 3

The seed yield per plant was affected by the plant density treatments applied. The highest seed yield per plant (6.6g) was obtained at the lowest plant density of 69 plants m^{-2} while the lowest seed yield per plant (3.9g) was produced at the highest plant density of 200 plants m^{-2}. The general trend observed was a reduction in seed yield per plant with increasing plant density (Figure 3.2).

The seed yield per unit area increased from 462.2g m^{-2} to 822.2g m^{-2} as plant density increased from 69 to 139 plants m^{-2} (Figure 3.2). The seed yield declined to 783.2g m^{-2} as plant density was further increased from 139 to 200 plants m^{-2}. Significant differences occurred in seed yield m^{-2} between the plant densities of 100 and 139 plants m^{-2}, while differences between the plant densities of 69 and 100 and also between 139 and 200 plants m^{-2} were not significant.

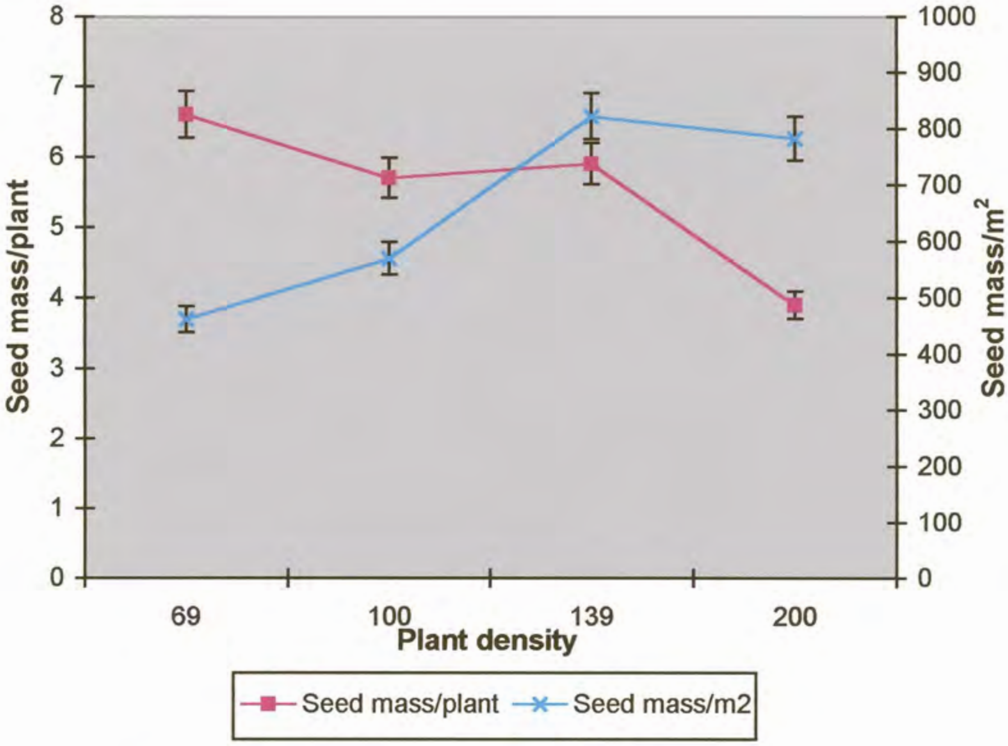

Figure 3.2 Effect of plant density on seed mass (g) of dry bean cv Kranskop

Figure 3.3 shows a decrease in the number of pods per plant as plant density increased from 69 to 200 plants m^{-2}. The pods decreased from 7.4 to 3.4 as the plant density increased. The number of seeds per pod remained relatively stable ranging from 3.0 to 3.2 seeds per pod.

The largest seed size (53.1g / 100 seeds) was obtained at a plant density of 100 plants m^{-2} while the smallest seed size (38.0g /100 seeds) was obtained at the highest plant density (Figure 3.4).

Only small differences were observed in the harvest index among the different plant density treatments as shown in Figure 3.4. A harvest index of 42.4% was obtained at the low plant density of 69 plants m^{-2} while 38.5% was obtained at the highest plant density of 200 plants m^{-2}.

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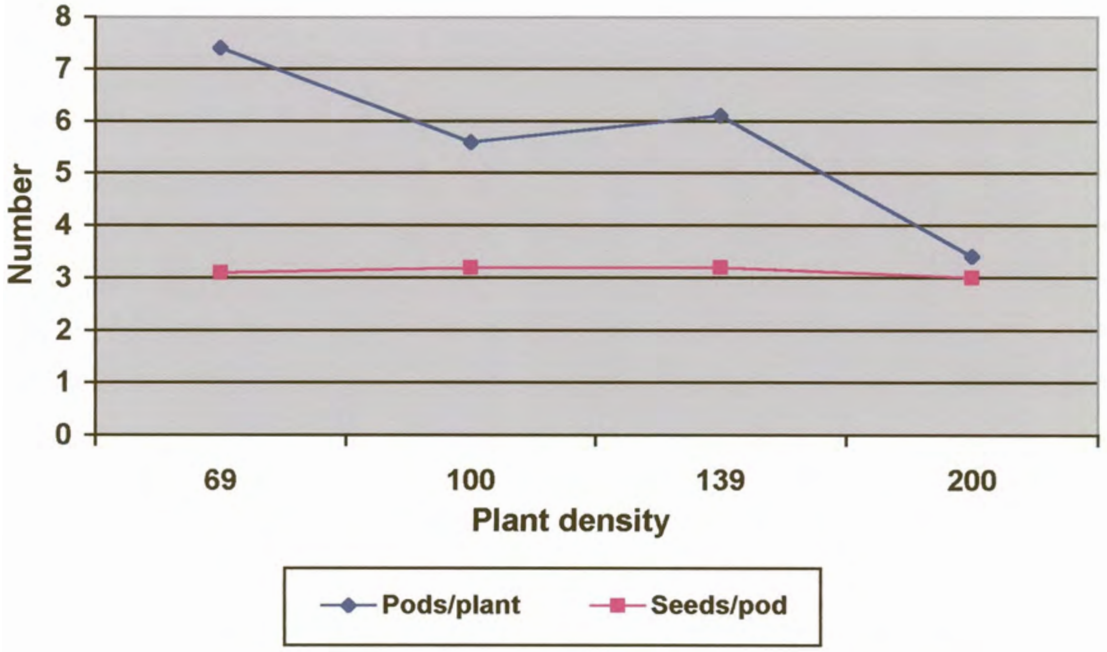

Figure 3.3 Effect of plant density on pods/plant and seeds/pod of dry bean cv Kranskop

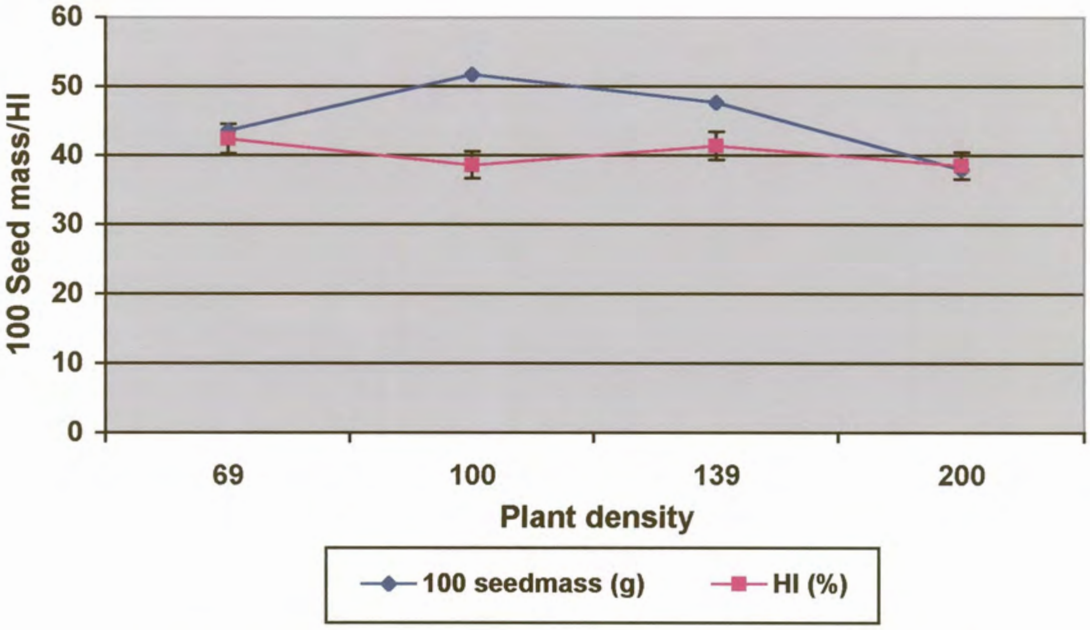

Figure 3.4 Effect of plant density on 100 seed mass (g) and HI (%) of dry bean cv Kranskop

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3.4 DISCUSSION

The results of the three experiments indicate an increase in yield m^{-2} as plant density increased. The yield m^{-2} continued to increase linearly for the treatments used in experiments 1 and 2, indicating the potential for continued increase in seed yield with increase in the plant density (Tables 3.2 and 3.6). Similar responses have been reported for faba beans (Pilbeam *et al.*, 1989), cowpeas (Kwapata & Hall, 1990), field beans (Crothers & Westermann, 1976) and soybeans (Lehman *et al*, 1960; Cooper, 1977). Seed yield increases in narrow rows compared to wide row spacings have been attributed to greater light interception (Shibles & Weber, 1966; Taylor, Mason, Bennie & Rowse, 1982). Greater light interception in narrow rows results from either larger leaf area index (LAI) and/or increased light interception per unit leaf area due to more uniform plant arrangement (Board & Harville, 1992). It has also been reported by Wells,Burton & Kilen (1993) that different canopy radiation environments created by plant architectural changes may increase plant productivity as reported for wheat, *Triticum aestivum* L. (Turner, Prasertsak & Setter, 1994), cotton, *Gossypium hirsutum* L. (Heitholt, 1994), sorghum, *Sorghum bicolor* (L) Moench (Caravetta, Cherney & Johnson, 1990) and soybean, *Glycine max* (L) Merr.(Duncan, 1986). Increased yield of soybean planted in narrow rows was attributed to enhanced radiation interception and greater photosynthetic rate. (Shibles *et al.*, 1966, Board, Harville & Saxton, 1990, and Wells, 1991). According to Board & Harville (1992) plants in narrow rows accumulate leaf area index faster than those in wide rows resulting in increased light interception.

Consistently an increase in yield per unit area was associated with a decrease in yield per plant. The reduction in seed yield per plant is associated with a reduced number of pods per plant. Seed yield per plant seems to be strongly related to number of pods per plant as shown in all three experiments. This was also reported by Crothers & Westermann (1976) and Aguilar *et al.* (1977). They indicated a direct relationship between number of pods per plant and bean seed yield. This follows a pattern reported earlier by other researchers (Adams, 1967; Bennett *et al.* 1977;) who stated that the first yield component formed in the reproductive phase, number of pods per plant, generally shows the greatest sensitivity, followed by number of seeds per pod and then seed size as stress intensifies.

As there were no changes in the number of seeds per pod, density stress was not strong enough to affect it, indicating the possibility of increasing density without effect on seeds per pod. It seems that the number of seeds per pod is a relatively stable yield component regardless of the intensity of the density stress applied. Yield component compensation in these trials was only observed between number of seeds per pod and 100 seed mass in experiment 2. The treatment with the lowest number of seeds per pod had the largest 100 seed mass while that with the largest number of seeds per pod had the lowest seed size. However, this was not enough to offset the reduction in the number of pods per plant hence a decrease in yield per plant at high density in the first two experiments.

Donald (1968) defined the partitioning of photosynthate to seed as the ratio of seed yield to total shoot dry mass. This ratio, referred to as the harvest index, does not only link seed yield to total plant biomass, but also integrates the complex processes of plant growth, development and translocation of photosynthates from source leaves to the seed (Kwapata & Hall, 1990). However, since it is measured at maturity, it neglects changes in partitioning between vegetative and reproductive plant parts that may occur during the growth and development of the crop (Donald & Hamblin, 1976). In all three trials, the first yield component of number of pods per plant was reduced with increasing plant population, indicating an early limitation in the sink size. The potential sink size seem to have been determined during the flowering and podset stages (R1 - R6). Any excess photosynthate could only be partitioned to non storage organs such as leaves and petioles as observed in dry bean and soybean (Liebenberg, 1989). Thus the proportion of assimilates allocated to reproductive growth during this period could have a direct effect on pod and seed number and seed size (Egli *et al.*, 1985). In experiment 2 the magnitude of the compensatory effect observed between seeds per pod and seed size was too subtle to offset the observed reduction in pods per plant and seed yield per plant.

3.5 CONCLUSION

The study has demonstrated that seed yield can be increased by increasing plant density in greenhouse multiplication. Yields as high as 822.2g m^{-2} were obtained at a plant density of 139 plants m^{-2} beyond which a reduction was observed. There was a minimal effect on seed size and number of seeds per pod. The cost of production per unit area and the cost of a unit area of greenhouse space and the convenience of crop management would ultimately determine the density level for production at such high densities.

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CHAPTER 4

SEED YIELD AND YIELD COMPONENTS OF DRY BEANS AS AFFECTED BY ROW AND INTRA-ROW SPACING UNDER FIELD CONDITIONS

4.1 INTRODUCTION

Plant spacing (plant density) is important in obtaining maximum seed yield under given soil and climatic conditions. It influences the morphology of the crop (Ramseur, Wallace, & Quisenberry, 1985) and in some crops, spacing has indirect effect on weed control, soil erosion, insect populations and disease development (Nangju, Little & Anjorin-Ohu, 1975). Narrow row spacing and high density planting have increased seed yield of some crops. Lehman & Lambert (1960) reported that narrow row spacing of 0.51m increased yield of two soybean (*Glycine max* L. Merrill) cultivars compared to planting at 0.9m spacing. It has also been observed that when environmental stress affecting final yield occurs during the development of a bean plant, the yield component that is formed first in the reproductive phase, the number of pods per plant, generally shows the greatest stress response, followed by seeds per pod and finally weight per seed (Bennet *et al.*, 1977). Plant density constitutes a special kind of stress, approaching its greatest effect at the time of maximum leaf area that coincides with the early reproductive phase of the bean plant. Westerman & Crothers (1977) reported the existence of a positive and highly significant relationship between seeds per pod and pods per plant of indeterminate cultivars and no correlation for determinate cultivars. They also observed a positive linear relationship between pods per plant and growing area per plant for both determinate and indeterminate cultivars.

For successful seed production of dry beans, knowledge of the optimum row and intra-row spacing is required under field conditions. Understanding the response of dry bean to increasing plant density in the field should contribute towards optimising plant density under greenhouse conditions.

It is against this background that the seed production of two South African dry bean cultivars, Kranskorp and Teebus was studied at varying row and intra-row spacings in a field experiment. The objective of this study was to determine the effect of row width, intra-row spacing and the resulting plant density, on yield and yield components

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4.2 MATERIALS AND METHODS

Two South African cultivars Kranskop and Teebus were planted in a field experiment on 31st January, 2000 at the University of Pretoria experimental farm (Lat. 25° 45'S, Long.28° 16'E, elevation 1372masl). The soil is classified as mesotrophic, luvic dark red brown soil of the Hutton form (Soil Classification Working Group, 1991) and by the USDA Soil Taxonomy System (Soil Survey Staff, 1990), as loamy, mixed thermic Rhodic Kaundidalf (Nel, Barnard, Steynberg, De Beer & Groeneveld, 1996).

A systematic planting design was used in which the position of the plants were determined by the intersection of radii and arcs of concentric circles. The concentric circle lengths of 20, 40, 60, 80 & 100cm between two adjacent radii, increasing as the radii length increase from the centre were designated as the row width. The radii length from the centre were six metres in and the outermost spacing between two adjacent radii was 100cm. Different intra-row spacings of 15, 20,30 and 40cm were used along the radii. Four adjacent radii were planted to each intra-row spacing of 15, 20, 30, and 40cm. The growing area occupied by each plant therefore increased systematically as the radii length from the centre increased. Plants were harvested from each of the intersection of radii and arcs as designated. Each treatment consisted of four radii as replications. The general layout is illustrated in figure 4.1 and the applicable growing area available per plant is shown in Table 4.1. Table 4.2 shows the number of plants m^{-2} associated with the respective row x intra-row spacing used. Nelder (1962); Crothers & Westermann (1976) and Westermann & Crothers (1977) describe similar experimental layouts.

The cultivar Kranskop was planted on one half of the circle and cultivar Teebus on the other (see figure 4.1). The crop was rainfed and supplementary irrigation was applied when dry spells occurred. Aldicarb (Temik), a systemic insecticide, was applied for control of aphids and Triforine (Fungitex), a systemic fungicide, was also applied. Hoe and hand weeding were done to keep the field weed free during the production period. Harvesting was done on the 11th of May, 2000 for cultivar Teebus and 21st May for cultivar Kranskop after most of the leaves had dropped.

The experiment was considered as a completely randomised design as suggested by Crothers & Westermann (1976).

The data set was analysed using the General Linear Models (GLM) procedure of the Statistical System (SAS Institute Inc. Cary, NC., USA 1989) computer program. Differences at the $P< 0.05$ level of significance are reported.

Table 4.1 Growing area per plant (m^2) at each radius x arc intersection.

Intra-row (between arcs) spacing (m)	Row (between radii) spacing (m)				
	0.20	0.40	0.60	0.80	1.00
0.15	0.03	0.06	0.09	0.12	0.15
0.20	0.04	0.08	0.12	0.16	0.20
0.30	0.06	0.12	0.18	0.24	0.30
0.40	0.08	0.16	0.24	0.32	0.40

Table 4.2 Plant population m^{-2} at each radius x arc intersection.

Intra-row (between arcs) spacing (m)	Row (between radii) spacing (m)				
	0.20	0.40	0.60	0.80	1.00
0.15	33.3	16.7	11.1	8.3	6.7
0.20	25.0	12.5	8.3	6.2	5
0.30	16.7	8.3	5.6	4.2	3.3
0.40	12.5	6.2	4.2	3.1	2.5

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Figure 4.1 Layout of field experiment showing the design and two cultivars, Teebus on the left and Kranskop on the right side.

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4.3 RESULTS

Effect of row and intra-row spacing on yield per plant

As can be expected from a field experiment with four replicates and only one plant per treatment plot, the coefficient of variation was relatively high (40%). Consequently some treatment effects are obscured. Row and intra-row main effects, cultivar x intra-row interaction and second order interactions significantly affected seed yield per plant, while cultivar main effect, cultivar x row and row x intra-row interactions did not (Tables 4.3a & 4.3b).

Main effects. No difference in mean seed yield per plant was observed between cultivar Kranskop and cultivar Teebus, but was somewhat higher for cultivar Kranskop (9.8g) than cultivar Teebus (9.6g). Significant differences were observed among all intra-row spacing treatments except between 20 and 30cm and between 15 and 30cm spacing (Table 4.3b). Decreasing intra-row spacing from 40 to 15cm resulted in decreased mean seed yield per plant. Similarly, mean seed yield per plant decreased as row spacing decreased from 100 to 20cm apart (Table 4.3b). The difference between 20cm and all other row spacing treatments and between 100cm and all other row spacing treatments were significant. No differences were observed among the 40, 60 and 80cm row spacing treatments. The best yields per plant were obtained at the 80cm row spacing (11.5g) and 40cm intra-row spacing (12.0g) (Table 4.3b).

First order interactions. The significant cultivar x intra-row spacing treatment shows that the two cultivars responded differently to different intra-row spacing treatments. As can be seen in Table 4.3a, cultivar Teebus produced the highest yield per plant (11.6g) at intra-row spacing of 40cm. For cultivar Kranskop the intra-row spacing of 20cm apart resulted in the best yield per plant (12.4g).

Second order interactions. The significant second order interactions shows that the three parametres were not independent of each other in influencing seed yield per plant. The highest seed yield per plant was obtained at 80 x 40cm row x intra-row spacing for cultivar Teebus (16.8g) followed by 60 x 40cm (16.1g) and the lowest at 20 x 20cm (3.5g). Cultivar

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Kranskop produced the highest seed yield per plant (17.8g) at 60 x 20cm followed by 15.8g at 40 x 40cm spacing and lowest (4.9g) at 20 x 20cm spacing.

Table 4.3a Effect of row and intra-row spacing on seed yield per plant (g) of two dry bean cultivars (ANOVA: Appendix Table 8.4A).

INTRA-ROW SPACING (cm)	ROW SPACING (cm)					
	20	40	60	80	100	INTRA-ROW MEAN
			TEEBUS			
15	3.9	8.1	8.5	9.3	9.1	7.8
20	3.5	8.8	8.0	10.1	8.2	7.7
30	5.9	13.4	12.8	13.9	10.3	11.3
40	6.1	12.2	16.1	16.8	7.0	11.6
ROW MEAN	4.9	10.6	11.4	12.5	8.7	9.6
			KRANSKOP			
15	7.1	7.3	8.0	7.7	6.2	7.3
20	4.9	12.3	17.8	14.5	12.2	12.4
30	6.2	7.7	7.1	6.8	7.6	7.1
40	12.0	15.8	10.2	12.6	11.0	12.3
ROW MEAN	7.6	10.8	10.8	10.4	9.3	9.8

LSD ($p \leq 0.05$) : C x I = 2.3; C x R x I = 5.0; SE = 1.8 $R^2 = 0.7$ CV (%) = 40.0

C = Cultivar R = Row spacing I = Intra-row spacing

LSD - values given only where treatment effects were significant.

Table 4.3b Mean seed yield per plant (g) of dry bean as affected by row and intra-row spacing (ANOVA: Appendix Table 8.4A).

INTRA-ROW SPACING (cm)	ROW SPACING (cm)					
	20	40	60	80	100	INTRA-ROW MEAN
15	5.5	7.7	8.2	8.5	7.7	7.5
20	4.2	10.5	12.9	12.3	10.2	10.0
30	6.0	10.5	10.0	10.4	9.0	9.2
40	9.0	14.0	13.2	14.7	9.0	12.0
ROW MEAN	6.2	10.7	11.1	11.5	9.0	9.7

LSD ($p \leq 0.05$) : R = 1.8; I = 1.6; SE = 1.3 $R^2 = 0.7$ CV (%) = 40.0

R = Row spacing I = Intra-row spacing

LSD - values given only where treatment effects were significant.

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Effect of row and intra-row spacing on seed yield per unit area

The data for the effect of cultivar, row and intra-row spacing on seed yield m^{-2} is presented in Table 4.4a, while Table 4.4b shows the mean seed yield m^{-2} (g m^{-2}) as affected by row and intra-row spacing. All main effects and all first order interactions were significant while second order interactions were not.

Main effects. As first order interactions were significant, little can be said about main effect treatments. On average cultivar Kranskop yielded better (88.0g m^{-2}) than cultivar Teebus (76.6g m^{-2}) over all spacing treatments (Table 4.4a). Decreasing intra-row spacing from 40cm to 15cm was associated with significantly increasing seed yield per unit area except between 15 and 20cm and between 30 and 40cm intra-row spacing treatments (Table 4.4b). Decreasing row spacing from 100cm to 20cm apart also contributed to higher seed yield per unit area with all row spacing treatments differing significantly (Table 4.4 b). The best seed yield m^{-2} (125.8g m^{-2}) was obtained at the narrow row spacing of 20cm and 106.5g m^{-2} was produced at 15cm intra-row spacing (Table 4.4b).

First order interactions. The significant first order interactions indicate that the cultivars responded differently to both row and intra-row spacing. Cultivar Kranskop produced somewhat higher yields per unit area than cultivar Teebus, with a significantly higher yield (115.4g m^{-2}) at 20cm intra-row spacing. The low yield (51.7g m^{-2}) of cultivar Kranskop at 30cm intra-row spacing, contributed to the significance of the interaction (Table 4.4a). For cultivar Teebus the intra-row spacing of 15cm resulted in a significantly higher yield per unit area (99.8g) than the three wider intra-row spacings. For cultivar Kranskop the intra-row spacings of 15 and 20cm resulted in higher yield (113.2g m^{-2} and 115.4g m^{-2} respectively) than the two wider spacings.

The cultivar x row interaction was due to the fact that the cultivars produced similar yields per unit area at all the row spacings except where the rows were 20cm apart. At this narrow row spacing cultivar Kranskop (153.0g m^{-2}) far out yielded cultivar Teebus (98.7 g m^{-2}), indicating that cultivar Kranskop adapts better to high plant population situations than cultivar Teebus. The highest seed yield (108.2g m^{-2}) was produced at the 40cm row spacing for cultivar Teebus whereas the narrow row spacing of 20cm produced the highest seed yield

m^{-2} (153.0g m^{-2}) for cultivar Kranskop (Table 4.4 a). The row x intra-row interaction significantly affected the seed yield m^{-2}. The highest yield (183.6g m^{-2}) was produced at the narrow row x intra-row spacing treatment combination of 20 x 15cm, followed by 131.6g m^{-2} at 40 x 20cm (Table 4.4b).

Second order interactions. Inspite of the second order interaction not being significant, interesting trends in performance among the treatment combinations were observed. Cultivar Kranskop produced the highest yield (235.8g m^{-2}) at the 20 x 15cm row x intra-row spacing while cultivar Teebus did so at the 40 x 15cm spacing producing 135.4g m^{-2}. The lowest yield (17.5g m^{-2}) was obtained at 100 x 40cm row x intra-row spacing for cultivar Teebus and 100 x 30cm row x intra-row spacing for cultivar Kranskop (29.9g m^{-2}) (Table 4.4a).

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Table 4.4a Effect of row and intra-row spacing on seed yield m^{-2} (g m^{-2}) of two dry bean cultivars (ANOVA: Appendix Table 8.4B).

INTRA-ROW SPACING (cm)	ROW SPACING (cm)					
	20	40	60	80	100	INTRA-ROW MEAN
			TEEBUS			
15	131.4	135.4	94.6	77.2	60.7	99.8
20	88.4	109.4	66.5	63.2	41.1	73.7
30	99.0	111.6	71.0	57.9	34.5	74.8
40	75.9	76.6	67.0	52.5	17.5	57.9
ROW MEAN	98.7	108.2	74.8	62.7	38.4	76.6
			KRANSKOP			
15	235.8	122.4	102.3	63.9	41.7	113.2
20	123.2	153.8	148.4	90.4	61.3	115.4
30	103.3	62.2	39.7	28.2	25.3	51.7
40	149.6	98.6	43.2	39.4	27.4	71.6
ROW MEAN	153.0	109.2	83.4	55.5	38.9	88.0

LSD ($p \leq 0.05$): C = 10.2; C x R = 22.8; C x I = 20.4

SE = 16.5 R^2 = 0.7 CV (%) = 40.1

C = Cultivar R = Row spacing I = Intra-row spacing

LSD - values given only where treatment effects were significant.

Table 4.4b Mean seed yield m^{-2} (g m^{-2}) of dry bean as affected by row and intra-row spacing (ANOVA: Appendix Table 8.4B).

INTRA-ROW SPACING (cm)	ROW SPACING (cm)					
	20	40	60	80	100	INTRA-ROW MEAN
15	183.6	128.9	98.4	70.6	51.2	106.5
20	105.8	131.6	107.4	76.8	51.2	94.6
30	101.2	86.9	55.3	43.0	29.9	63.3
40	112.7	87.6	55.1	46.0	22.4	64.8
ROW MEAN	125.8	108.8	79.0	59.1	38.7	82.3

LSD ($p \leq 0.05$) : R =16.2; I = 14.4; R x I = 32.3; SE = 11.6 R^2 = 0.7 CV (%) = 40.1

R = Row spacing I = Intra-row spacing

LSD - values given only where treatment effects were significant.

Effect of row and intra-row spacing on the number of pods per plant

Tables 4.5a and 4.5b summarise the data of the effect of cultivar, row and intra-row spacing on the number of pods per plant and mean number of pods per plant of dry bean as affected by row and intra-row spacing respectively. All main effects, first order and second order interactions were highly significant.

Main effects. On average cultivar Kranskop had a higher number of pods per plant (6.4) than cultivar Teebus (5.9). The number of pods per plant decreased with decreasing intra-row spacing (Table 4.5b). Over all row spacing and cultivar treatments, the highest number of pods per plant (6.9) was produced at the 40cm intra-row spacing. The row spacing treatments did not show a clear trend as row spacing decreased from 100 to 20cm apart. The highest number of pods per plant (7.2) was produced at the 40cm row spacing treatment while the lowest (5.0) was produced at the narrow row spacing of 20cm.

First order interactions. The largest number of pods per plant (7.6) over all row spacing treatments was obtained at the 15cm intra-row spacing for cultivar Teebus and 40cm intra-row spacing for cultivar Kranskop (8.9) (Table 4.5a). The trend observed was an increase in the number of pods per plant with decreasing intra-row spacing treatments from 40 to 15cm apart for cultivar Teebus while for cultivar Kranskop the trend was opposite, decreasing with decreasing intra-row spacing. The significant cultivar x row spacing interaction was due to the fact that pod numbers for the two cultivars were affected similarly by row width, except at the 20cm row width where cultivar Kranskop produced significantly more pods per plant (5.7) than cultivar Teebus (4.4). The two cultivars had the largest number of pods per plant at the 40cm row spacing. Cultivar Teebus produced on average 6.8 pods per plant while cultivar Kranskop produced 7.5 pods per plant (Table 4.5a).

Second order interactions. The significant second order interaction indicates that cultivars were affected differently by the different row and intra-row spacing treatment combinations. Cultivar Teebus produced the highest number of pods per plant (9.8) at the row x intra-row spacing of 40 x 15cm, followed by 8.1pods per plant at 80 x 15cm and lowest (2.9) at 20 x 30cm. On the other hand cultivar Kranskop produced the highest number of pods per plant (12.2) at 40 x 40cm followed by 10.9 pods per plant at 20 x 40cm and lowest (3.4) at 20 x 20cm (Table 4.5a).

Table 4.5a Effect of row and intra-row spacing on number of pods per plant of two dry bean cultivars (ANOVA: Appendix Table 8.4C).

INTRA-ROW SPACING (cm)	ROW SPACING (cm)					
	20	40	60	80	100	INTRA-ROW MEAN
			TEEBUS			
15	7.1	9.8	7.6	8.1	5.2	7.6
20	3.8	6.6	5.4	6.1	5.6	5.5
30	2.9	5.6	7.4	6.7	6.0	5.7
40	3.8	5.2	5.4	5.1	4.9	4.9
ROW MEAN	4.4	6.8	6.5	6.5	5.4	5.9
			KRANSKOP			
15	4.5	5.2	5.6	4.8	4.5	4.9
20	3.4	6.6	9.9	7.8	7.0	6.9
30	3.9	5.9	4.4	4.5	5.0	4.7
40	10.9	12.2	6.4	8.5	6.5	8.9
ROW MEAN	5.7	7.5	6.6	6.4	5.8	6.4

LSD ($p \leq 0.05$): C x R = 1.1; C x I = 1.0; C x R x I = 2.2;

SE = 0.8 $R^2 = 0.7$ CV (%) = 26.9

C = Cultivar R = Row spacing I = Intra-row spacing

LSD - values given only where treatment effects were significant

Table 4.5b Mean number of pods per plant of dry bean as affected by row and intra-row spacing (ANOVA: Appendix Table 8.4C).

INTRA-ROW SPACING (cm)	ROW SPACING (cm)					
	20	40	60	80	100	INTRA-ROW MEAN
15	5.8	7.5	6.6	6.4	4.8	6.2
20	3.6	6.6	7.6	7.0	6.3	6.2
30	3.4	5.8	5.9	5.6	5.5	5.2
40	7.4	8.7	5.9	6.8	5.7	6.9
ROW MEAN	5.0	7.2	6.6	6.4	5.6	6.1

LSD ($p \leq 0.05$): R = 0.8; I = 0.7; R x I = 1.6 SE = 0.6 $R^2 = 0.7$ CV (%) = 26.9

R = Row spacing I = Intra-row spacing

LSD - values given only where treatment effects were significant

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Effect of row and intra-row spacing on number of seeds per pod

The data for the effect of cultivar, row and intra-row spacing on the number of seeds per pod and the mean number of seeds per pod of dry bean as affected by row and intra-row spacing are presented in Tables 4.6a & 4.6b respectively. Only cultivar and intra-row spacing main effects were significant while row main effect and both first and second order interactions were not.

Main effects. Cultivar Teebus produced significantly more seeds per pod (3.7) than cultivar Kranskop (3.2). The number of seeds per pod decreased as intra-row spacing decreased from 40 to 15cm apart within the row. The highest number of seeds per pod (3.6) was set at the wide intra-row spacing treatment of 40cm. Row spacing did not affect the number of seeds per pod (Table 4.6b).

Second order interaction. The non significant second order interaction indicate that the different parametres affected seed set independent of each other at all treatment combinations applied. However, the highest number of seeds per pod (4.1) was set by cultivar Teebus at the 80 x 40cm row x intra-row spacing while cultivar Kranskop produced the highest number of seeds per pod (3.8) at 80 x 20cm row x intra-row spacing (Table 4.6a).

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Table 4.6a Effect of row and intra-row spacing on number of seeds per pod of two dry bean cultivars (ANOVA: Appendix Table 8.4D).

INTRA-ROW SPACING (cm)	ROW SPACING (cm)					
	20	40	60	80	100	INTRA-ROW MEAN
			TEEBUS			
15	3.2	4.0	4.0	3.6	3.5	3.6
20	3.3	4.0	3.6	3.7	3.8	3.7
30	3.8	3.7	4.0	3.9	3.7	3.8
40	4.0	3.6	3.6	4.1	3.9	3.8
ROW MEAN	3.6	3.8	3.8	3.8	3.7	3.7
			KRANSKOP			
15	3.1	2.9	2.9	2.9	2.9	2.9
20	3.0	3.1	3.3	3.8	3.1	3.3
30	3.5	2.9	3.2	3.3	3.2	3.2
40	3.2	3.7	3.3	3.3	3.3	3.4
ROW MEAN	3.2	3.1	3.2	3.4	3.1	3.2

LSD ($p \leq 0.05$): C = 0.1; SE = 0.1 $R^2 = 0.5$ CV (%) = 13.4

C = Cultivar I = Intra-row spacing

LSD - values given only where treatment effects were significant

Table 4.6b Mean number of seeds per pod of dry bean as affected by row and intra-row spacing (ANOVA: Appendix Table 8.4D).

INTRA-ROW SPACING (cm)	ROW SPACING (cm)					
	20	40	60	80	100	INTRA-ROW MEAN
15	3.2	3.4	3.4	3.2	3.2	3.3
20	3.2	3.6	3.4	3.8	3.4	3.5
30	3.7	3.3	3.6	3.6	3.4	3.5
40	3.6	3.6	3.4	3.7	3.6	3.6
ROW MEAN	3.4	3.4	3.5	3.6	3.4	3.5

LSD ($p \leq 0.05$): I = 0.2 SE = 0.2 $R^2 = 0.5$ CV (%) = 13.4

R = Row spacing I = Intra-row spacing

LSD - values given only where treatment effects were significant

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Effect of row and intra-row spacing on hundred seed mass (g)

Tables 4.7a & b outline the effect of cultivar, row and intra-row spacing on hundred seed mass and mean hundred seed mass (g) of dry bean as affected by row and intra-row spacing respectively. Only cultivar main effects were highly significant while row, intra-row and both first and second order interactions were not.

Main effects. Cultivar Kranskop had a larger seed size (47.5g per 100 seed) than cultivar Teebus (22.9g per 100 seed) over all row and intra-row spacing treatment combinations (Table 7a). Although row and intra-row spacing main effects were not significant the trend was for the seed size to decrease as spacing decreased from 40 to 15cm within the row, and as spacing decreased from 100 to 20cm between the rows (Table 4.7b).

Second order interactions. The cultivar x row width x intra-row spacing interaction was not significant.. The largest seed size (27.9g per 100 seed) was produced at 60 x 30cm row x intra-row spacing for cultivar Teebus while for cultivar Kranskop the largest seed size (52.0g per 100 seed) was produced at 100 x 30cm row x intra-row spacing (Table 4.7a).

Table 4.7a Effect of row and intra-row spacing on hundred seed mass (g) of two dry bean cultivars (ANOVA: Appendix Table 8.4E).

INTRA-ROW SPACING (cm)	ROW SPACING (cm)					
	20	40	60	80	100	INTRA-ROW MEAN
			TEEBUS			
15	19.4	17.7	21.8	24.1	23.0	21.2
20	21.7	22.5	22.6	24.3	22.9	22.8
30	20.9	24.1	27.9	23.7	22.2	23.8
40	22.3	23.2	25.1	25.6	22.5	23.7
ROW MEAN	21.1	21.9	24.4	24.4	22.6	22.9
			KRANSKOP			
15	47.3	48.2	49.7	44.8	50.3	47.0
20	45.1	45.2	42.9	45.6	49.9	49.1
30	48.9	48.9	48.1	47.4	52.0	45.7
40	45.7	47.7	48.1	45.1	48.4	48.1
ROW MEAN	46.8	47.5	47.2	45.7	50.2	47.5

LSD ($p \leq 0.05$): C = 1.4 SE = 2.3 $R^2 = 0.9$ CV (%) = 12.9

C = Cultivar R = Row spacing I = Intra-row spacing

LSD - values given only where treatment effects were significant

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Table 4.7b Mean hundred seed mass (g) of dry bean as affected by row and intra-row spacing (ANOVA: Appendix Table 8.4E).

INTRA-ROW SPACING (cm)	ROW SPACING (cm)					
	20	40	60	80	100	INTRA-ROW MEAN
15	32.5	32.7	35.0	34.6	35.7	34.1
20	35.3	35.7	35.4	35.9	37.4	35.9
30	33.0	34.6	35.4	34.6	36.0	34.7
40	34.8	35.7	37.4	35.2	36.4	35.9
ROW MEAN	33.9	34.7	35.8	35.1	36.4	35.2
LSD ($p \leq 0.05$); C = 1.4			SE = 1.6	R^2 = 0.9	CV (%) = 12.9	

C = Cultivar R = Row spacing I = Intra-row spacing

LSD - values given only where treatment effects were significant

Effect of row and intra-row spacing on harvest index (%)

The data for the effect of cultivar, row and intra-row spacing on harvest index are presented in Table 4.8a while the mean harvest index of dry bean as affected by row and intra-row spacing are in Table 4.8b. Cultivar and row main effects and all first order interactions were significant while the intra-row main effect and second order interaction were not.

Main effects. The significance of cultivar and row main effects suggest that these two parametres had an influence on harvest index while intra-row spacing did not. As all first order interactions were significant, the effect of the treatments were not independent of each other. On average cultivar Kranskop had a higher harvest index (56.8%) than cultivar Teebus (46.4%) (Table 4.8a).

First order interactions. All first order interactions were significant, an indication that the two cultivars responded differently to different row x intra-row spacing treatment combinations. The highest harvest index was produced at 30cm intra-row spacing for cultivar Teebus (49.6%) and 40cm intra-row spacing for cultivar Kranskop (59.2%). Cultivar Teebus produced the highest harvest index (50.8%) at 80cm row spacing while cultivar Kranskop (58.6%) did so at 60cm row spacing (Table 4.8a). Furthermore, the highest harvest index (57.8%) was produced at 80 x 20cm row x intra-row spacing combination (Table 4.8b).

Second order interactions. The second order interaction was not significant. For cultivar

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Teebus the highest harvest index of 54.8% was obtained at 80 x 30cm row x intra-row spacing and the lowest (33.0%) at 20 x 15cm row x intra-row spacing. For cultivar Kranskop the highest harvest index (64.0%) was observed at 80 x 20cm row x intra-row spacing and the lowest harvest index of 50.2% at 100 x 15cm spacing (Table 4.8a).

Table 4.8a Effect of row and intra-row spacing on harvest index (%) of two dry bean cultivars (ANOVA: Appendix Table 8.4E).

INTRA-ROW SPACING (cm)	ROW SPACING (cm)					
	20	40	60	80	100	INTRA-ROW MEAN
			TEEBUS			
15	33.0	47.0	50.5	48.2	45.0	44.7
20	33.5	49.0	48.5	51.5	48.0	46.1
30	41.2	54.2	48.2	54.8	49.5	49.6
40	39.8	49.2	47.5	48.8	40.0	45.1
ROW MEAN	36.9	49.8	48.7	50.8	45.6	46.4
			KRANSKOP			
15	53.2	56.2	59.5	50.5	50.2	53.9
20	51.8	59.0	63.2	64.0	56.8	59.0
30	58.8	57.0	52.8	53.0	53.8	55.1
40	62.5	59.0	59.0	61.5	54.2	59.2
ROW MEAN	56.6	57.8	58.6	57.2	53.8	56.8

LSD ($p \leq 0.05$): C = 1.9; C x R = 7.2; C x I = 6.5; SE = 3.0 $R^2 = 0.7$

CV (%) = 11.8

C = Cultivar R = Row spacing I = Intra-row spacing

LSD - values given only where treatment effects were significant

Table 4.8b Mean harvest index (%) of dry bean as affected by row and intra-row spacing (ANOVA: Appendix Table 8.4E).

INTRA-ROW SPACING (cm)	ROW SPACING (cm)					
	20	40	60	80	100	INTRA-ROW MEAN
15	43.1	51.6	55.0	49.4	47.6	49.3
20	42.6	54.0	55.9	57.8	52.4	52.5
30	50.0	55.6	50.5	53.9	51.6	52.3
40	51.1	54.1	53.2	55.1	47.1	52.1
ROW MEAN	46.7	53.8	53.6	54.0	49.7	51.6

LSD ($p \leq 0.05$): R = 4.2; R x I = 10.2; SE = 2.1 $R^2 = 0.7$ CV (%) = 11.8

C = Cultivar R = Row spacing I = Intra-row spacing

LSD - values given only where treatment effects were significant

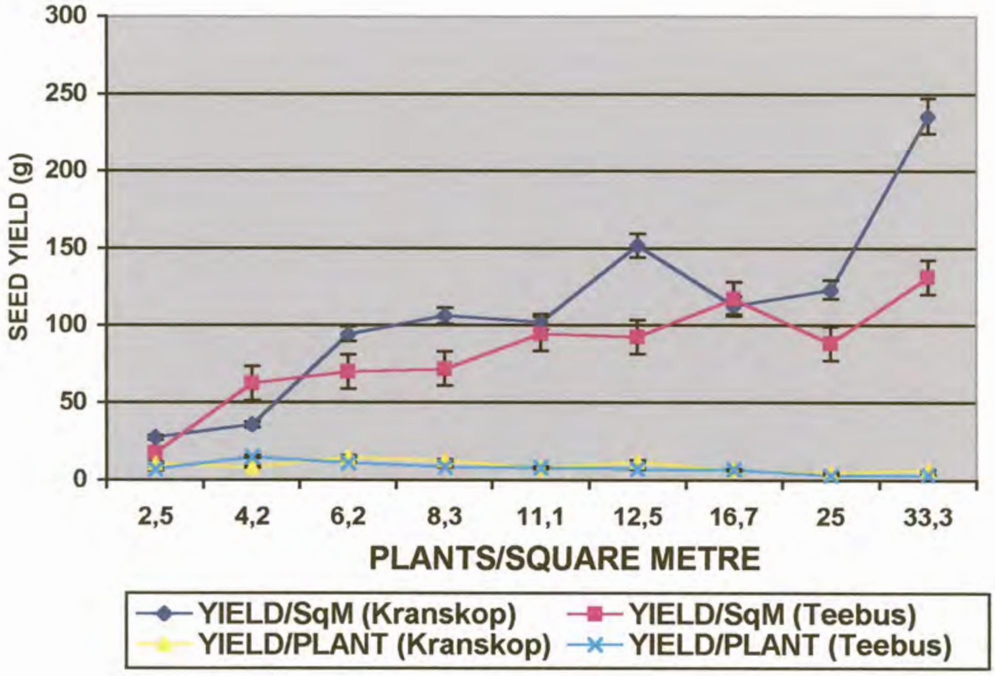

Figure 4.2 Effect of plant density on seed yield of dry bean

Effect of plant density on seed yield and yield components

By expressing the combined effect of row and intra-row spacing in terms of plant population per unit area, the effects of plant density on seed yield and yield components were quantified. These results are presented in Figure 4.2 to Figure 4.4. Not all treatment combinations are presented as some combinations were either the same or so similar that their exclusion had little or no influence on the treatment effects (see Table 4.1 & 4.2).

The seed yield per plant for both cultivar Kranskop and cultivar Teebus remained relatively stable as plant density increased from 2.5 to 33.3 plants m^{-2} (Figure 4.2). On the other hand, seed yield m^{-2} increased with increasing plant density for both cultivars. The rate of increase in seed yield m^{-2} was similar for both cultivars, with cultivar Kranskop producing somewhat higher yield than cultivar Teebus.

Figure 4.3 shows the effect of plant density on the number of pods per plant and number of seeds per pod for both cultivar Kranskop and cultivar Teebus. The number of pods per plant decreased as plant density increased for both cultivars. Cultivar Kranskop had a slightly higher number of pods per plant than cultivar Teebus at almost all plant density treatments.

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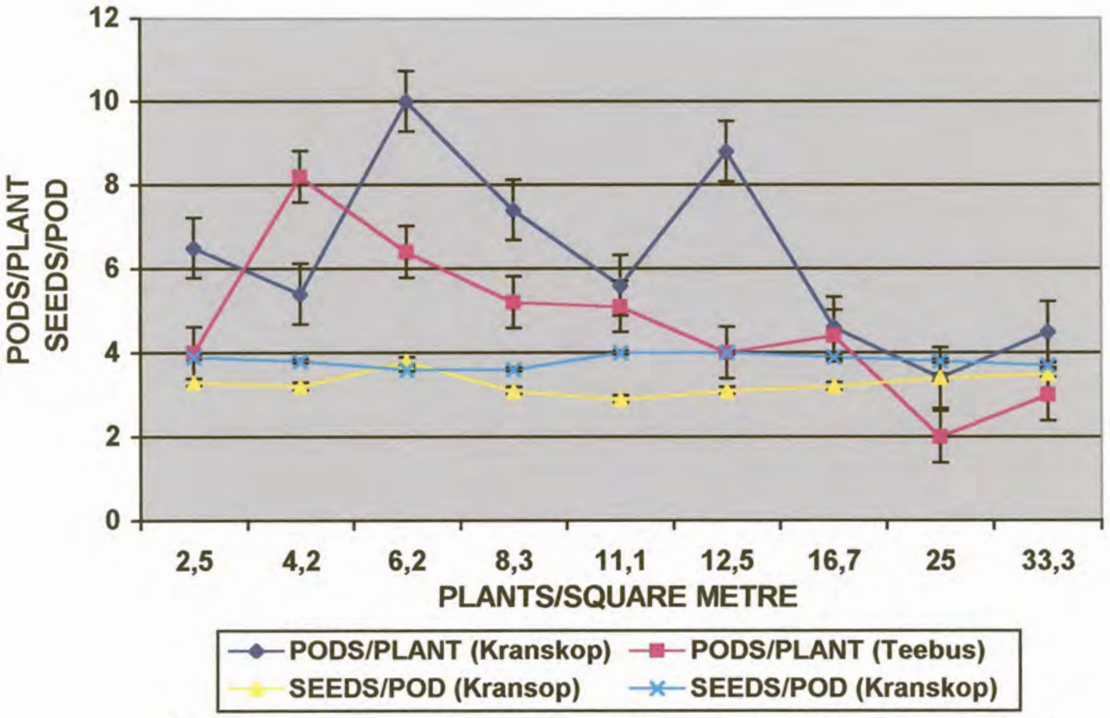

Figure 4.3 Effect of plant density on number of pods per plant and seeds per pod of dry bean

The number of seeds per pod were not affected by plant density for both cultivars. This yield component remained relatively stable as plant density increased despite a decrease in the number of pods per plant, an indication that the density stress was not strong enough to affect the number of seeds per pod. Cultivar Teebus consistently had a slightly higher number of seeds per pod than cultivar Kranskop

The effect of plant density on hundred seed mass and harvest index is shown in Figure 4.4. Cultivar Kranskop had a significantly larger hundred seed mass than cultivar Teebus but remained relatively stable for both cultivars as plant density increased.

The harvest index was higher for cultivar Kranskop than cultivar Teebus at all plant density treatments. The harvest index for both cultivars initially remained stable, but decreased slightly as plant density increased beyond 12.5 plants m^{-2}.

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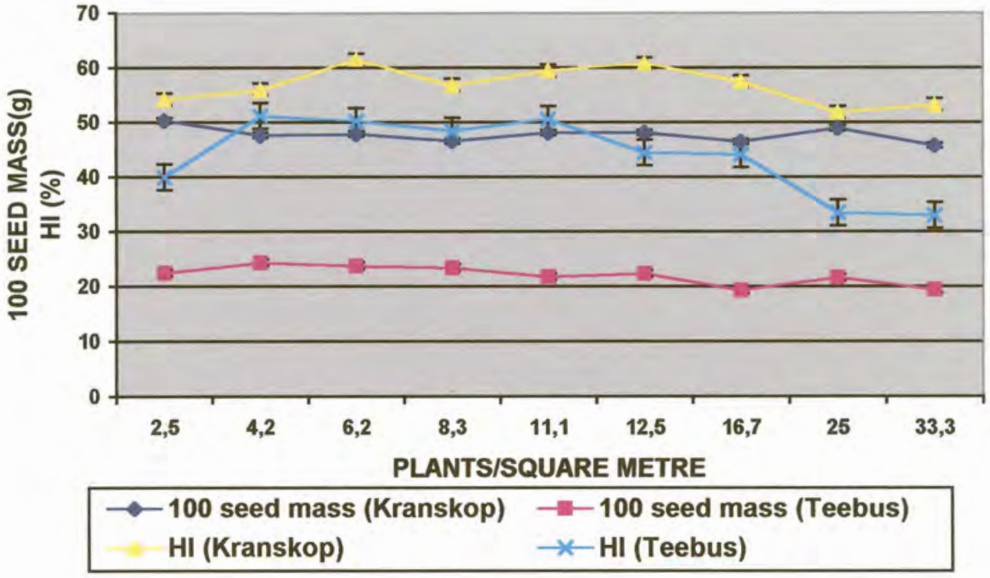

Figure 4.4 Effect of plant density on 100 seed mass (g) and HI (%) of dry bean

4.4 DISCUSSION

The data on seed yield m^{-2} shows that planting at both narrow row and intra-row spacings result in higher yields than planting at wider spacings. This is however dependent on the cultivar. Both cultivar Teebus and cultivar Kranskop produced highest seed yield m^{-2} at different row x intra-row spacing (Table 4.4a), an indication of the difference in yield potential. There was tendency of yield m^{-2} increasing with increasing plant density for both cultivar Teebus and cultivar Kranskop (Figure 4.2). Similar trends and cultivar differences have been reported for cowpea by Kwapata & Hall (1990). They observed significant seed yield increases in one cultivar but not in the other as plant density increased from 100 000 to 400 000 ha^{-1} (10 to 40 plants m^{-2}). Seasonal differences were also reported with higher yields at high densities in one season, but not in another season. This is a typical example of where another factor other than plant density limits the yield in poor seasons. It is therefore possible that yield response to higher plant density is greatest when conditions are more favourable.

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Although the small number of plants actually harvested does not warrant extrapolation of the yields obtained to a hectare basis, it is interesting to note that the yield for the best treatment combination in our trial of 20 x 15cm row x intra-row was equivalent to 2.36t ha^{-1}. Liebenberg, (1989) obtained seed a yield of 4.3t ha^{-1} in his source-sink relationship trial of dry bean, cultivar Teebus at a density of 15 plants m^{-2}. In cowpea, yields of 3.3t ha^{-1} were observed by Kwapata & Hall (1990) at a density of 40 plants m^{-2} in plant density trials while Kayode & Odulaja (1985) found cowpea seed yields of 3.7t ha^{-1} at a density of 16.6 plants m^{-2}. Higher seed yields of up to 8.2t ha^{-1} were observed in the greenhouse trial at a plant density of 139 plants m^{-2} (see Chapter 3).

The number of pods per plant significantly decreased with increasing plant density while the seed size was only slightly affected. The number of seeds per pod and 100 seed mass showed subtle declines with increasing plant population. Differences were also observed in the response of the cultivars to plant density. Cultivar Kranskop seemed to be less sensitive to increased density than cultivar Teebus. This indicates that cultivar Kranskop would better adapt to high density and narrow row x intra-row spacing. Wiggans (1939) reported that the soybean plant have the ability to adjust to differences in plant densities, and that the narrower the distance between rows, until the distance between rows equals the space between plants in the row, the greater the yield.

Mack & Hatch (1968) report that dry bean plants planted in a square (12.7 x 12.7 to 15.2 x 15.2cm) produced the highest number of pods per unit area than those planted in more rectangular spacings, with the optimum depending upon the cultivar. According to Crandall (1971) snap beans for processing produced 64% more pods with a narrow row spacing of 30cm compared to a row spacing of 90cm. Cooper (1977) also reported yield advantages of between 10 to 20% in soybean when planted at narrow row spacing of 17cm compared to row spacing of either 50 or 75cm. In all these studies the number of pods per plant decreased, but on a unit area basis significant increases were recorded. Brathwaite (1982) reported significant reductions in the number and size of pods per plant of bodie bean as density increased. This was associated with a significant increase in the number of pods per unit area.

The number of plants per unit area seem to be more critical than the number of pods per plant in influencing seed yield per unit area. This was observed for both cultivars Kranskop and

Teebus with the highest yield m^{-2} and number of pods per plant obtained at different row x intra-row spacing. The highest number of pods per plant was obtained at a lower density than seed yield m^{-2}. According to Wiley & Heath (1961) yield of plants depends on both plant density and the spatial arrangement of these plants (plant rectangularity), i.e. the ratio of the distance between plants within the row to the distance between the rows. This highlights the importance of equidistant spacing even at high plant density as a way of optimising production as indicated by Mack & Hatch (1968).

4.5 CONCLUSION

The results presented here and by Kueneman *et al.* (1979) and Brathwaite (1982) point to the fact that high seed yield m^{-2} can be obtained at high plant density and narrow row and intra-row spacing. The 20 x 15cm row x intra-row spacing produced the highest seed yield. Since seed yield m^{-2} continued to increase linearly, higher plant densities are possible as suggested by Mack & Hatch (1968). However, more equidistant planting generally tend to give higher yields than in more rectangular planting (Kueneman *et al.*, 1979). Cultivar differences seem to exist in their responses to both plant density and growing environment.

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