# OPTIMISATION OF DRY BEAN (*Phaseolus vulgaris* L.) SEED PRODUCTION UNDER GREENHOUSE CONDITIONS

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BY

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## ABSTRACT

Means of optimising dry bean seed production under greenhouse conditions were investigated using two dry bean cultivars, Kranskop and Teebus. The objective was to optimise dry bean seed multiplication in the greenhouse with the view to multiplying disease free dry bean seed. The effect of plant density on seed yield and yield components was determined. Furthermore, the influence of different nitrate / ammonium ratios and their concentration in the nutrient solution were quantified. Finally, the effect of a cytokinin-containing growth regulator, a seaweed extract, was also evaluated.

Seed yield $m^{-2}$ increased linearly with increasing plant population, until a plant density of 139 plants $m^{-2}$ was reached, beyond which no further increase was observed. A seed yield of 823.6g $m^{-2}$ was produced. This was associated with a steady decrease in seed yield per plant and number of pods per plant. The number of seeds per pod and the seed size remained stable with a small decrease observed at very high plant densities.

The nitrate / ammonium ratio affected vegetative growth, seed yield and yield components. Plants receiving the nutrient solution containing 14:1 and 1:1 $NO_3^-$: $NH_4^+$ ratios grew vigorously and produced seed yields of 19.1g and 21.2g per plant respectively, while those receiving the nutrient solution containing 1:14 $NO_3^-$: $NH_4^+$ ratio produced only 7.3g of seed per plant. No significant differences were observed among plants receiving the different nutrient solution concentration treatments. However, plants receiving the full strength and half strength nutrient solutions produced seed yields of 16.2g and 16.0g per plant respectively, while those receiving the quarter strength nutrient solution yielded 15.5g per plant. The results indicate that the half strength nutrient solution containing either 1:14 or 1:1

$NO_3^-$: $NH_4^+$ ratios would be the most cost effective.

Treatment with a cytokinin-containing growth regulator, a seaweed extract (trade name Marinure) at the recommended and double rates did not effect seed yield and yield components under greenhouse conditions.

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**KEY WORDS**: Plant density, Nitrate / ammonium ratio, concentration, nutrient solution, cytokinin-containing growth regulator.

## SUMMARY

The effect of plant density, nitrate / ammonium ratio and concentration and a cytokinin-containing growth regulator on vegetative growth, seed yield and yield components of dry bean were studied in a series of pot experiments and a plant density field trial.

### Plant density

One pot experiment, two crate experiments and a field experiment were undertaken to study the effect of plant density on vegetative growth, seed yield and yield components of beans.

Pot experiment

Cultivars Teebus and Kranskop were planted in one litre pots filled with a clay loam soil. Plant densities of 42 and 29 plants $m^{-2}$ were established using spacings of 15.5 x 15.5 cm and 18.5 x 18.5 cm in the greenhouse. The seed yield per unit area of cultivar Teebus increased from 232g to 321g $m^{-2}$ while that of cultivar Kranskop increased from 283g to 360g $m^{-2}$ as plant density increased from 29 to 42 plants $m^{-2}$. No cultivar differences were observed. Seed yield per plant did not differ between cultivars nor between plant densities.

Crate experiment 1

Three plant densities of 44, 25 and 16 plants $m^{-2}$ were established by planting cultivar Kranskop at spacings of 15 x 15 cm, 20 x 20 cm and 25 x 25 cm in crates of size 60 x 55 x 20 cm. Seed yield per unit area increased from 354 to 581g $m^{-2}$ as plant density increased from 16 to 44 plants $m^{-2}$ while seed yield per plant decreased from 22.1 to 13.1g.

Crate experiment 2

High plant densities of 200, 139, 100 and 69 plants $m^{-2}$ were established by planting cultivar Kranskop at spacings of 10 x 5, 12 x 6, 10 x 10 and 12 x 12 cm in crates of size 60 x 55 x 20 cm. Seed yield per unit area increased from 462 to 822g $m^{-2}$ as plant density was increased from 69 to 139 plants $m^{-2}$, beyond which seed yield declined to 783g $m^{-2}$. Seed yield per plant decreased from 6.6 to 3.9g per plant as plant density increased from 69 to 200 plants $m^{-2}$.

Field experiment

Cultivars Teebus and Kranskop were planted in a systematic planting design where the position of plants were determined by the intersection of radii and arcs of concentric circles. The growing area occupied by each plant increased systematically as the radius increased. Seed yield data was recorded from four adjacent radii at each concentric circle for each plant population of 2.5, 4.2, 6.2, 8.3, 11.1, 12.5 16.7, 25 and 33.3 plants $m^{-2}$. Seed yield per unit area increased as plant density increased while seed yield per plant remained relatively stable for both cultivars. However, cultivar Kranskop yielded somewhat more seed per plant than cultivar Teebus at all plant densities.

**Nitrate / ammonium ratio**

Two pot experiments were conducted to determine the effect of nitrate / ammonium ratio and the concentration of nutrient solutions on vegetative growth, seed yield and yield components of dry bean cultivar Kranskop

Pot experiment 1

Cultivar Kranskop was planted in 10 litre Mitscherlich pots filled with sterilised sand. The plants were supplied with 14:1 and 1:1 $NO_3^-$: $NH_4^+$ ratios at full strength and half strength nutrient solution concentrations. Although differences were observed in vegetative growth of the crop due to different $NO_3^-$: $NH_4^+$ ratios and nutrient solution concentrations, no differences were observed in seed yield and yield components.

Pot experiment 2

In the second experiment cultivar Kranskop was planted in 8 litre pots filled with sterilised sand. The plants were supplied with 14:1, 1:1 and 1:14 $NO_3^-$: $NH_4^+$ ratios at full strength, half strength and quarter strength nutrient solution concentrations. Vegetative growth decreased with decreasing nutrient solution concentration, while plants receiving high $NH_4^+$-N (1:14 $NO_3^-$: $NH_4^+$ ratio) showed poor vegetative growth compared to those in the other treatments. Plants receiving the nutrient solutions containing 14:1and 1:1 $NO_3^-$: $NH_4^+$ ratios at full strength and half strength concentrations performed far better than those receiving the nutrient solution containing a higher ammonium ratio or any of the nutrient solutions at the quarter strength.

**Cytokinin-containing growth regulator**

The cytokinin-containing growth regulator, a seaweed extract, was applied at the recommended rate of 8ml per 1 litre nutrient solution, double rate of 16ml per 1 litre nutrient solution and a control (no growth regulator) to plants grown in 8 litre pots filled with sterilised sand. Data for vegetative growth, seed yield and yield components was recorded and analysed. Vegetative growth, seed yield and yield components were not affected by the different growth regulator treatments applied.

The more important conclusions from these trials are:

i. The relative high seed yields of 580g $m^{-2}$ and 822g $m^{-2}$ obtained with the cultivar Kranskop is indicative of the viability of greenhouse multiplication in the dry bean seed multiplication programme. Very high plant populations (up to 139 plants $m^{-2}$) are indicated. However, the optimum plant population for commercial multiplication will depend on a number of factors which include cultivar, container size, nutrition and convenience of management.

ii. A nitrate / ammonium ratio in the nutrient solution with more ammonium than nitrate detrimentally affected yield. The results indicate that good yields can be obtained with nitrate/ammonium ratios of 14:1 or 1:1. Similar yields were obtained with the nutrient solutions at the full strength and half strength, indicating possible cost savings by applying diluted nutrient solutions.

iii. Application of a cytokinin-containing growth regulator did not increase seed yield. The use of plant growth regulants to limit abscission of flowers and pods deserves more research attention.

## OPSOMMING

Die invloed van plantdigtheid, die nitraat / ammoniak verhouding in die voedingsmedium en die effek van 'n sitokinien bevattende groeireguleerder, op vegetatiewe groei, saadopbrengs en opbrengskomponente van droëbone is ondersoek.

Plantdigtheid

Een potproef, twee proewe in plantkratte en 'n veldproef is onderneem om die effek van plantdigtheid op vegetatiewe groei, saadopbrengs, en opbrengskomponente te kwantifiseer.

Potproef

Kultivars Teebus en Kranskop is in een liter potte, gevul met 'n kleileem grond, geplant. Plantdigthede van 42 en 29 plant $m^{-2}$ is verkry met spasiërings van 15,5 x 15,5 cm en 18,5 x 18,5 cm in die kweekhuis. Die saadopbrengs per eenheidsoppervlakte van die kultivar Teebus het verhoog vanaf 232g $m^{-2}$ na 321g $m^{-2}$, terwyl dié van kultivar Kranskop verhoog het vanaf 283g $m^{-2}$ na 360g $m^{-2}$ namate die plantdigtheid verhoog het vanaf 29 na 42 plant $m^{-2}$. Saadopbrengs per plant het nie verskil tussen die kultivars en die plantdigthede wat gebruik is nie.

Kratproef 1

Drie plantdigthede van 44, 25 en 16 plante $m^{-2}$ is verkry deur kultivar Kranskop te plant met spasiërings van 15 x 15 cm, 20 x 20 cm en 25 x 25 cm in kratte van 60 x 55 x 20 cm grootte. Saadopbrengs per vierkante meter het verhoog van 354 na 581g $m^{-2}$ namate die plantdigtheid verhoog het vanaf 16 na 44 plante $m^{-2}$, terwyl die saadopbrengs per plant terselfdertyd afgeneem het vanaf 22,1 na 13,1g.

Kratproef 2

Hoë plantdigthede van 200, 139 en 69 plante $m^{-2}$ is gevestig deur kultivar Kranskop te plant in spasiërings van 10 x 5, 12 x 6, 10 x 10 en 12 x 12 cm in kratte van 60 x 55 x 20 cm grootte. Saadopbrengs het verhoog vanaf 462 na 822g $m^{-2}$ namate die plantdigtheid verhoog is vanaf 69 na 139 plante $m^{-2}$. Saadopbrengs per plant het afgeneem vanaf 6,6g per plant tot 3,9g per plant namate die plantdigtheid verhoog het vanaf 69 na 200 plante $m^{-2}$.

Veldproef

Kultivars Teebus en Kranskop is geplant in 'n wawiel-uitleg waar die posisie van die plante bepaal is deur die interseksie van radiusse en boë van konsentriese sirkels. Die groei-area wat opgeneem is deur elke plant het dus sistematies vergroot namate die radius verleng het. Saadopbrengs is bepaal by populasies van 2.5, 4.2, 6.2, 8.3, 11.1, 12.5, 16.7, 25 en 33.3 plante $m^{-2}$. Saadopbrengs per eenheidsoppervlakte het verhoog namate die plantdigtheid verhoog het, terwyl saadopbrengs per plant relatief stabiel gebly het vir beide kultivars. Kranskop het ietwat meer saad per plant geproduseer as Teebus.

Nitraat / ammoniak verhouding

Twee potproewe is gedoen om die effek van nitraat / ammoniak verhoudings en konsentrasies van voedingsoplossings op groei, saadopbrengs en opbrengskomponente van droëboon kultivar Kranskop te bepaal.

Potproef 1

Saad van kultivar Kranskop is geplant in 10 liter Mitscherlich potte, gevul met gesteriliseerde saad. Die plante is voorsien met voedingsoplossings met 'n 1:14 $NO_3^-$ : $NH_4^+$ verhouding of 'n 1:1 $NO_3^-$ : $NH_4^+$ verhouding. Die voedingsoplossings is teen volle sterkte (die aanbevole konsentrasie) en teen half sterkte toegedien.

Alhoewel verskille waargeneem is in vegetatiewe groei as gevolg van die $NO_3^-$ : $NH_4^+$ verhouding en nutriënt konsentrasie, is geen verskille waargeneem in saadopbrengs en opbrengskomponente nie.

Potproef 2

In die tweede proef is kultivar Kranskop geplant in 8 liter potte gevul met gesteriliseerde saad. Die plante is benat met voedingsoplossings met 'n 1:14, 'n 1:1 en 'n 14:1 $NO_3^-$ : $NH_4^+$ verhouding teen volle sterkte, half sterkte en kwart sterkte van die voedingsoplossings. Vegetatiewe groei het afgeneem met verlaagde voedingsoplossing konsentrasies, terwyl die plante wat hoë $NH_4^+$ -N ontvang het genieg was om swakker vegetatiewe groei te ontwikkel as dié in die ander behandelings. Plante wat die 1:14 verhouding en die 1:1 verhouding teen volle sterkte en half sterkte ontvang het, het hoër opbrengste gelewer as behandelings met die hoë $NH_4^+$ - konsentrasie, of waar 'n kwart van die standaard voedingsoplossing konsentrasie

gebruik is.

Sitokinien-bevattende groeireguleerder

'n Sitokinien-bevattende groeireguleerder is toegedien teen die aanbevole peil van 8ml per 1 liter asook teen 16 ml per 1 liter voedingsoplossing. Vegetatiewe groei, saadopbrengs en opbrengskomponente is nie geaffekteer deur die verskillende groeireguleerder-behandelings nie.

Die belangrikste gevolgtrekkings van hierdie ondersoek is:

I. Die relatiewe hoë saadopbrengste van 580 g $m^{-2}$ en 820 g $m^{-2}$ wat met die kultivar Kranskop verkry is in die glashuisproewe dui op die lewensvatbaarheid van 'n glashuis-vermeerderingsfase in 'n droëboon saad-program. Baie hoë plantpopulasies (139 $m^2$) het die beste resultate gelewer. Die optimum plantpopulasie vir kommersiële vermeerdering sal afhang van faktore soos kultivar, kratgrootte, voeding, ensovoorts.

II. 'n Mengsel van $NO_3^-$-N en $NH_4^+$-N met dieselfde hoeveelheid of meer $NO_3^-$ as $NH_4^+$ word aanbeveel. Die resultate dui daarop dat die standaard voedingsoplossing-konsentrasie onnodig hoog is, en dat dieselfde opbrengste behaal kan word deur die voedingsoplossing teen halfsterkte toe te dien.

III. Geen verbetering in opbrengs is verkry met die gebruik van 'n sitokinien-bevattende groeireguleerder nie. Die gebruik van plantgroeistowwe om afspening van blomme en jong peule te beperk verdien egter verdere navorsingsaandag.

# 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.

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.



[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).

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).

## 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

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.

## 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).

## 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

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

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,

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

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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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

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 25$^{th}$ 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 2$^{nd}$ 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.

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

## 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).

**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.

**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.

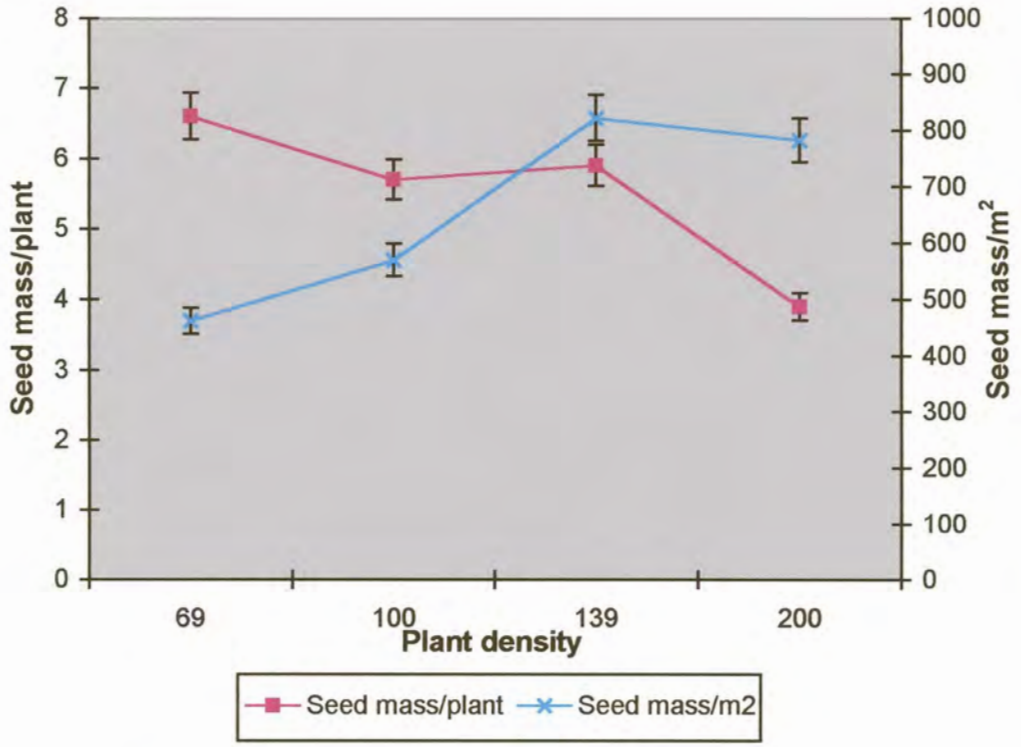


**Figure 3.2** Effect of plant density on seed mass (g) of dry bean cv Kranskop

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 $m^{-2}$.

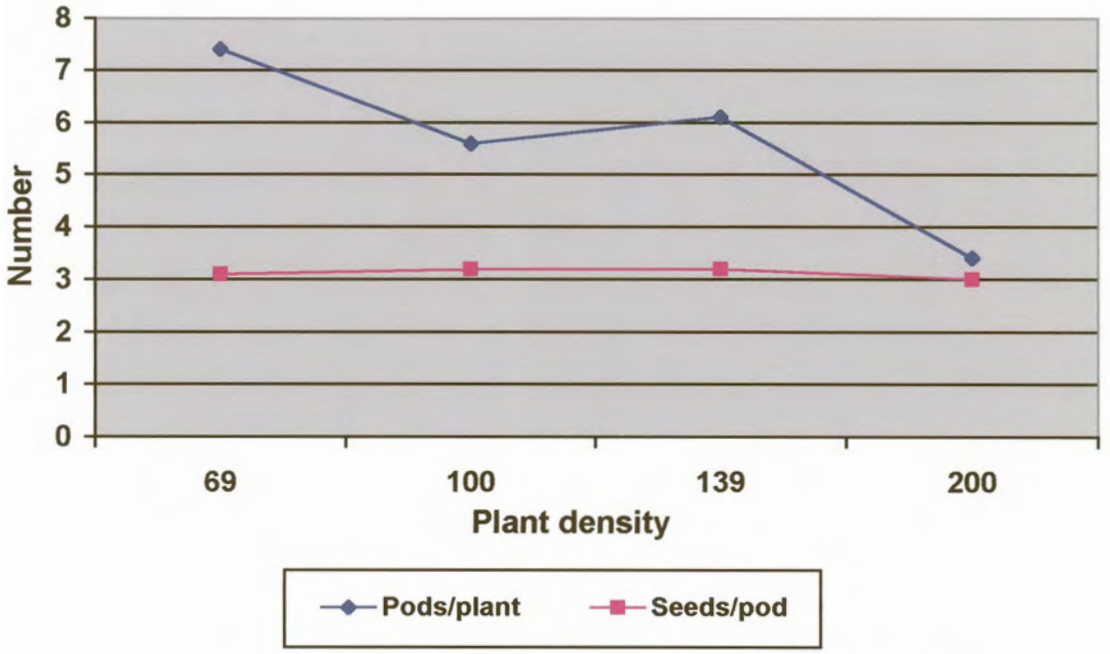


**Figure 3.3** Effect of plant density on pods/plant and seeds/pod of dry bean cv Kranskop

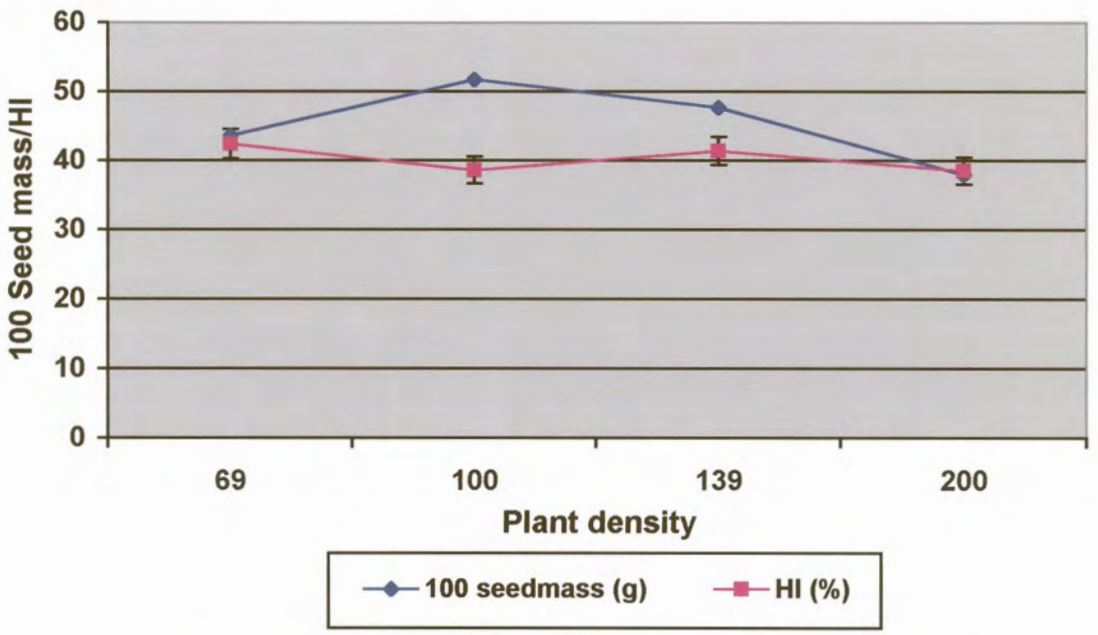


**Figure 3.4** Effect of plant density on 100 seed mass (g) and HI (%) of dry bean cv Kranskop

## 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

## 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 |

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

## 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

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.

**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).

**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

**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).

**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

**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

**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

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

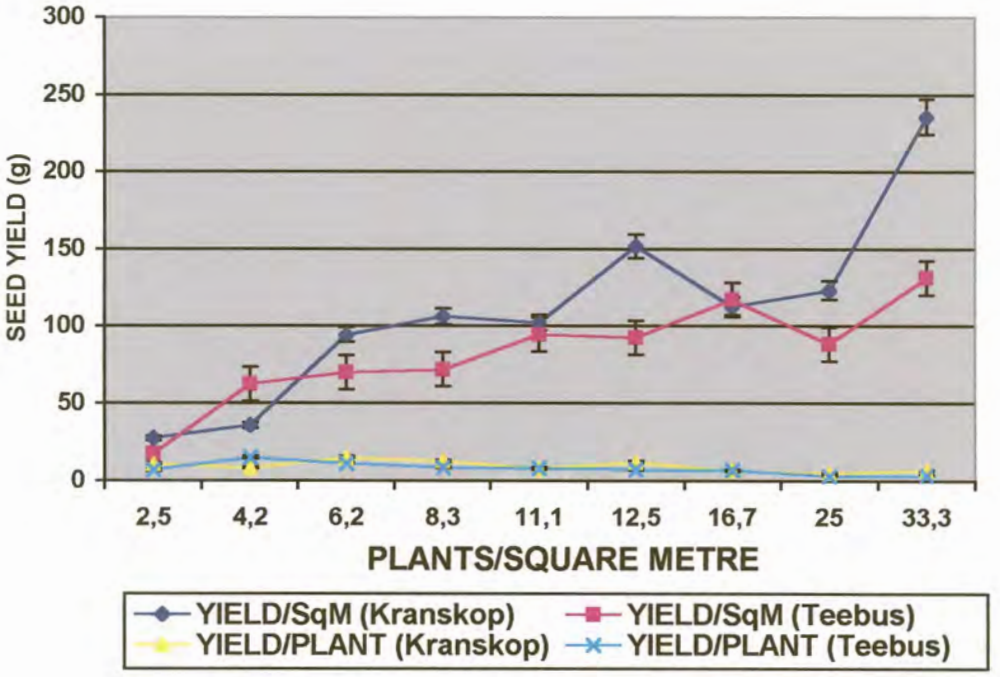


**Figure 4.2** Effect of plant density on seed yield of dry bean

**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.

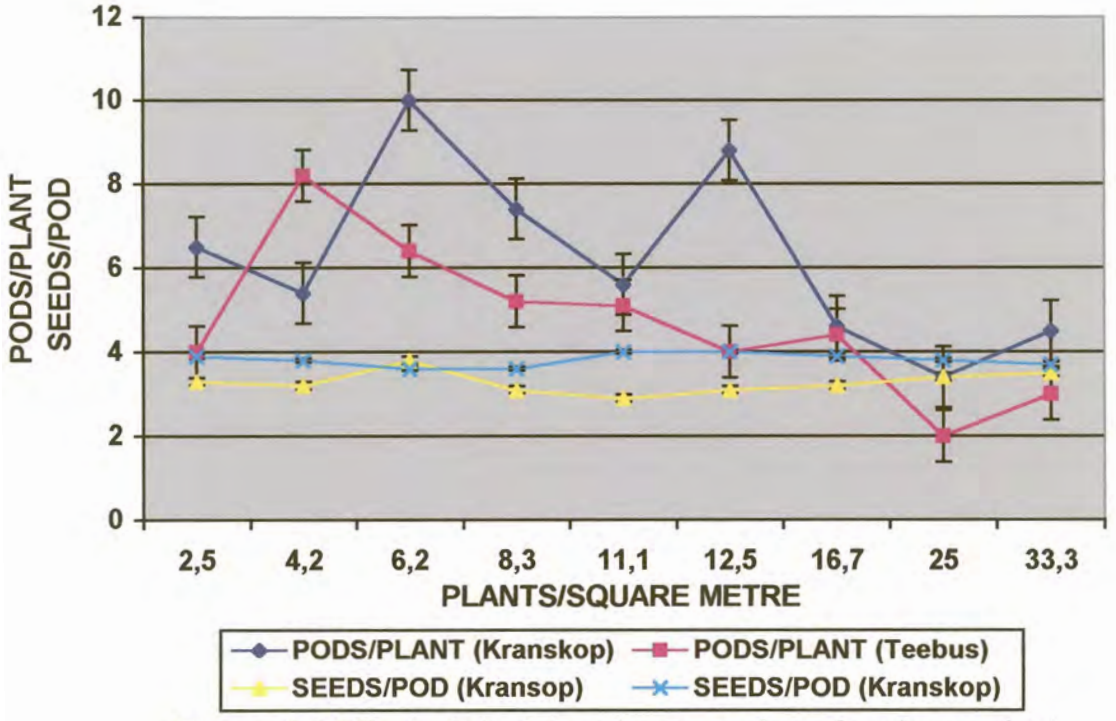


**Figure 4.3** Effect of plant density on number of pods per plant and seeds per pod of dry bean

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 $m^{-2}$.

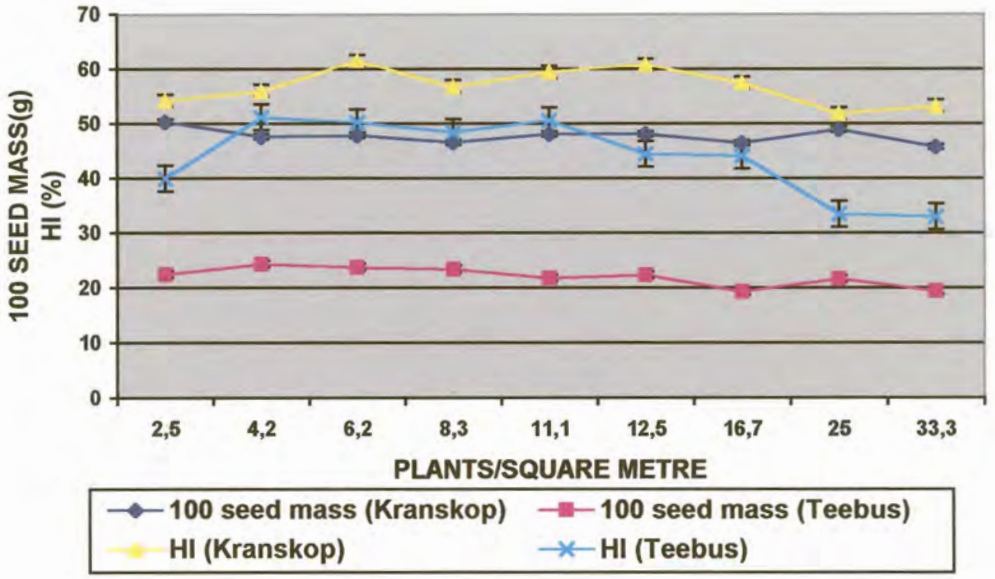


**Figure 4.4** Effect of plant density on 100 seed mass (g) and HI (%) of dry bean

## 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.

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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# CHAPTER 5

# EFFECT OF NITRATE/AMMONIUM RATIO AND CONCENTRATION ON VEGETATIVE GROWTH, SEED YIELD AND YIELD COMPONENTS OF DRY BEAN UNDER GREENHOUSE CONDITIONS

## 5.1 INTRODUCTION

Ammonium ($NH_4^+$) and nitrate ($NO_3^-$) are the two forms of nitrogen available for plant growth. The use of $NH_4^+$ in nutrient solutions has been reported as early as 1860, and mixtures of $NH_4^+$ and $NO_3^-$ have been adapted into many nutrient solution formulas (Hewitt, 1966). Barker & Mills, 1980 and Cao & Tibbitts (1993) state that most plant species grow better with $NO_3^-$ than $NH_4^+$ nutrition. Other hydroponics studies have demonstrated advantages of mixed nitrogen forms with several different crops such as wheat (Cox & Reisenauer, 1973), triticale, wheat and rye (Gashaw & Mugwira, 1981), corn and sorghum (Clark, 1982), potato (Davis, Loescher, Hammond & Thornton, 1989) and tomato (Ikeda & Tan, 1998). For potatoes, applications of combined nitrogen forms are generally recommended for production in most growing areas (Hendrickson Keeney, Walsh, & Liegel, 1978). Studies with spring wheat showed increase in growth and yield when plants were fed on combined $NH_4^+$-N and $NO_3^-$-N compared with those fed on predominantly $NO_3^-$-N (Wang & Below, 1992). In similar experiments, Cox & Reisenauer (1973) report that plants grown with $NO_3^-$ as the sole source of nitrogen often develop Fe deficiency while those grown in $NH_4^+$ as the sole source of nitrogen may show $NH_4^+$ toxicity effects if the $NH_4^+$ levels are too high. The growth rates of both wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) were stimulated when $NH_4^+$ was added to growth media containing $NO_3^-$ over the growth rates of plants grown with $NO_3^-$ alone. More nitrogen is said to be absorbed and assimilated when both $NH_4^+$ and $NO_3^-$ are provided in the growth solutions than when either $NH_4^+$ or $NO_3^-$ alone is given (Jackson, Kwik & Volk, 1976).

The form of nitrogen in a nutrient solution influences the solution pH. The pH of nutrient solutions with $NO_3^-$ as the sole source of N rises to near or above 7 for many plants (Hewitt, 1966). On the other hand the pH of nutrient solutions with $NH_4^+$ as the sole source of nitrogen decreases to near 4 when many plants are grown in them. This prompted Trelease &

Trelease (1935) to suggest a balance of $NO_3^-$ and $NH_4^+$ as a buffer against large changes in pH.

According to Claassens (2000, personal communication[3]) the nutritional status of the Hoagland type nutrient solutions commonly used are relatively high, especially for environmental conditions like in South Africa where the rate of crop transpiration may be much higher than in Europe. Lower concentration of nutrient solutions would be less expensive and make production more cost efficient. The objective of this experiment was to determine the optimum $NO_3^-$:$NH_4^+$ ratio, and the concentration of nutrient solution that would optimise growth and yield of dry bean under greenhouse conditions.

## 5.2 MATERIALS AND METHODS

### Experiment 1

Seed of cultivar Kranskop was planted in 10 litre Mitscherlich pots filled with sterilised sand media. Three seeds were planted in each pot and thinned to one plant per pot during the V2 growth stage. Four treatments were used each replicated three times. There were an adequate number of pots to allow five serial harvests at two weeks intervals and a final harvest at physiological maturity (figure 5.1a). Treatments included two $NO_3^-$:$NH_4^+$ ratios of 14:1 meq/l (93% $NO_3^-$-N: 7% $NH_4^+$-N) and 7:7 meq/l (50% $NO_3^-$-N: 50% $NH_4^+$-N), designated as 14:1 and 1:1 $NO_3^-$:$NH_4^+$ ratios respectively, each applied at full strength (FS) and half strength (HS) concentrations. The four nutrient solutions were prepared separately. The full strength (FS) concentration of the 14:1 $NO_3^-$:$NH_4^+$ ratio is equivalent to the standard Hoagland nutrient solution. Micronutrients as suggested by Nitsch (1972) (Table 1c) were added at the same concentration (20ml per 20 litre water) to all the four solutions. The pH of the nutrient solutions was not adjusted and ranged between 5.58 - 8.5 while electrical conductivity (EC) ranged between 1.25 - 2.25 $mS.cm^{-1}$ (Table 5.1a). The recommended pH values are between 5.3 - 6.3 and electrical conductivity (EC) between 1.5 - 2.5$mS.cm^{-1}$ (Association for Intensive Plant Production, 1999). The nutrient solutions were applied three times a week, twice with fresh solution and a third with recycled solution after which the pots were flushed with water to avoid salt accumulation. The composition of the nutrient solutions is outlined in Table 1b.



[3] Prof A.S. Claassens, Department of Plant Production and Soil Science, University of Pretoria, Pretoria 0002, Republic of South Africa.

Serial harvesting started two weeks after emergence. Three pots were harvested fortnightly from each treatment over a period of eight weeks to monitor fresh biomass, dry matter accumulation and leaf area development. The data was plotted in a graph to observe the growth trend of each treatment. Furthermore, statistical analysis was applied to the vegetative growth data at 58 days after emergence (DAE). Three replicates from each treatment were left to reach maturity. These were used to collect data for evaluation of seed yield and yield components of the crop.

**Table 5.1a**. Composition of four nutrient solutions with two $NO_3^-$:$NH_4^+$ ratios and two concentrations (full strength (FS) and half strength (HS)) used in the first experiment.

| $NO_3^-$:$NH_4^+$ RATIO (meq/l) | | | | |
|---|---|---|---|---|
| SALT | 14:1 (FS) | 14:1 (HS) | 1:1 (FS) | 1:1(HS) |
| $Ca(NO_3)_2.4H_2O$ | 8 | 4 | 7 | 3.5 |
| $MgSO_4.7H_2O$ | 4 | 2 | 4 | 2 |
| $KNO_3$ | 6 | 3 | 0 | 0 |
| $K_2SO_4$ | 0 | 0 | 6 | 3 |
| $NH_4H_2PO_4$ | 1 | 0.5 | 1 | 0.5 |
| $(NH_4)_2SO_4$ | 0 | 0 | 6 | 3 |
| TOTAL-N | 15 | 7.5 | 14 | 7 |
| Mean pH | 8.45 | 8.23 | 5.58 | 6.70 |
| Mean EC ($mS.cm^{-1}$) | 1.65 | 1.25 | 2.25 | 1.35 |

**Table 5.1b**. Composition of micronutrients*

| INGREDIENT | QUANTITY PER LITRE |
|---|---|
| KCl | 2.7g |
| $H_3BO_3$ | 2.9g |
| $MnSO_4$ | 1.7g |
| $ZnSO_4$ | 0.27g |
| $(NH_4)_2Mo_7O_{24}$ | 0.27g |
| $CuSO_4$ | 0.14g |
| $H_2SO_4$ | 0.31ml |

* Added at rate of 20ml per 20l nutrient solution.


**Figure 5.1a** General appearance of the bean crop in experiment 1 of the nitrate / ammonium ratio and concentration.

**Figure 5.1b** General appearance of the bean crop in experiment 2 of the nitrate / ammonium ratio and concentration.

**Experiment 2**

In the second experiment, cultivar Kranskop was planted in 8 litre capacity pots filled with sterilised sand media (Figure 5.1b). Three seeds were planted in each pot and thinned to one plant per pot during the V2 growth stage as in experiment 1. Nine treatments were compared each replicated three times. Treatments included three $NO_3^-$:$NH_4^+$ ratios of 14:1 meq/l (93% $NO_3^-$-N: 7% $NH_4^+$-N), 7:7 meq/l (50% $NO_3^-$-N: 50% $NH_4^+$-N) and 1:14 meq/l (7% $NO_3^-$-N: 93% $NH_4^+$-N), designated as 14:1, 1:1 and 1:14 $NO_3^-$:$NH_4^+$ ratios respectively, each at, full strength (FS), half strength (HS) and quarter strength (QS) concentrations. The nine nutrient solutions were prepared separately and their composition is presented in Table 5.2. The full strength nutrient solution of the 14:1 $NO_3^-$:$NH_4^+$ ratio is equivalent to the standard Hoagland nutrient solution while the others are modifications of it. Micronutrients were added as suggested by Nitsch (1972) (Table 5.1b) at the same concentration (20ml per 20 litre water) to all the nine solutions. The pH of the fresh solution was monitored and adjusted to the recommended values of between 5.3 and 6.3 (Association for Intensive Plant Production, 1999). Electrical conductivity (EC) varied between 0.9 and 2mS.cm$^{-1}$ although the recommended conductivity is between 1.5 and 2.5mS.cm$^{-1}$ (Association for Intensive Plant Production, 1999). The drain to waste system with no recycling of nutrient solution was used. The nutrient solutions were prepared in 20 litre plastic containers and applied three times a week and then flushed with water to avoid salt accumulation. Three replicates were harvested from each treatment at 40 DAE for comparison of vegetative and reproductive growth. Three replicates from each treatment were left to reach maturity. These were used to collect data for evaluation of seed yield and yield components of the crop.

**Data analysis**

In both experiments data 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. Means were separated using Tukey's studentised range test.

**Table 5.2**. Composition of nine nutrient solutions of three $NH_4^+$: $NO_3^-$ ratios (meq/l) and three concentrations (full strength (FS), half strength (HS) and quarter strength (QS)) used in the second experiment.

| | $NO_3^-$:$NH_4^+$ RATIO (meq/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SALTS | 14:1 (FS) | 14:1 (HS) | 14:1 (QS) | 1:1 (FS) | 1:1 (HS) | 1:1 (QS) | 1:14 (FS) | 1:14 (HS) | 1:14 (QS) |
| $Ca(NO_3)_2 4H_2O$ | 8 | 4 | 2 | 7 | 3.5 | 1.75 | 1 | 0.5 | 0.25 |
| $MgSO_4.7H_2O$ | 4 | 2 | 1 | 4 | 2 | 1 | 2 | 1 | 0.5 |
| $KNO_3$ | 6 | 3 | 1.5 | - | - | - | - | - | - |
| $K_2SO_4$ | - | - | - | 6 | 3 | 1.5 | 3 | 1.5 | 0.75 |
| $NH_4H_2PO_4$ | 1 | 0.5 | 0.25 | 1 | 0.5 | 0.25 | 1 | 0.5 | 0.25 |
| $(NH_4)_2SO_4$ | - | - | - | 6 | 3 | 1.5 | 13 | 6.5 | 3.25 |
| TOTAL-N | 15 | 7.5 | 3.75 | 14 | 7 | 3.5 | 15 | 7.5 | 3.75 |

## 5.3 RESULTS

### Experiment 1

#### General observations

Plants receiving the nutrient solution containing 50% $NO_3^-$-N with 50% $NH_4^+$-N (1:1 $NO_3^-$:$NH_4^+$ ratio) showed deep pigmentation. The leaves developed deep green colouration unlike those receiving the nutrient solution containing 93% $NO_3^-$-N with 7% $NH_4^+$-N (14:1 $NO_3^-$:$NH_4^+$ ratio) at both the full strength and half strength concentrations. This gives an indication that $NH_4^+$-N enhances chlorophyl development, the green pigmentation in leaves. According to Makus (1984) vegetable amaranth plants fertilized with more $NH_4^+$-N were higher in leaf pigments than those receiving nitrogen in the other form. Cao & Tibbits (1993) attributed this to the concentration and accumulation of more nitrogen in the shoots and roots with a combination of $NH_4^+$-N and $NO_3^-$-N nutrition. The physiological aspect of this is not yet established.

**Effect of nitrate / ammonium ratio and concentration on vegetative growth**

**Fresh biomass (g)**

Data from the five serial harvests is presented in Figure 5.2, and the results of the last of these sampling periods (58 DAE) are summarised in Table 5.3. The nitrate / ammonium ratio main effect significantly affected fresh biomass accumulation while the concentration main effect and the ratio x concentration interactions did not.

Fresh biomass accumulation of plants differed in the different treatments. Plants receiving the nutrient solutions containing 14:1 $NO_3^-$:$NH_4^+$ ratio at the full strength and half strength concentrations showed better growth rates than those receiving the nutrient solutions containing 1:1 $NO_3^-$:$NH_4^+$ ratio at the two concentrations (Figure 5.2). Within the 1:1 $NO_3^-$:$NH_4^+$ ratio, plants receiving the half strength nutrient solution grew better than those receiving the full strength nutrient solution.

Signifiant ratio main effect indicates that the different ratio treatments affected the fresh biomass differently. The 14:1 $NO_3^-$:$NH_4^+$ ratio accumulated significantly more fresh biomass (89.3g) than the 1:1 $NO_3^-$:$NH_4^+$ ratio (66.1g). Differences between plants receiving the full strength and half strength nutrient solution were not significant, although there was a tendency by plants receiving the full strength nutrient solution developing a somewhat larger (80.5g) fresh biomass than those receiving the half strength nutrient solution (74.9g)(Table 5.3).

**Leaf area ($cm^2$)**

Data from the five serial harvests is presented in Figure 5.3, and the results of the last of these sampling periods (58 DAE) are summarised in Table 5.3. The nitrate / ammonium ratio main effect significantly affected the leaf area development while the concentration main effect and the ratio x concentration interactions did not.

The leaf area development followed a similar trend as fresh biomass accumulation. Poor leaf area development was observed in some plants receiving the full strength nutrient solution treatment containing the 1:1 $NO_3^-$:$NH_4^+$ ratio. This affected the treatment's overall performance. On the other hand, plants receiving the half strength nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio maintained a steady increase in leaf area similar to plants

receiving the full strength and half strength nutrient solutions containing the 14:1 $NO_3^-$:$NH_4^+$ ratio (Figure 5.3). Differences emerged 29 DAE where plants receiving the full strength and half strength nutrient solutions containing the 14:1 $NO_3^-$:$NH_4^+$ ratio developed a somewhat larger leaf area than those receiving the nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio (Figure 5.3).

Plants receiving the nutrient solution containing 14:1$NO_3^-$:$NH_4^+$ ratio developed a somewhat larger leaf area (1365.7cm$^2$) than those receiving the nutrient solution containing 1:1 $NO_3^-$ :$NH_4^+$ ratio (1159.3 cm$^2$ ). No differences were observed between plants receiving the full strength and half strength nutrient solution concentration treatments (Table 5.3). The non significant ratio x concentration interaction shows that there were no difference in leaf area development among plants receiving the different treatment combinations.

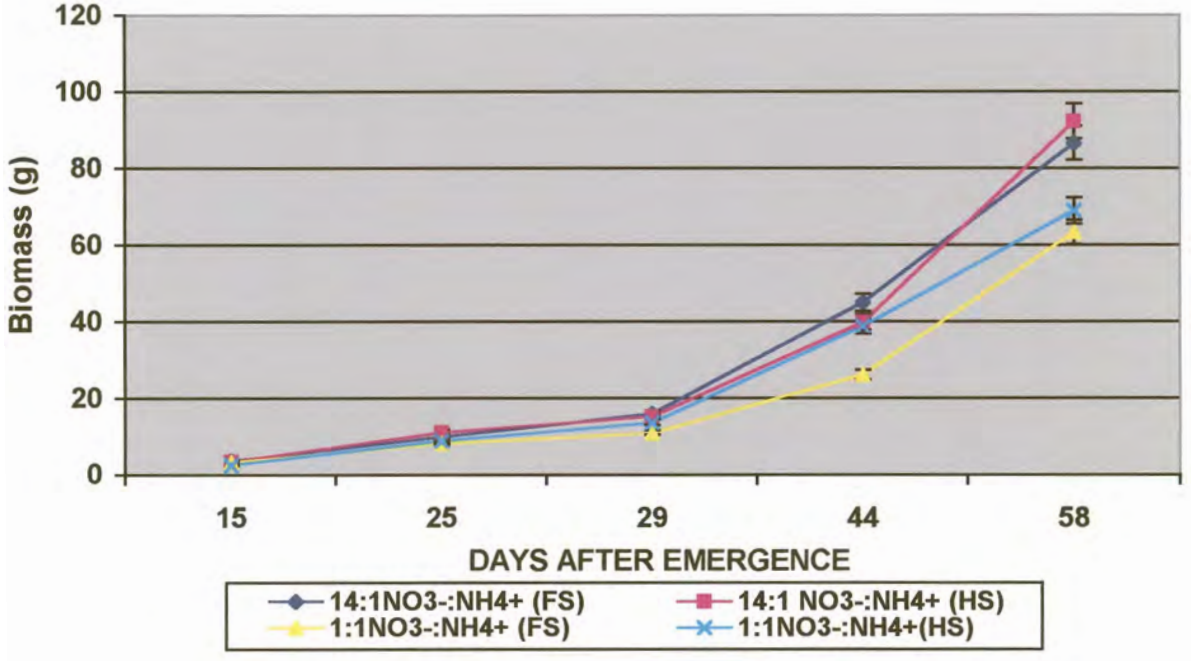


**Figure 5.2** Effect of nitrate / ammonium ratio and concentration on fresh biomass accumulation

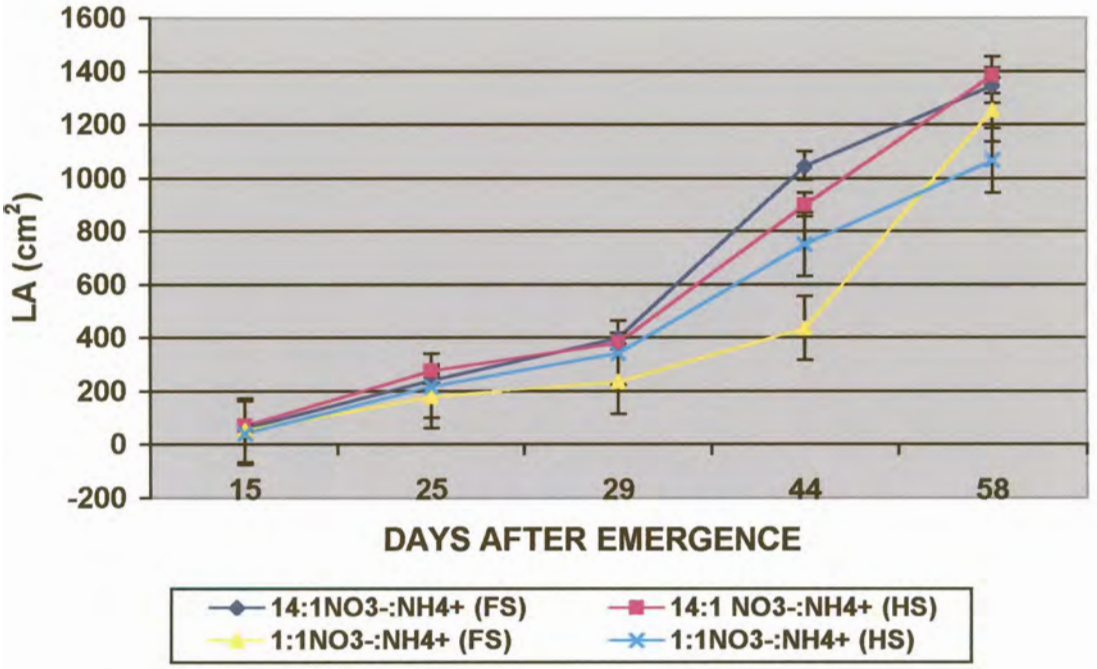


**Figure 5. 3** Effect of nitrate / ammonium ratio and concetration on leaf area ($cm^2$)

**Table 5.3** Effect of $NO_3^-$:$NH_4^+$ ratio and concentration on vegetative growth of dry bean 58 DAE (ANOVA: Appendix Tables 8.5A – 8.5E).

| | FRESH BIOMASS (g) | LEAF AREA ($cm^2$) | DRY BIOMASS (g) | SHOOT DRY WEIGHT (g) | ROOT DRY WEIGHT (g) |
|---|---|---|---|---|---|
| **$NO_3^-$:$NH_4^+$ RATIO** | | | | | |
| 14:1 | 89.3a | 1365.7a | 12.4a | 11.5a | 0.85a |
| 1:1 | 66.1b | 1159.3b | 9.5b | 8.77b | 0.71a |
| **CONCENTRATION** | | | | | |
| Full strength (FS) | 80.5a | 1300.2a | 11.4a | 10.6a | 0.80a |
| Half strength (HS) | 74.9a | 1224.8a | 10.5a | 9.7a | 0.76a |
| SE | 4.7 | 39.3 | 0.58 | 0.61 | 0.07 |
| LSD (P≤0.05) | 15.4 | 128.2 | 1.88 | 1.98 | 0.24 |
| $R^2$ | 0.61 | 0.71 | 0.63 | 0.58 | 0.21 |
| CV (%) | 14.9 | 7.62 | 12.9 | 14.7 | 23.2 |

Means within the columns followed by the same letter are not significantly different (P≤0.05) according to Tukey's studentized range test.

**Dry biomass (g)**

Table 5.3 shows the effect of $NO_3^-$:$NH_4^+$ ratio and concentration on dry biomass accumulation of dry bean. The ratio main effect was significantly different while the concentration main effect and the ratio x concentration interactions were not.

Plants receiving the nutrient solution containing the 14:1 $NO_3^-$:$NH_4^+$ ratio accumulated larger dry biomass (12.4g) than those receiving the nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio (9.5g). No differences in dry biomass were observed among plants receiving the full strength and half strength nutrient solutions. A somewhat larger dry biomass (11.4g) was produced by plants receiving the full strength nutrient solution than 10.5g produced by plants receiving the half strength nutrient solution.

**Shoot dry weight (g)**

The effect of nitrate / ammonium ratio and concentration on shoot dry weight is shown in Table 5.3. Only the ratio main effect was significant while the concentration main effect and the ratio x concentration interactions were not.

Plants receiving the nutrient solution containing 14:1 $NO_3^-$:$NH_4^+$ ratio produced significantly larger shoot dry weight (11.5g) than those receiving the nutrient solution containing 1:1 $NO_3^-$:$NH_4^+$ ratio (8.77g). No differences were observed between plants receiving the different nitrogen concentration treatments. However, plants receiving the full strength nutrient solution produced a somewhat larger (10.6g) shoot dry weight than those fed on the half strength nutrient solution (9.7g).

The non significant ratio x concentration interactions effects show that different treatment combinations produced similar shoot dry weights.

**Root dry weight (g)**

The data for the effect of nitrate / ammonium ratio and concentration on the root dry weight of dry bean cultivar Kranskop at 58 DAE is presented in Table 5.3. Both the ratio and concentration main effect and the ratio x concentration interactions were not significant.

A somewhat larger (0.85g) root dry weight was produced by plants receiving the nutrient solution containing 14:1 $NO_3^-$:$NH_4^+$ ratio than those receiving the nutrient solution containing 1:1 $NO_3^-$:$NH_4^+$ ratio (0.71g). No differences were observed among plants receiving the two different nutrient solution concentrations. However, plants receiving the full strength nutrient solution developed a somewhat larger (0.80g) root dry weight than 0.76g produced by plants receiving the half strength nutrient solution.

**Effect of nitrate / ammonium ratio and concentration on seed yield and yield components**

Table 5.4 shows the effect of nitrate / ammonium ratio and concentration on seed yield and yield components of dry bean cultivar Kranskop. Both the ratio and concentration main effects and the ratio x concentration interactions effects were not significant.

Despite the differences observed in vegetative growth of dry bean plants receiving the two different nitrate / ammonium ratios, no significant differences were observed in seed yield and yield components. The number of pods per plant, seeds per pod, 100 seed mass, seed yield per plant and harvest index were similar among all plants receiving both the nutrient solutions containing 14:1 $NO_3^-$:$NH_4^+$ ratio and 1:1 $NO_3^-$:$NH_4^+$ ratio (Table 5.4). Similarly no differences were observed in seed yields and yield components among plants receiving the full strength and half strength nutrient solutions (Table 5.4). Both the full strength and half strength nutrient solutions affected seed yields and yield components in a similar way, indicating that either of the concentrations can be used without affecting seed yields of the crop.

**Table 5.4** Effect of $NH_4^+$:$NO_3^-$ ratio and concentration on yield and yield components of dry bean (ANOVA: Appendix Table 8.5 F – 8.5J).

| | PODS/PLANT | SEEDS/POD | 100 SEED MASS (g) | YIELD/PLANT (g) | HI (%) |
|---|---|---|---|---|---|
| **$NO_3^-$:$NH_4^+$ RATIO** | | | | | |
| 14:1 | 10.17a | 3.7a | 54.4a | 20.4a | 47.2a |
| 1:1 | 10.67a | 3.7a | 49.0a | 17.2a | 48.4a |
| **CONCENTRATION** | | | | | |
| Full strength (FS) | 11.0a | 3.7a | 52.2a | 21.0a | 47.7a |
| Half strength (HS) | 9.83a | 3.7a | 51.2 | 16.6a | 48.0a |
| SE | 0.75 | 0.17 | 2.61 | 2.82 | 0.49 |
| LSD (P≤0.05) | 2.46 | 0.49 | 8.53 | 4.60 | 1.61 |
| $R^2$ | 0.30 | 0.08 | 0.23 | 0.58 | 0.30 |
| CV (%) | 17.7 | 9.92 | 12.4 | 18.4 | 2.53 |

Means within the columns followed by the same letter are not significantly different (P≤0.05) according to Tukey's studentized range test.

## Experiment 2

### General observations

Initially, plant growth was normal for all the treatment combinations as observed in figure 5.1b. However visual differences were observed among the different treatments with time, especially between plants receiving the nutrient solution containing 1:14 $NO_3^-$:$NH_4^+$ ratio and those receiving the 14:1 and 1:1 $NO_3^-$:$NH_4^+$ ratios. Plants receiving the nutrient solution containing 1:14 $NO_3^-$:$NH_4^+$ ratio were poorly developed, stunted and weak. The leaves were rather small, curled, thick and initially with a deep green pigmentation that faded with time becoming chlorotic at both the full strength and half strength nutrient solution treatments (see Figure 5.4). When grown to maturity the leaves of the plants in this treatment were completely chlorotic resulting in early harvest of the treatment (see Figure 5.5). On the other hand plants receiving the full strength and half strength nutrient solutions containing the 14:1 and 1:1 $NO_3^-$:$NH_4^+$ ratios were healthy.


Figure 5.4 Comparison of plants receiving different $NO_3^-$:$NH_4^+$ ratios and concentrations: A. 14:1 (FS); B. 14:1 (HS); C. 14:1 (QS); D. 1:1 (FS); E. 1:1 (HS); F. 1:1 (QS); G. 1:14 (FS); H. 1:14 (HS); I. 1:14 (QS).

Figure 5.5 Plants receiving 1:14 $NO_3^-$:$NH_4^+$ ratios showing chlorosis on the far left. From left: 1:14 (QS); 1:14 (HS); 1:14 (FS); 1:1 (QS)

Plants receiving the quarter strength nutrient solution initially grew better in all the three $NO_3^-$:$NH_4^+$ ratios but changed with age. The plants receiving the quarter strength nutrient solutions containing the 14:1 and 1:1 $NO_3^-$:$NH_4^+$ ratios were healthy and good looking throughout the growing period, becoming slightly yellowish with slight chlorosis especially on the edges (see Figure 5.4 & 5.5). On the other hand the plants receiving the quarter strength nutrient solution containing the 1:14 $NO_3^-$:$NH_4^+$ ratio became more yellowish and rather weak as they grew older. Slight curling of leaves and chlorosis were also observed (Figure 5.5).

**Effect of nitrate / ammonium ratio and concentration on vegetative growth 40 DAE**

Table 5.5 shows the effect of nitrate / ammonium ratio on the vegetative growth of dry bean cultivar Kranskop at 40 DAE.

**Fresh biomass (g)**

The data for the effect of nitrate / ammonium ratio and concentration on fresh biomass of dry bean cultivar Kranskop at 40 DAE are presented in Table 5.5. The concentration main effect was significant while both the ratio main effect and the ratio x concentration interactions effects were not.

No difference was observed among plants receiving the different nitrate / ammonium ratios. Plants receiving the nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio accumulated somewhat more (45.2g) fresh biomass than those receiving the nutrient solutions containing 14:1 $NO_3^-$:$NH_4^+$ ratio (42.7g) and 1:14 $NO_3^-$:$NH_4^+$ ratio (38.0g).

Significant differences in fresh biomass accumulation were observed among plants receiving the different nutrient solution concentrations (Table 5.5). Plants receiving the full strength and half strength nutrient solution concentrations accumulated more fresh biomass (48.5g and 44.6g respectively) than those receiving the quarter strength nutrient solution (32.8g).

**Leaf area ($cm^2$)**

The data for the effect of nitrate / ammonium ratio and concentration on leaf area of dry bean cultivar Kranskop at 40 DAE are presented in Table 5.5. The ratio and concentration main effects were significant while the ratio x concentration interaction effects were not.

Plants receiving the nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio developed a significantly larger (1216.3 $cm^2$) leaf area than those receiving the nutrient solution containing the 1:14 $NO_3^-$:$NH_4^+$ ratio (924.8$cm^2$). The leaf area (1077.2 $cm^2$) for plants receiving the nutrient solution containing the 14:1 $NO_3^-$:$NH_4^+$ ratio was intermediate and not different from that of plants in the other two treatments.

Significant differences were also observed in leaf area among plants receiving the different nutrient solution concentrations. Plants receiving the full strength nutrient solution developed a significantly larger leaf area (1268.8$cm^2$) than those receiving the quarter strength nutrient solution (804.4$cm^2$). The leaf area of plants receiving the half strength nutrient solution was intermediate (1145.1) and significantly larger than that of plants receiving the quarter strength nutrient solution but not different from the leaf area of plants receiving the full strength nutrient solution.

**Dry biomass (g)**

Table 5.5 shows the data for the effect of nitrate / ammonium ratio and concentration on dry biomass of dry bean cultivar Kranskop 40 DAE. Significant concentration main effect was observed while both the ratio and ratio x concentration interaction effects were not.

Although the ratio main effect was not significant, plants receiving the nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio accumulated somewhat more (14.0g) dry biomass than those receiving the nutrient solutions containing the 14:1 $NO_3^-$:$NH_4^+$ ratio (13.0g) and the 1:14 $NO_3^-$:$NH_4^+$ ratio (11.8g). The significant concentration main effect shows that differences existed in dry biomass accumulation among plants receiving the different nutrient solution concentrations. Plants receiving the full strength and half strength nutrient solutions accumulated significantly more (14.5g and 14.0g respectively) dry mass than those receiving the quarter strength nutrient solution (10.3g).

**Shoot dry weight (g)**

Table 5.5 also shows the data for the effect of nitrate / ammonium ratio and concentration on shoot dry weight of dry bean cultivar Kranskop 40 DAE. Significant concentration main effect was observed while both the ratio and the ratio x concentration interaction effects were not.

Plants receiving the nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio developed somewhat more (6.4g) shoot dry weight than those receiving the nutrient solutions containing the 14:1 $NO_3^-$:$NH_4^+$ ratio (6.1g) and the 1:14 $NO_3^-$:$NH_4^+$ ratio (5.3g). The significant concentration main effect indicates that plants receiving the different nutrient solution concentrations differed in their shoot dry weight accumulation. Plants receiving the full strength and half strength nutrient solutions accumulated significantly more shoot dry weight (6.8g and 6.4g respectively) than plants receiving the quarter strength nutrient solution (4.8g).

**Root dry weight (g)**

Table 5.5 shows the data for the effect of nitrate / ammonium ratio and concentration on root dry weight of dry bean cultivar Kranskop 40 DAE. Both the ratio and concentration main effects and the ratio x concentration interaction effects were not significant.

Despite the non significant ratio main effect, plants receiving the nutrient solution containing the 1:14 $NO_3^-$:$NH_4^+$ ratio developed somewhat larger (0.99g) root dry weight than that of plants receiving the nutrient solutions containing the 1:1 $NO_3^-$:$NH_4^+$ ratio (0.85g) and the 14:1 $NO_3^-$:$NH_4^+$ ratio (0.71g). Plants receiving the full strength nutrient solution developed somewhat more (0.95g) root dry weight than those receiving the half strength (0.92g) and quarter strength (0.68g) nutrient solutions.

**Table 5.5** Effect of $NO_3^-$:$NH_4^+$ ratio and concentration on vegetative growth of dry bean 40 DAE (ANOVA: Appendix Tables 8.6A - 8.6E).

| | FRESH BIOMAS (g) | LEAF AREA ($cm^2$) | DRY BIOMASS (g) | SHOOT DRY WEIGHT (g) | ROOT DRY WEIGHT (g) |
|---|---|---|---|---|---|
| **$NO_3^-$:$NH_4^+$ RATIO** | | | | | |
| 14:1 | 42.7a | 1077.2ab | 13.0a | 6.1a | 0.71a |
| 1:1 | 45.2a | 1216.3a | 14.0a | 6.4a | 0.85a |
| 1:14 | 38.0a | 924.8b | 11.8a | 5.3a | 0.99a |
| **CONCENTRATION** | | | | | |
| Full strength (FS) | 48.5a | 1268.8a | 14.5a | 6.8a | 095a |
| Half strength (HS) | 44.6a | 1145.1a | 14.0a | 6.4a | 0.92a |
| Quarter strength (QS) | 32.8b | 804.4b | 10.3b | 4.8b | 0.68a |
| SE | 3.02 | 66.14 | 0.91 | 0.39 | 0.17 |
| LSD (P≤0.05) | 10.9 | 238.7 | 3.28 | 1.40 | 0.62 |
| $R^2$ | 0.53 | 0.70 | 0.52 | 0.58 | 0.19 |
| CV (%) | 21.6 | 18.5 | 21.1 | 19.6 | 60.6 |

Means within the columns followed by the same letter are not significantly different (P≤0.05) according to Tukey's studentized range test.

**Effect of nitrate / ammonium ratio and concentration on seed yield and seed yield components at harvest**

After physiological maturity, seed yield and yield components data from all treatments were analysed.

**Seed mass per plant (g)**

The effect of nitrate / ammonium ratio and concentration on seed mass per plant (g) of dry bean cultivar Kranskop is presented in Table 5.6. Only the ratio main effect and the ratio x concentration interaction effects were highly significant while concentration main effect was not.

**Table 5.6** Effect of nitrate / ammonium ratio and concentration on seed mass (g) per plant of dry bean cultivar Kranskop at maturity (ANOVA: Appendix Table 8.6F)

| Concentration | Nitrate / ammonium ratio (R) | | | |
|---|---|---|---|---|
| (C) | 14:1 | 1:1 | 1:14 | Mean |
| Full strength | 24.9 | 20.6 | 3.0 | 16.2 |
| Half strength | 18.8 | 22.7 | 6.4 | 16.0 |
| Quarter strength | 13.5 | 20.5 | 12.6 | 15.5 |
| Mean | 19.1 | 21.2 | 7.3 | 15.9 |
| LSD (R) = 3.4 | LSD (C) = ns | | LSD (R x C) = 10.7 | |
| CV (%) = 14.6 | SE = 1.9 | | $R^2 = 0.5$ | |

*Main effects.* Different $NO_3^-$:$NH_4^+$ ratio treatments affected the seed mass of dry bean differently. The highest seed mass per plant (21.2g) was produced by plants receiving the nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio even though this was not significantly different from the seed mass per plant (19.1g) produced by plants receiving the nutrient solution containing the 14:1 $NO_3^-$:$NH_4^+$ ratio (Table 5.6). Plants receiving the nutrient solution containing the 1:14 $NO_3^-$:$NH_4^+$ ratio produced the lowest seed mass per plant (7.3g). No difference was observed among plants receiving the different nutrient solution concentrations. A somewhat larger seed mass per plant (16.2g) was produced by plants receiving the full strength nutrient solution. This decreased as the concentration treatment decreased. On average plants receiving the nutrient solution containing the 1:14 $NO_3^-$:$NH_4^+$ ratio produced the lowest seed mass per plant at all nutrient solution concentrations and over all concentration treatments.

*Interaction.* The significant ratio x concentration interaction shows that different ratio x concentration treatment combinations affected the seed mass per plant differently. The largest (24.9g) seed mass per plant was produced by plants receiving the full strength nutrient solution containing the 14:1 $NO_3^-$:$NH_4^+$ ratio followed by 22.7g produced by plants receiving the half strength nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio.

Table 5.7 shows the effect of nitrate / ammonium ratio and concentration on number of pods per plant. The ratio main effect and ratio x concentration interaction were significant ($P \leq 0.05$) while the concentration main effect was not.

**Table 5.7** Effect of ammonium/nitrate ratio and concentration on number of pods per plant of dry bean cultivar Kranskop at maturity (ANOVA: Appendix Table 8.6G)

| Concentration | Nitrate / Ammonium ratio (R) | | | |
|---|---|---|---|---|
| (C) | 14:4 | 1:1 | 1:14 | Mean |
| Full strength | 12.0 | 8.8 | 1.2 | 7.3 |
| Half strength | 8.5 | 9.5 | 5.5 | 7.8 |
| Quarter strength | 6.5 | 8.0 | 7.3 | 7.3 |
| Mean | 9.0 | 8.8 | 4.7 | 7.5 |
| LSD (R) = 1.4 | LSD (C) = ns | | LSD (R x C) = 4.3 | |
| CV (%) = 21.0 | SE = 0.78 | | $R^2 = 0.81$ | |

*Main effects.* The significant ratio main effect indicates that there were differences in the number of pods per plant due to changes in the $NO_3^-$:$NH_4^+$ ratio. The highest number of pods per plant (9.0) was produced by plants receiving the 14:1 $NO_3^-$:$NH_4^+$ ratio followed by plants receiving the 1:1 $NO_3^-$:$NH_4^+$ ratio (8.8) and then those receiving the 1:14 $NO_3^-$:$NH_4^+$ ratio (4.7) (Table 5.7). Although the effect of nitrogen concentration in the nutrient solution was not significant, the highest number of pods per plant (7.8) was produced by plants receiving the half strength nutrient solution while those receiving the full strength and quarter strength nutrient solutions both produced 7.3 pods per plant.

*Interaction.* The significant ratio x concentration interaction effect reflects the differences in podset per plant due to different ratio x concentration treatment combinations. Different ratios at different nutrient solution concentrations produced different number of pods per plant. The highest number of pods per plant (12) was set by plants receiving the full strength nutrient solution containing the 14:1 $NO_3^-$:$NH_4^+$ ratio followed by those receiving the half strength nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio which produced 9.5 pods per plant.

The effect of nitrate / ammonium ratio and concentration on number of seeds per pod is shown in Table 5.8. Both the ratio and concentration main effects and the ratio x concentration interaction effects were not significant ($P \leq 0.05$).

**Table 5.8** Effect of nitrate / ammonium ratio and concentration on number of seeds per pod of dry bean cultivar Kranskop at maturity (ANOVA: Appendix Table 8.6H)

| Concentration | Nitrate / Ammonium ratio (R) | | | |
|---|---|---|---|---|
| (C) | 14:1 | 1:1 | 1:14 | Mean |
| Full strength | 3.4 | 4.0 | 4.0 | 3.8 |
| Half strength | 3.5 | 4.0 | 3.8 | 3.8 |
| Quarter strength | 3.6 | 3.8 | 3.8 | 3.8 |
| Mean | 3.6 | 3.9 | 3.9 | 3.8 |
| LSD (R) = ns | LSD (C) = ns | | LSD (R x C) = ns | |
| CV (%) = 13.5 | SE = 0.26 | | $R^2 = 0.14$ | |

*Main effects.* The non significant main effects indicate that there were no differences in the number of seeds per pod set due to changes in the nitrate / ammonium ratio and nutrient solution concentration. Plants receiving the nutrient solutions containing the 1:1 and the 1:14 $NO_3^-$:$NH_4^+$ ratios set relatively more seeds per pod (3.9) than those receiving the nutrient solution containing the 14:1 $NO_3^-$:$NH_4^+$ ratio (3.6). For some unclear reason, plants receiving the nutrient solution containing the 14:1 $NO_3^-$:$NH_4^+$ ratio produced somewhat less number of seeds per pod at all nutrient solution concentrations (Table 5.8).

*Interaction.* Just as with the main effects, no differences were observed in seedset among all the ratio x concentration interaction combinations. Relatively more seeds per pod (4 seeds) were set by plants receiving the nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio at the full strength and half strength and those receiving the full strength nutrient solution containing the 14:1 $NO_3^-$:$NH_4^+$ ratio. The lowest number of seeds per pod was set by plants receiving the nutrient solution containing the 1:14 $NO_3^-$:$NH_4^+$ ratio at all nutrient solution concentrations, with plants receiving the full strength nutrient solution setting the lowest (3.4 seeds per pod).

Table 5. 9 shows the effect of the nitrate / ammonium ratio and concentration on 100 seed mass (g) of dry bean. The ratio main effect and the ratio x concentration interaction effects were highly significant ($P \leq 0.01$) while the concentration main effect was not.

**Table 5.9** Effect of nitrate / ammonium ratio and concentration on 100 seed mass (g) of dry bean cultivar Kranskop at maturity (ANOVA: Appendix Table 8.6I)

| Concentration | Nitrate / Ammonium ratio (R) | | | |
|---|---|---|---|---|
| (C) | 14:1 | 1:1 | 1:14 | Mean |
| Full strength | 60.5 | 57.7 | 59.0 | 59.1 |
| Half strength | 60.0 | 61.5 | 29.4 | 50.3 |
| Quarter strength | 55.6 | 65.7 | 45.6 | 55.6 |
| Mean | 58.7 | 61.6 | 44.7 | 55.0 |
| LSD (R) = 7.9 | LSD (C) = ns | | LSD (R x C) = 24.6 | |
| CV (%) = 16.2 | SE = 4.5 | | $R^2 = 0.65$ | |

*Main effects.* The significant nitrate / ammonium ratio main effect shows that changes in the $NO_3^-$:$NH_4^+$ ratio affected the seed size of dry bean cultivar Kranskop. The largest seed size (61.6g/100 seed) was produced by plants receiving the nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio although this was not significantly different from the 58.7g/100 seed produced by plants receiving the nutrient solution containing the 14:1 $NO_3^-$:$NH_4^+$ ratio. The smallest seed size (44.7g/100 seed) was produced by plants receiving the nutrient solution containing the 1:14 $NO_3^-$:$NH_4^+$ ratio. The non significant concentration main effect shows that changes in the nutrient solution concentration did not affect the seed size of dry bean in the experiment. Plants receiving the full strength nutrient solution produced a somewhat larger seed size (59.9g/100 seed) than those receiving the quarter strength (55.6g/100 seed) nutrient solution. The smallest seed size (50.3g/100 seed) was produced by plants receiving the half strength nutrient solution.

*Interaction.* The significant interaction effects indicate that the different ratio x concentration interaction treatment combinations affected seed size of dry bean differently. The largest seed size (65.7g/100 seed) was produced by plants receiving the quarter strength nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio followed by 61.5g/100 seed produced by plants receiving the half strength nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio too. The

significant ratio x concentration treatment combination could be attributed to the unexpected low seed size (29.4g/100 seed) produced by plants receiving the half strength nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio. This may have been due to the termination of assimilate supply during pod fill stage as almost all the leaves of plants in this treatment senesced early due to chlorosis. This prompted early harvest of the treatment.

Table 5. 10 shows the effect of nitrate / ammonium ratio and concentration on harvest index (%) of dry bean. Only the ratio main effect was highly significant ($P \leq 0.01$) while the concentration main effect and the ratio x concentration interaction effects were not.

**Table 5.10** Effect of nitrate / ammonium ratio and concentration on harvest index (HI) (%) of dry bean cultivar Kranskop at maturity (ANOVA: Appendix Table 8.6J)

| N-Concentration | Nitrate / Ammonium ratio (R) | | | |
|---|---|---|---|---|
| (C) | 14:1 | 1:1 (7:7) | 1:14 | Mean |
| Full strength | 45.1 | 48.6 | 30.6 | 41.4 |
| Half strength | 46.1 | 50.0 | 40.3 | 45.5 |
| Quarter strength | 43.0 | 45.7 | 44.9 | 44.5 |
| Mean | 44.7 | 48.1 | 38.6 | 43.8 |
| LSD (R) = 5.6 | LSD (C) = ns | | LSD (R x C) = ns | |
| CV (%) = 14.6 | SE = 3.2 | | $R^2 = 0.50$ | |

*Main effects.* The significant ratio main effect shows that the different the $NO_3^-$:$NH_4^+$ ratios affected harvest index differently. The highest harvest index (48.1%) was observed among plants receiving the nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio. This was not significantly different from the harvest index observed among plants receiving the nutrient solution containing the 1:14 $NO_3^-$:$NH_4^+$ ratio (Table 5.10). No differences were observed among plants receiving the different nutrient solution concentrations. A somewhat higher harvest index (45.5%) was observed among plants receiving the half strength nutrient solution followed by that observed among plants receiving the quarter strength nutrient solution (44.5%) and the full strength nutrient solution (41.4%).

*Interaction.* The non significant ratio x concentration treatment interaction shows that the main effects affected the harvest index independent of each other. However, a somewhat

higher harvest index (50%) was obtained among plants receiving the half strength nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio followed by 48.6% produced by plants receiving the full strength nutrient solution containing the 1:1 $NO_3^-$:$NH_4^+$ ratio.

The non significant ratio x concentration interaction effect for harvest index, while that of seed mass was significant, could be attributed to the loss of biomass in the half strength nutrient solution containing the 1:14 $NO_3^-$:$NH_4^+$ ratio. The plants in this treatment lost the leaves due to chlorosis and suspected ammonium toxicity. As such, the high harvest index shown does not take into account this loss in biomass.

## 5.4 DISCUSSION

The main outcome of this experiment is that $NO_3^-$:$NH_4^+$ ratio and nutrient solution concentration affected growth, development and productivity of dry bean. More attention should be paid to $NO_3^-$:$NH_4^+$ ratio as it has an overriding effect on plant growth and productivity. Both vegetative and reproductive growth were enhanced with a combination of $NO_3^-$-N and $NH_4^+$-N in the nutrient solution. More vegetative growth was associated with plants receiving either the nutrient solutions containing 93% $NO_3^-$-N (14:1 $NO_3^-$:$NH_4^+$ ratio) or 50% $NO_3^-$-N (1:1 $NO_3^-$:$NH_4^+$ ratio) in combination with $NH_4^+$-N.

Theoretically, $NH_4^+$ is a more desirable form of nitrogen for plants as it is the form in which plants assimilate nitrogen directly into amides and amino acids (Davis *et al*, 1986). In contrast, $NO_3^-$-N requires a lot of energy for it to be reduced to $NH_4^+$ before assimilation. The toxicity observed among plants receiving high $NH_4^+$-N could be attributed to limited use of the absorbed and assimilated $NH_4^+$. Plants need to balance between the rates of uptake and detoxification during its utilisation as suggested by Ikeda & Tan (1998). They further observed a trend of $NH_4^+$ decreasing cation absorption and occasionally causing physiological disorders like Ca deficiency. The Association for Intensive Plant Production (1999) reports that high $NH_4^+$-N concentration may result in $NH_4^+$ competing with cation uptake of especially K, Ca and Mg and that the rhizosphere acidifies to unacceptably low pH. Ikeda & Tan (1998) concluded that $NH_4^+$-N is detrimental to potato growth regardless of stage of development if it is the sole source of nitrogen. They also state that nitrogen source influenced the mineral composition of potato tissue, particularly levels of P, Ca and Mg. Bernardo *et al* (1984 b) indicate that as the proportion of $NH_4^+$ in solution increased, K, Ca, Mn, and Zn concentrations decreased in the leaves, while Ca, Mg, Mn and Cu concentrations

decreased in roots.

In these experiments good plant growth was observed among plants receiving the nutrient solutions containing 14:1 and 1:1 $NO_3^-$:$NH_4^+$ ratios (93% $NO_3^-$-N with 7% $NH_4^+$-N and 50% $NO_3^-$-N with 50% $NH_4^+$-N respectively) and poor among plants receiving the nutrient solution containing 1:14 $NO_3^-$:$NH_4^+$ ratio (7% $NO_3^-$-N with 93% $NH_4^+$-N). More leaf area and total biomass (both fresh and dry) were produced by plants receiving the nutrient solution containing 1:1 $NO_3^-$:$NH_4^+$ ratio treatment than those receiving the nutrient solution containing 14:1 $NO_3^-$:$NH_4^+$ ratio treatment although the differences were not significant. Dry biomass production was poor among plants receiving the nutrient solution containing 1:14 $NO_3^-$:$NH_4^+$ ratio treatment. Gashaw & Mugwira (1981) found similar results in their work with triticale in which a 1:1 $NO_3^-$:$NH_4^+$ ratio produced more shoot and root dry matter than with the mixture of 1:3 $NO_3^-$:$NH_4^+$ ratio and sole $NH_4^+$-N. They further report poor performance of wheat and rye when grown in solutions containing 0:4: than with 4:0, 3:1, 1:1 and 1:3 $NO_3^-$:$NH_4^+$-N mixtures, indicating that high $NH_4^+$-N in nutrient solutions affects plant growth. Poor growth of plants receiving the nutrient solution containing high $NH_4^+$-N has also been reported for potato. Reports using potato meristem and stem culture show that $NH_4^+$-N may be detrimental to potato growth. In studies of potatoes grown to maturity in solution and sand cultures, Davis *et al.* (1986) report that $NH_4^+$-N reduced growth, caused leaf roll, suppressed Ca and Mg absorption and increased P and N accumulation.

Studies with maize have also shown the benefit of combining different nitrogen sources in nutrient solutions (Schrader, Domska, Jung & Peterson, 1972 and Below & Gentry, 1992). In all these experiments, results have shown that plant growth is usually greater at 25% and 50% $NH_4^+$-N than with 75% $NH_4^+$-N (Gamnore - Newmann & Kafkafi, 1980; Gashaw & Mugwira, 1981). Working with potatoes Cao & Tibbitts (1993) found that dry weights of whole plant and separate plant parts were significantly higher with all $NO_3^-$-N / $NH_4^+$-N combinations from 4% to 20% $NH_4^+$-N than with $NO_3^-$-N only.

While a number of studies have been undertaken to determine the effect of $NO_3^-$:$NH_4^+$ ratio on different crops, many have mostly focussed on vegetative growth and have been terminated before physiological maturity. In the first experiment there were no differences in yields and yield components due to changes in the $NO_3^-$:$NH_4^+$ ratio. The non significant yield and yield components among plants receiving the nutrient solutions containing 14:1 and 1:1

$NO_3^-$:$NH_4^+$ ratios shows that either of the two ratios can be used without any compromise on seed yield quantity (Table 5.4). Differences were observed in the second experiment in which significantly higher seed yields per plant (21.2g and 19.1g) were produced by plants receiving the nutrient solutions containing 1:1 and 14:1 $NO_3^-$:$NH_4^+$ ratios respectively than the 7.5g seed yield per plant produced by plants receiving the nutrient solution containing 1:14 $NO_3^-$:$NH_4^+$ ratio. The use and benefits of combined nitrogen sources in crop production have been reported for potatoes (Hendrickson *et al.*, 1978), wheat and rye (Gashaw & Mugwira, 1981) and tomatoes (Ikeda & Tan, 1998) under hydroponic systems. Solanaceous crops such as tobacco and tomato have also been reported to prefer a high $NO_3^-$:$NH_4^+$-N ratio (Davis *et al.*, 1986).

The concentration of nitrogen in the nutrient solution plays a role in determining seed yield and yield components of dry bean. In the first experiment there was no advantage in seed yields and yield components among plants receiving the full strength nutrient solution over those receiving the half strength nutrient solution concentration. For the nutrient solutions containing 14:1 and 1:1 $NO_3^-$:$NH_4^+$ ratios, the concentration of the nutrient solution does not matter. Both the full strength and half strength nutrient solution concentrations may be used with minimal yield differences.

If a high $NH_4^+$-N source is to be used, there may be need to reduce the concentration of the nutrient solution. $NH_4^+$-N source is reported to be less toxic at low concentration. As plants require large quantities of nitrogen, this level of nitrogen may not be adequate for plant growth. Nitrogen deficiency symptoms may be observed as the case in this study. Plants receiving the quarter strength nutrient solution in all the three $NO_3^-$:$NH_4^+$ ratios developed nitrogen deficiency symptoms. Plants developed pale yellow coloration. The quarter strength nutrient solution with high $NH_4^+$-N treatment (7% $NO_3^-$-N with 93% $NH_4^+$-N) showed severe deficiency with age and some brownish blotches on the leaf edges. This has been associated with Ca deficiency (Ikeda & Tan, 1998 and Association for Intensive Plant Production, 1999). Similar results have been reported for tomato plants too (Kirkby & Mengel, 1967).

## 5.5 CONCLUSION

A combination of $NO_3^-$-N and $NH_4^+$-N in nutrient solutions is suitable for dry bean production. Limiting the $NH_4^+$-N to between 7 - 50% in combination with $NO_3^-$-N would enhance vegetative growth and provide adequate nutrients for good growth and seed yield. Both the full strength and half strength concentrations produced similar seed yields indicating possibility of cost saving by using the half strength nutrient solution. These combined $NH_4^+$ and $NO_3^-$-N sources have also been associated with more stable nutrient solution pH due to their relatively high buffering capacities as observed by Clark (1982) and Bernardo, *et al.* (1984a & b).

## 5.6 REFERENCES


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# CHAPTER 6

# EFFECT OF A CYTOKININ-CONTAINING GROWTH REGULATOR ON SEED YIELD AND YIELD COMPONENTS OF DRY BEAN

## 6.1 INTRODUCTION

Seed yield per plant is determined by number of flowers formed per plant, percentage podset, number of seeds per pod and seed size. Dry beans form more flowers than mature pods. The difference between number of flowers and number of pods set has been attributed to abscission of both flowers and immature pods (Binnie & Clifford, 1981) and this may be one of the possible reasons for not maximising seed yield in dry beans. According to Tamas, Ozbun, Wallace, Powell & Engels (1979) abscission of pods appears to be the last step in the process of fruit abortion, which is characterised by cessation of seed development, flattening of pod walls and loss of green colour. These processes have been said to be under hormonal control and events leading to pod abortion have been associated with a decrease in the concentration of auxins (Luckwill, 1953, 1981) and an increase in the concentration of ethylene and abscisic acid (ABA) (Davis & Addicott, 1972; Lipe & Morgan 1972).

Although it cannot be stated categorically that overcoming abscission would result in yield increase, information concerning flower and pod abscission and the possible causes of the phenomenon is vital (Van Schaik & Probst, 1958 and Ojehomon, 1970). There is a need to evaluate available growth regulators to identify products with the potential to improve the productivity of dry bean by reducing flower and pod abortion. This information could provide a basis for possible intervention to control the phenomenon. Application of exogenous growth regulators offers one possibility of intervening in the process of abscission (Keller & Belluci, 1983).

The objective of this experiment was to establish whether a cytokinin-containing growth regulator (trade name Marinure), a seaweed extract containing 15ml per litre cytokinin and 22ml per litre auxin (Canyon Report, 1998), affects vegetative growth and yield of dry bean by limiting abscission and enhancing dry matter partitioning to the reproductive organs.

## 6.2 MATERIALS AND METHODS

### Plant material and growth conditions

Seed of two dry bean cultivars, Teebus and Kranskop, were planted in a pot experiment in a greenhouse on 10th August 2000 at the University of Pretoria Experimental Farm (Lat. 25° 45'S, Long.28° 16'E, elevation 1372masl). Five litre capacity pots were filled with sterilised sand and three seeds were planted per pot and thinned to one plant per pot five days after emergence. The 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 sand and hence avoid salt accumulation.

Aldicarb (Temik), a systemic insecticide and Triforine (Fungitex), a systemic fungicide, were applied for control of aphids and fungal infection respectively. Tetradifon, a red spidercide was also applied once weekly for three weeks to control spidermite infection.

### Cytokinin - containing growth regulator treatments

Three treatments of a cytokinin-containing growth regulator (trade name Marinure), a sea weed extract, were used in the experiment. A control (without growth regulator) and two growth regulator treatments namely the recommended rate of 8ml growth regulator per litre nutrient solution (Canyon Report, 1998) and double the recommended rate at 16ml growth regulator per litre nutrient solution, were applied in the experiment. The seaweed extract is composed of 15ml per litre cytokinin and 22ml per litre auxin. The cytokinin-containing seaweed extract was mixed with the full strength Nitsch nutrient solution and applied twice fortnightly as a full cover spray.

### Harvest and analysis

During the growing period three plants were harvested fortnightly from each treatment to monitor biomass accumulation, leaf area development, shoot and root development. The experiment was arranged in a completely randomised design with three replications. Three replicates of each treatment were left to reach maturity and were harvested on 25th November 2000. Data on seed yield and yield components were recorded. The seed yield and yield components data was subjected to statistical analysis using the SAS statistical package (SAS

Institute, 1989) with cultivar and growth regulator treatments as main effects in the ANOVA. The separation of means was done by means of the Duncan Multiple Range Test.

## 6.3 RESULTS AND DISCUSSION

### Vegetative growth

The effect of a cytokinin-containing growth regulator on biomass accumulation is presented in Figure 6.1. Biomass accumulation in all the treatments increased exponentially as days after emergence (DAE) increased. Differences were observed for cultivar Teebus in which plants treated with the double rate cytokinin-containing growth regulator (T2) developed at a slower rate than plants treated with the control (T0) and the recommended rate (T1). No differences were observed for cultivar Kranskop, although plants receiving the double rate treatment had a somewhat larger biomass accumulation than those treated with the other two treatments especially during the first five weeks of growth.

Figure 6.2 shows the effect of the cytokinin-containing growth regulator treatment on leaf area development. No differences were observed among plants treated with different levels of cytokinin-containing growth regulator in the first six weeks for both Kranskop and Teebus cultivars. Cultivar differences in leaf area was observed after six weeks of growth. Cultivar Kranskop had a larger and more vigorous leaf area development than cultivar Teebus over all growth regulator treatments. Plants receiving both the recommended rate and the double rate treatments developed a somewhat higher leaf area than those in the control for cultivar Kranskop. For cultivar Teebus, plants receiving both the recommended and double rate treatments had a smaller leaf area than those of the control treatment.

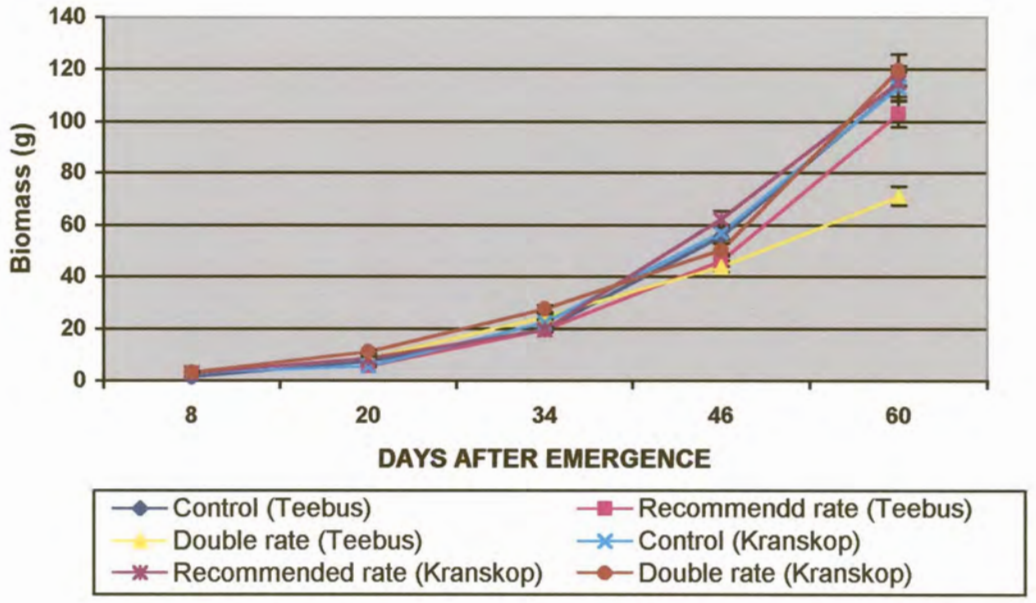


**Figure 6.1** Effect of the cytokinin-containing growth regulator on fresh biomass (g) of dry bean, cultivars Kranskop and Teebus

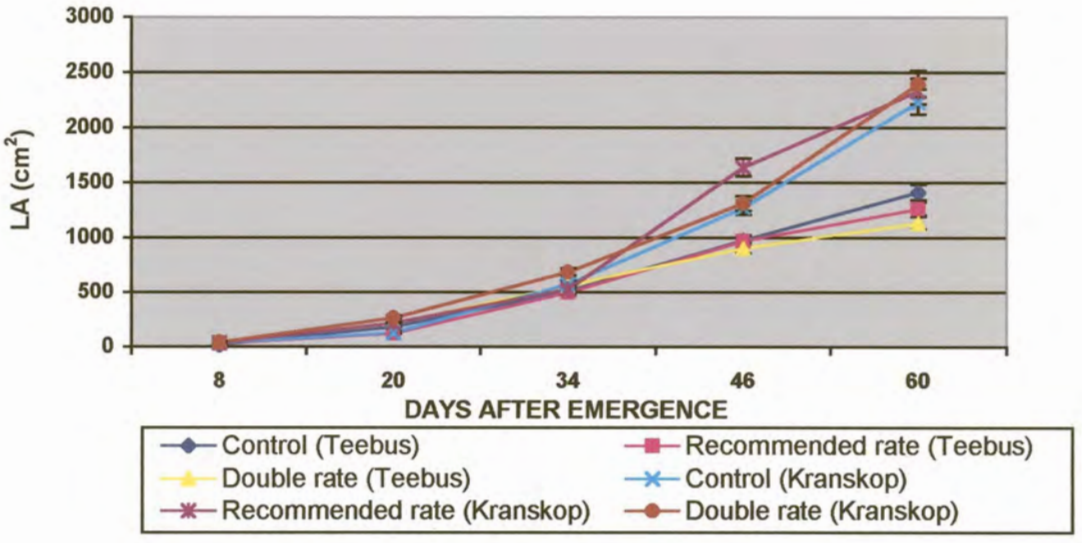


**Figure 6.2** Effect of the cytokinin-containing growth regulator on the leaf area (LA) of dry bean cultivars Krankop and Teebus

The effect of the cytokinin-containing growth regulator on shoot dry weight of cultivars Kranskop and Teebus is presented in Figure 6.3. The shoot dry weight during the first six weeks of growth did not differ significantly between both cultivar and growth regulator

treatments. Differences were observed six weeks after emergence where cultivar Kranskop had a relatively higher shoot dry weight than cultivar Teebus. Plants in the two growth regulator treatments did not perform any better than those receiving control treatment for cultivar Kranskop. For cultivar Teebus the plants receiving the recommended rate treatment had a somewhat larger shoot dry weight than those receiving control and double rate treatments.

Figure 6.4 shows the effect of the cytokinin-containing growth regulator on root dry weight of cultivars Kranskop and Teebus. No clear trend was observed in the development of root dry weight between both cultivars and growth regulator treatments. For cultivar Teebus, plants receiving the control treatment had a somewhat larger root dry weight than plants receiving growth regulator treatment while for cultivar Kranskop, plants receiving the double rate treatment had a somewhat larger root dry weight than the other treatments.

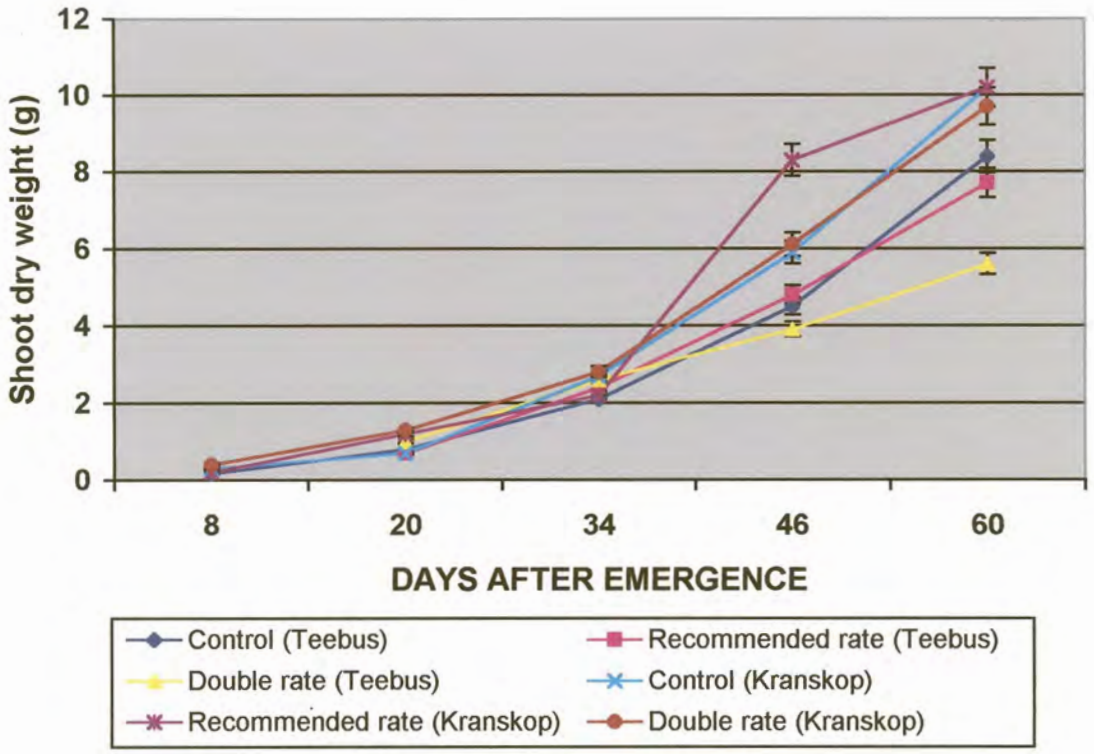


**Figure 6.3** Effect of the cytokinin-containing growth regulator on the shoot dry weight of dry bean cultivars Kranskop and Teebus

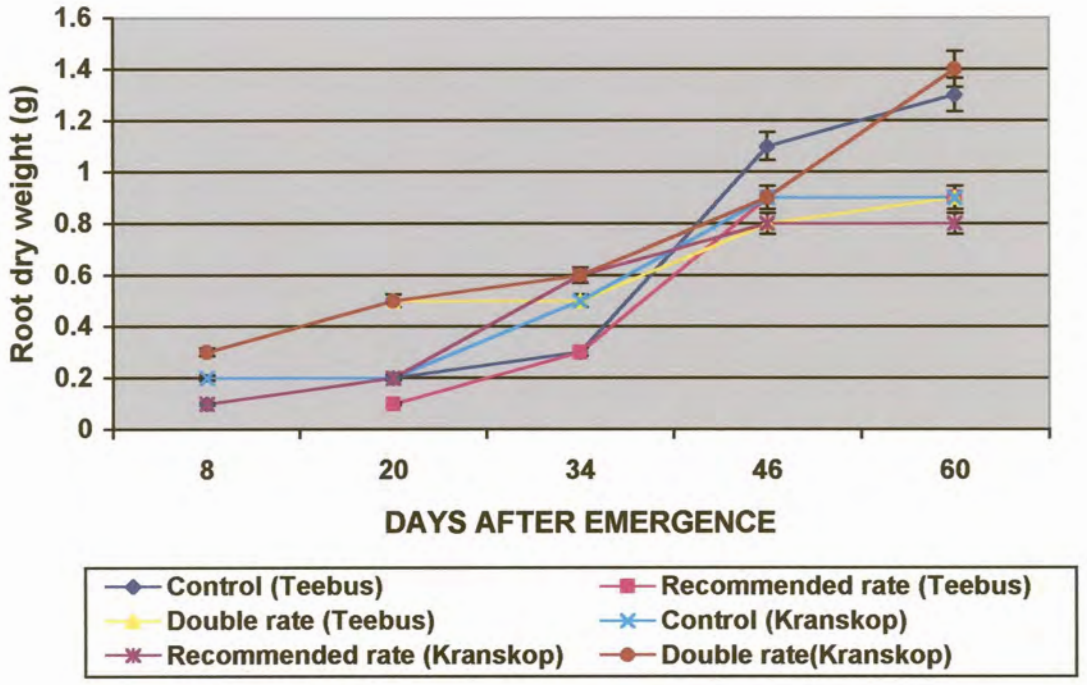


**Figure 6.4** Effect of the cytokinin-containing growth regulator on the root dry weight of dry bean cultivars Kranskop and Teebus

## Seed yield and yield components

The effect of the cytokinin-containing growth regulator on seed yield and yield components of dry bean cultivars Kranskop and Teebus are given in Tables 6.1 to 6.5.

## Seed yield

Table 6.1 shows the effect of cultivar and cytokinin-containing growth regulator on seed yield per plant. Only the cultivar main effect was significant while the growth regulator main effect and the cultivar x growth regulator interaction were not.

*Main effects.* Significant seed yield differences were observed between cultivar Kranskop and cultivar Teebus over all growth regulator treatments (Table 6.1). Cultivar Kranskop produced a higher seed mass per plant (15.4g) than cultivar Teebus (11.0g). No differences were observed among growth regulator treatments for either of the cultivars.

*Interaction.* The non significant cultivar x growth regulator interaction indicates that both cultivar and growth regulator treatments influenced seed mass independent of each other.

**Table 6.1** Effect of the cytokinin-containing growth regulator on seed yield per plant of dry bean, cultivars Teebus and Kranskop (ANOVA: Appendix Table 8.7A)

| Growth regulator treatment | Cultivar | | Mean |
|---|---|---|---|
| | Teebus | Kranskop | |
| Control | 11.3 | 14.4 | 12.8 |
| Recommended rate | 11.4 | 16.3 | 13.9 |
| Double rate | 10.2 | 15.5 | 12.9 |
| Mean | 11.0 | 15.4 | 13.2 |
| LSD (C) (P≤0.05) = 3.6 | CV(%) = 26.2 | $R^2$ = 0.40 | SE = 2.0 |

*LSD values given only where effects are significant.*

**Number of pods per plant**

Data for the effect of cultivar and growth regulator on number of pods per plant is shown in Table 6.2. The cultivar main effect was highly significant while both the growth regulator main effect and the cultivar x growth regulator interaction were not.

*Main effect.* The significant cultivar main effect indicates that the cultivars differed in the production of pods per plant. Cultivar Teebus produced a significantly higher number of pods per plant (15.4) than cultivar Kranskop (9.0). The non-significant growth regulator main effect observed shows that the three treatments did not influence the number of pods per plant differently. This means that there was no advantage in using growth regulator treatments over control treatment for improving number of pods per plant. However, the recommended rate treatment produced a somewhat higher number of pods per plant (13.3) than both the control and double rate treatments which produced 11.7 pods.

*Interaction.* The non significant cultivar x growth regulator interaction indicates that the growth regulator treatments did not affect the two cultivars differentially.

**Table 6.2** Effect of the cytokinin-containing growth regulator on the number of pods per plant of dry bean cultivars Teebus and Kranskop (ANOVA: Appendix Table 8.7B)

| Growth regulator treatment | Cultivar | | Mean |
|---|---|---|---|
| | Teebus | Kranskop | |
| Control | 16.3 | 7.0 | 11.7 |
| Recommended rate | 16.3 | 10.3 | 13.3 |
| Double rate | 13.7 | 9.7 | 11.7 |
| Mean | 15.4 | 9.0 | 12.2 |

LSD (C) (P≤0.05) = 2.2 CV(%) = 17.2 $R^2$ = 0.80 SE = 1.2

*LSD values given only where effects are significant.*

**Number of seeds per pod**

Effect of cultivar and growth regulator on number of seeds per pod is presented in Table 6.3. Only the cultivar main effect was significant while the growth regulator main effect and the cultivar x growth regulator interaction were not.

*Main effects.* The significant cultivar main effect indicates that both cultivars performed differently over all growth regulator treatments. Number of seeds per pod was higher for cultivar Teebus (4.7) than for cultivar Kranskop (3.7) (Table 6.3). The non significant growth regulator main treatment effect highlights the fact that the treatments applied did not affect the number of seeds per pod over both cultivars. Nevertheless, a somewhat decreasing trend in the number of seeds per pod with increasing growth regulator treatments was observed. The control had a somewhat higher number of seeds per pod (4.4) than the recommended rate (4.2) and the double rate (4.1) treatments.

*Interaction.* The cultivar x growth regulator interaction was not significant showing that the cultivars were not affected differently by the growth regulator treatments.

**Table 6.3** Effect of the cytokinin-containing growth regulator on the number of seeds per pod of dry bean cultivars Teebus and Kranskop (ANOVA: Appendix Table 8.7C)

| Growth regulator treatment | Cultivar | | Mean |
|---|---|---|---|
| | Teebus | Kranskop | |
| Control | 4.7 | 4.0 | 4.4 |
| Recommended rate | 4.8 | 3.6 | 4.2 |
| Double rate | 4.7 | 3.5 | 4.1 |
| Mean | 4.7 | 3.7 | 4.2 |
| LSD (C) (P≤0.05) = 0.5 | CV(%) = 11.2 | $R^2$ = 0.64 | SE = 0.3 |

*LSD values given only where effects are significant*

**Seed size (100 seed mass)**

The data for the effect of cultivar and growth regulator on seed size is given in Table 6.4. Only the cultivar main effect was significant while the growth regulator main effect and the cultivar x growth regulator interaction were not.

*Main effects.* The significant cultivar main effect shows that the two cultivars differed in seed size. Cultivar Kranskop produced a significantly larger seed (46.6g) than cultivar Teebus (22.9g). The non significant growth regulator main treatment effect shows that the three treatments did not affect seed size differently over both cultivars. No clear trend was observed in seed size as growth regulator treatment increased. The largest seed size over both cultivars was observed in plants receiving the control treatment (36.7g) followed by those receiving the double rate treatment (35.5g) and the recommended rate treatment (32.6g).

*Interaction.* No significant interactive effect was observed in seed size between cultivar and growth regulator treatments. This indicates that the effect of the growth regulator on the two cultivars was similar. The trend showed an increase in seed size from 22.1g to 23.9g for cultivar Teebus as growth regulator treatment increased from the control treatment to the

double rate treatment. No clear trend was observed for cultivar Kranskop, producing the largest seed size by plants receiving the control treatment (51.3g) and the smallest size among plants receiving the recommended rate treatment. Plants receiving the double rate treatment were intermediate.

**Table 6.4** Effect of the cytokinin-containing growth regulator on the seed size (g) of dry bean cultivars Teebus and Kranskop (ANOVA: Appendix Table 8.7D)

| Growth regulator treatment | Cultivar | | Mean |
|---|---|---|---|
| | Teebus | Kranskop | |
| Control | 22.1 | 51.2 | 36.7 |
| Recommended rate | 22.8 | 42.4 | 32.6 |
| Double rate | 23.9 | 46.2 | 35.0 |
| Mean | 22.9 | 46.6 | 34.8 |
| LSD (C) (P≤0.05) = 5.7 | CV(%) = 15.8 | $R^2$ = 0.88 | SE = 3.2 |

*LSD values given only where effects are significant.*

**Harvest index (%)**

Table 6.5 shows the effect of cultivar and growth regulator on harvest index of dry bean. No significant cultivar main effect was observed, while the growth regulator main effect and the cultivar x growth regulator interaction were significant.

*Main effects.* The non significant cultivar main effect shows that no difference in harvest index was observed between the two cultivars over all growth regulator treatments, averaging 48.8% for cultivar Teebus and 46.3% for cultivar Kranskop. The growth regulator main effect was highly significant showing that the different treatments affected harvest index for both cultivars. The highest harvest index was observed among plants receiving the recommended rate treatment (54.1%) and lowest among plants receiving the control treatment (36.9%) while those receiving the double rate treatment were intermediate (51.7%).

*Interaction.* The significant cultivar x growth regulator interaction indicates that the harvest index for both cultivars were affected differently by the different growth regulator treatments. For cultivar Teebus the highest harvest index (59.0%) was observed for plants receiving the recommended rate of the growth regulator, followed by those receiving the double rate treatment (46.7%) and plants receiving the control treatment had the lowest harvest index (40.6%). For cultivar Kranskop, the highest harvest index (56.7%) was observed for plants receiving the double rate treatment followed by those receiving the recommended rate treatment (49.1%) while plants receiving the control treatment had the lowest harvest index (36.9%).

**Table 6. 5** Effect of the cytokinin-containing growth regulator on the harvest index (%) of dry bean cultivars Teebus and Kranskop (ANOVA: Appendix Table 8.7E).

| Growth regulator (GR) treatment | Cultivar (C) | | Mean |
|---|---|---|---|
| | Teebus | Kranskop | |
| Control | 40.6 | 33.1 | 36.9 |
| Recommended rate | 59.0 | 49.1 | 54.1 |
| Double rate | 46.7 | 56.7 | 51.7 |
| Mean | 48.8 | 46.3 | 47.6 |
| LSD (GR) (P≤0.05) = 10.2 | | LSD (C x GR) (P≤0.05) = 11.8 | |
| CV(%) = 13.9 | $R^2 = 0.73$ | SE = 3.8 | |

LSD values given only where effects are significant.

According to Donald (1968) harvest index is the ratio of seed yield to total shoot dry matter, which reflects the partitioning of photosynthate to seed. The results of the experiment clearly show that a cytokinin-containing growth regulator had some positive effect on harvest index of the two cultivars. While there were no differences in seed yield and yield components due to different growth regulator treatments, the significant harvest index indicates the possible influence of growth regulator on the reproductive sink of dry bean.

More assimilates have been allocated to the sink (the seed) than other plant parts as reported by Clifford, Pentland & Baylis (1992) who indicated the role of growth regulators in the

control of photosynthate competition between reproductive and vegetative sinks. However, Cipollini (1997) suggests to the contrary that due to the numerous effects that exogenously applied hormones can have on plant growth, it is impossible that a particular plant hormone treatment can alter a plants assimilatory capacity and / or resource allocation pattern (such as root/shoot ratio). It may therefore be possible that the improved harvest index observed may be associated with limited vegetative growth of plants in the cytokinin-containing growth regulator treatments.

## 6.4 CONCLUSION

There may be a possibility of improving bean production with the growth regulator used in this experiment, a cytokinin-containing seaweed extract (trade name marinure) treatment, and that different cultivars may be affected differently. Somewhat higher seed yield and yield component values were obtained with the recommended rate of application.

As the results are not conclusive, further research is required. The cytokinin-containing growth regulator evaluated in this trial did not improve seed set and seed development and can not be recommended for dry bean seed production under greenhouse conditions.

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# CHAPTER 7

## GENERAL DISCUSSION AND CONCLUSION

The objective of this study was to evaluate ways of optimising dry bean seed multiplication under greenhouse conditions. This is with a view to improve the commercial dry bean seed multiplication programme by increasing the quantity of disease-free seed produced in the greenhouse multiplication phase.

Three factors, (i) plant density, (ii) nitrate/ammonium ratio and concentration and (iii) the use of a cytokinin-containing growth regulator were investigated.

## 7.1 PLANT DENSITY

This investigation has shown that dry bean seed yield per unit area can be increased by planting at very high plant densities. A plant population of 139 plants $m^{-2}$, achieved by a spacing of 12 x 6cm produced a seed yield of 822g $m^{-2}$ in the greenhouse, which is equivalent to 8.2 tons $ha^{-1}$. Such high plant densities have been reported by many authors (Mack & Hatch, 1968; Crandall, 1971; Cooper, 1977), with an equidistant spacing being more beneficial than a rectangular arrangement (Crothers & Westermann, 1976). While in most of these reports there has not been an indication of seed yield per plant, there is a tendency of a negative relationship between seed yield per plant and seed yield per unit area. An increase in seed yield per unit area in our investigation was associated with reduced seed yield per plant. It seems that 139 plants $m^{-2}$ approaches the threshhold plant population for cultivar Kranskop indicating that there is no benefit in increasing the plant density beyond this threshhold level. Plant morphology and / or growth habit has been reported to influence seed yields at very high plant densities as suggested by Crothers & Westermann (1976). This indicates that different cultivars may require different spacings.

Large differences in yield per plant for comparable plant densities were observed between the pot trial, the first crate trial and the field trial, indicating the important role of other environmental factors (water supply, nutrition, climate, pests, growing period etc) in the determination of yield. This emphasises that the optimum plant density will differ between

different growing conditions.

The number of pods per plant seems to be the determining factor of seed yield per plant. The number of pods per plant showed a positive relationship with seed yield per plant, decreasing with increasing plant density. The number of seeds per pod and seed size remained relatively stable even at high plant densities. This is in agreement with Leakey (1972) and Crothers & Westermann (1976) who indicated a direct relationship between seed yield and number of pods per plant. They also stated that the number of pods per unit area was the major seed yield component influencing seed yield, with little influence of either seed size or seeds per pod on seed yield per unit area.

The greenhouse trials showed that relatively high seed yields of up to 822g $m^{-2}$ could be obtained using the cultivar Kranskop when seed was used as planting material. Provided similar results can be obtained with explants, this indicates that greenhouse multiplication can be a viable procedure in a seed multiplication programme. The highest yield was obtained with a high population of 139 plants $m^{-2}$. In a commercial situation the growing conditions and convenience of crop management practices will affect the optimum plant density. The optimum density will be determined by the unit cost of explants and the production cost per unit area of greenhouse space.

Although in practice explants from meristem cultures multiplied *in vitro* will be the main source of planting material in the greenhouse multiplication phase, plants in this investigation were produced from seed. No comparison between the performance of plants derived from *in vitro* culture and from seed was attempted. Based on the appearance of plants derived from *in vitro* plantlets in greenhouses of the Dry Bean Producers Organisation it was assumed that growth habit, reaction to plant density, nutritional requirements and other growth reactions are similar for plants from seed. Provided seed can be multiplied economically in greenhouses or other protective structures, multiplication for more than one generation after the *in vitro* phase with seed as planting material may also be a viable proposition.

## 7.2 NITROGEN SOURCE AND CONCENTRATION

Nitrogen plays a vital role in the growth and development of dry bean and determining seed yields and yield components. Experiments were conducted to determine the effect of the source of nitrogen ($NH_4^+$-N, $NO_3^-$-N or a combination of the two) as well as the

concentration of nitrogen in the nutrient solution on seed yield. Good plant growth and similar seed yields were observed among plants receiving the full strength and half strength nutrient solutions containing either 7% $NH_4^+$-N with 93% $NO_3^-$-N (1:14) or 50% $NH_4^+$-N with 50% $NO_3^-$-N (1:1). A nitrate / ammonium ratio in the nutrient solution with more ammonium than nitrate detrimentally affected yield. The high $NH_4^+$-N (93% $NH_4^+$-N with 7% $NO_3^-$-N) treatment caused stunted growth and chlorotic lesions on leaves. This was more pronounced in plants receiving the full strength and half strength nutrient solution, and almost all plants were dead by the time of harvest maturity due to ammonium toxicity. Similar findings have been reported for potatoes by Cao & Tibbitts (1993) where enhanced growth was observed when 80 to 92% of the nitrogen in the solution was in the nitrate form. Hydroponic studies with corn (Gashaw & Mugwira, 1981; Below & Gentry, 1992; Shrader *et al.* 1972), tomato (Gamnore-Newmann & Kafkafi, 1980) and wheat (Wang & Below, 1992) have shown better plant growth with 25% and 50% $NH_4^+$-N than with 75% $NH_4^+$-N. Barker & Mills, 1980; Below & Gentry (1992) and Pilbeam & Kirkby (1992) state that enhanced growth when both ammonium and nitrate is supplied, results from increased nitrogen accumulation in the plants, even though the physiological basis of the benefit is yet to be established.

The results indicate that good seed yields can be obtained with nitrate/ammonium ratios of either 14:1 or 1:1. As reported in Chapter 5 it seems that a nutrient solution containing a 1:1 nitrate/ammonium ratio may be advantagous for dry bean production. This ratio enhanced the green colouration in the bean plants and resulted in a somewhat larger leaf area and stronger shoot growth at 40 DAE (Table 5.4a). This ratio also results in a more stable nutrient solution pH due to its relatively high buffering capacity according to Clark (1982) and Bernardo, *et al.* (1984a & b).

Similar seed yields were produced when either the full strength or half strength nutrient solution concentrations were supplied, indicating possible cost savings by applying diluted nutrient solutions.

## 7.3 CYTOKININ-CONTAINING GROWTH REGULATOR

No yield benefit was obtained by applying a cytokinin-containing growth regulator to the nutrient solution in a pot trial. The use of plant growth regulants to limit abscission of flowers and pods deserves more research attention.

## 7.4 FUTURE RESEARCH

Aspects not included in this investigation and deserving further research include;

i. Comparison of the growth, development and yield of *in vitro* plantlets to that of plants derived from seed.

ii. Evaluation of the reaction of other important dry bean cultivars, as this research focussed on cultivars Kranskop and Teebus.

iii. Confirmation of the results on a larger (semi-commercial) scale. This should include a treatment where the cultivar Kranskop is grown at approximately 139 plants $m^{-2}$ and supplied with a half strength nutrient solution containing 1:1 $NO_3^-$: $NH_4^+$ ratio.

iv. Evaluation of other plant growth regulators to limit abscission of flowers and young pods.

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## APPENDIX

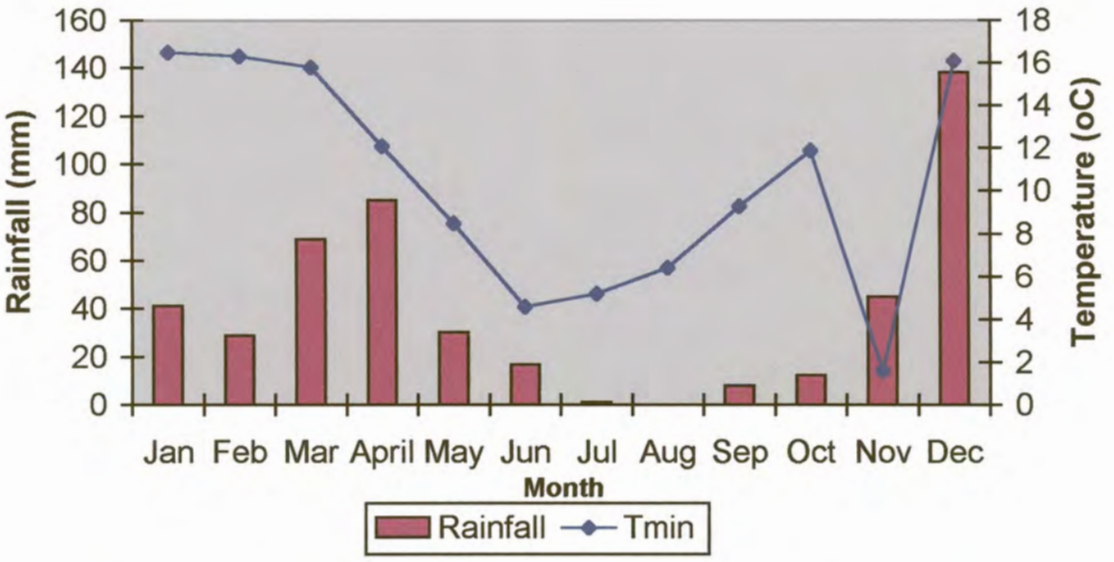


**Figure 8.1** Monthly meteorological data for Hatfield showing raifall (mm) and mean minimum temperatures, 1999.

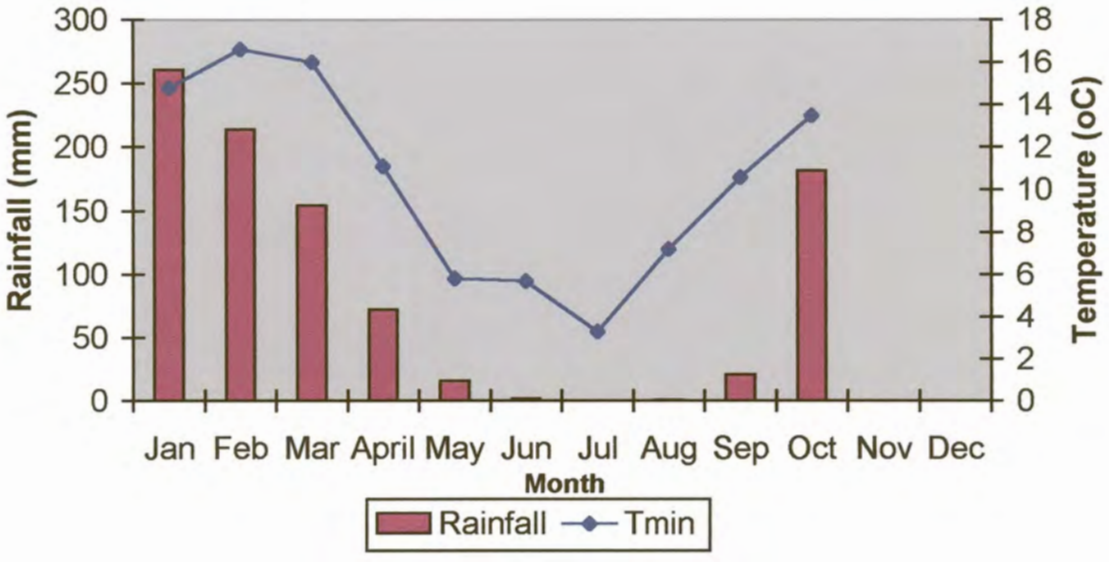


**Figure 8.2** Monthly meteorological data for Hatfield showing raifall (mm) and mean minimum temperatures, 2000.

**Table 8 1** Growth habit classification and description of *Phaseolus* as defined by CIAT

| GROWTH HABIT | DESCRIPTION |
|---|---|
| Type I | Determinate habit; reproductive terminals on main stem and no further node production on main stem after flowering. |
| Type II | Indeterminate habit (vegetative terminal on main stem); further node production on main stem after flowering; erect branches borne on lower nodes; erect plant with extremely variable guide development. |
| Type IIIa | Indeterminate habit; moderate node production on main stem after flowering; prostrate canopy with variable number of branches borne on lower nodes; main stem guide development extremely variable but generally showing poor climbing ability. |
| Type IIIb | Indeterminate habit; considerable node production on main stem after flowering; heavily branched with variable number of facultatively climbing branches borne on lower nodes; guide development variable; plants generally show moderate climbing tendency on supports with resulting cone-shaped canopy. |
| Type IVa | Indeterminate habit; heavy node production on main stem after flowering; branches not well developed compared to main stem development; moderate climbing ability on supports, with fruit load carried relatively uniformly along length of the plant. |
| Type IVb | Indeterminate habit; extreme node production after flowering; branches very poorly developed; strong climbing tendencies on supports, with fruit load borne on the upper node of main stem. |

**Table 8. 2A** ANOVA of the effect of plant density on seed yield per plant of dry bean cvs Teebus & Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 15 | 32.2 | | |
| Cultivar (C) | 1 | 7.3 | 7.3 | 3.85ns |
| Density (D) | 1 | 1.6 | 1.6 | 0.85ns |
| C x D | 1 | 0.7 | 0.7 | 0.35ns |
| Error | 12 | 22.7 | | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 2B** ANOVA of the effect of plant density on seed yield per square metre of dry bean cvs Teebus & Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 15 | 58538.7 | | |
| Cultivar (C) | 1 | 8192.5 | 8192.5 | 4.35ns |
| Density (D) | 1 | 27600.0 | 27600.0 | 14.65** |
| C x D | 1 | 145.3 | 145.3 | 0.08ns |
| Error | 12 | 22600.9 | | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 2C** ANOVA of the effect of plant density on number of pods per plant of dry bean cvs Teebus & Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 15 | 100.4 | | |
| Cultivar (C) | 1 | 75.1 | 75.1 | 39.88** |
| Density (D) | 1 | 2.2 | 2.2 | 1.19ns |
| C x D | 1 | 0.4 | 0.4 | 0.23ns |
| Error | 12 | 22.6 | | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 2D** ANOVA of the effect of plant density on number of seeds per pod of dry bean cvs Teebus & Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 15 | 1.2 | | |
| Cultivar (C) | 1 | 0.3 | 0.3 | 6.40* |
| Density (D) | 1 | 0.021 | 0.021 | 0.44ns |
| C x D | 1 | 0.2 | 0.2 | 5.09* |
| Error | 12 | 0.6 | 0.05 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 2E** ANOVA of the effect of plant density on hundred seed mass of dry bean cvs Teebus & Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 15 | 4635.6 | | |
| Cultivar (C) | 1 | 4544.1 | 45.1 | 704.34** |
| Density (D) | 1 | 14.0 | 14.0 | 2.17ns |
| C x D | 1 | 0.04 | 0.04 | 0.01ns |
| Error | 12 | 77.4 | | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 3A** ANOVA of the effect of plant density on seed yield per plant of dry bean cv Kranskop (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 256.4 | | |
| Density | 2 | 179.9 | 89.9 | 10.58 |
| Error | 9 | 76.5 | 8.5 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 3B** ANOVA of the effect of plant density on seed yield per square metre of dry bean cv Kranskop (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 14.0 | | |
| Density | 2 | 7.5 | 3.8 | 5.24 |
| Error | 9 | 6.4 | 0.7 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 3C** ANOVA of the effect of plant density on number of pods per plant of dry bean cv Kranskop (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 49.6 | | |
| Density | 2 | 39.3 | 19.7 | 17.18 |
| Error | 9 | 10.3 | 1.1 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 3D** ANOVA of the effect of plant density on number of seeds per pod of dry bean cv Kranskop (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 0.2 | | |
| Density | 2 | 0.1 | 0.05 | 4.84 |
| Error | 9 | 0.1 | 0.01 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 3E** ANOVA of the effect of plant density on hundred seed mass of dry bean cv Kranskop (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 38.1 | | |
| Density | 2 | 34.8 | 17.4 | 46.90 |
| Error | 9 | 3.3 | 0.4 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 4A** ANOVA of the effect of row, intra-row and plant density on seed yield per plant of two dry bean cultivars (Field experiment)

| Source | df | SS | MS | F-value |
|---|---|---|---|---|
| Total | 159 | 3591.3 | | |
| C | 1 | 0.8 | 0.8 | 0.06ns |
| I | 3 | 413.8 | 137.9 | 10.37** |
| C x I | 3 | 394.0 | 131.4 | 9.88** |
| R | 4 | 598.1 | 149.5 | 11.24** |
| C x R | 4 | 98.0 | 24.5 | 1.84ns |
| R x I | 12 | 178.1 | 14.8 | 1.12ns |
| C x R x I | 12 | 312.8 | 26.1 | 1.96* |
| Error | 120 | 1595.8 | 13.3 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 4B** ANOVA of the effect of row, intra-row and plant density on seed yield per square metre of two dry bean cultivars (Field experiment)

| Source | df | SS | MS | F-value |
|---|---|---|---|---|
| Total | 159 | 441358.3 | | |
| C | 1 | 5226.0 | 5226.0 | 4.81* |
| I | 3 | 56324.1 | 18774.7 | 17.27** |
| C x I | 3 | 21141.1 | 7047.0 | 6.48** |
| R | 4 | 161474.3 | 40368.6 | 37.13** |
| C x R | 4 | 19380.5 | 4845.1 | 4.46** |
| R x I | 12 | 25428.5 | 2119.0 | 1.95* |
| C x R x I | 12 | 21927.3 | 1827.3 | 1.68ns |
| Error | 120 | 130456.6 | 1087.1 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 4C** ANOVA of the effect of row, intra-row and plant density on pods per plant of two dry bean cultivars (Field experiment)

| Source | df | SS | MS | F-value |
|---|---|---|---|---|
| Total | 159 | 997.8 | | |
| C | 1 | 33.3 | 33.3 | 13.20** |
| I | 3 | 161.2 | 53.7 | 21.30** |
| C x I | 3 | 120.0 | 40.0 | 15.86** |
| R | 4 | 125.5 | 31.4 | 12.43** |
| C x R | 4 | 35.9 | 9.0 | 3.56** |
| R x I | 12 | 100.2 | 8.4 | 3.31** |
| C x R x I | 12 | 118.9 | 9.9 | 3.93** |
| Error | 120 | 302.8 | 2.5 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 4D** ANOVA of the effect of row, intra-row and plant density on number of seeds per of two dry bean cultivars (Field experiment)

| Source | df | SS | MS | F-value |
|---|---|---|---|---|
| Total | 159 | 47.9 | | |
| C | 1 | 11.8 | 11.8 | 54.58** |
| I | 3 | 2.1 | 0.7 | 3.23* |
| C x I | 3 | 0.5 | 0.2 | 0.81ns |
| R | 4 | 0.8 | 0.2 | 0.88ns |
| C x R | 4 | 0.5 | 0.1 | 0.62ns |
| R x I | 12 | 2.6 | 0.2 | 1.01ns |
| C x R x I | 12 | 3.7 | 0.3 | 1.42ns |
| Error | 120 | 25.9 | 0.2 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 4E** ANOVA of the effect of row, intra-row and plant density on hundred seed mass of two dry bean cultivars (Field experiment)

| Source | df | SS | MS | F-value |
|---|---|---|---|---|
| Total | 159 | 27386.7 | | |
| C | 1 | 24163.6 | 24163.6 | 1170.86** |
| I | 3 | 96.2 | 32.1 | 1.55ns |
| C x I | 3 | 112.6 | 37.5 | 1.82ns |
| R | 4 | 118.6 | 29.6 | 1.44ns |
| C x R | 4 | 197.6 | 49.4 | 2.39ns |
| R x I | 12 | 44.3 | 3.7 | 0.18ns |
| C x R x I | 12 | 177.3 | 14.8 | 0.72ns |
| Error | 120 | 2476.5 | 20.6 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 4F** ANOVA of the effect of row, intra-row and plant density on harvest index of two dry bean cultivars (Field experiment)

| Source | df | SS | MS | F-value |
|---|---|---|---|---|
| Total | 159 | 1284.7 | | |
| C | 1 | 434.7 | 434.7 | 118.12** |
| I | 3 | 27.0 | 9.0 | 2.44ns |
| C x I | 3 | 46.4 | 15.5 | 4.21** |
| R | 4 | 136.5 | 34.1 | 9.27** |
| C x R | 4 | 90.7 | 22.7 | 6.17** |
| R x I | 12 | 87.8 | 7.3 | 1.98* |
| C x R x I | 12 | 19.8 | 1.6 | 0.43ns |
| Error | 120 | 441.8 | 3.68 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 5A** ANOVA of the effect of nitrate / ammonium ratio and concentration on fresh biomass of dry bean cv Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 2781.9 | | |
| Ratio (R) | 1 | 1615.6 | 1615.6 | 12.06** |
| Concentration (C) | 1 | 94.9 | 94.9 | 0.71ns |
| R x C | 1 | 0.003 | 0.003 | 0.00ns |
| Error | 8 | 1071.4 | 133.9 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 5B** ANOVA of the effect of nitrate / ammonium ratio and concentration on leaf area of dry bean cv Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 257441.9 | | |
| Ratio (R) | 1 | 127759.5 | 127759.5 | 13.79** |
| Concentration (C) | 1 | 17065.3 | 17065.3 | 1.84ns |
| R x C | 1 | 38498.2 | 38498.2 | 4.16ns |
| Error | 8 | 74118.9 | 9264.9 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 5C** ANOVA of the effect of nitrate / ammonium ratio and concentration on dry biomass of dry bean cv Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 43.5 | | |
| Ratio (R) | 1 | 25.1 | 25.1 | 12.61** |
| Concentration (C) | 1 | 2.3 | 2.3 | 1.14ns |
| R x C | 1 | 0.1 | 0.1 | 0.06ns |
| Error | 8 | 16.0 | 2.0 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 5D** ANOVA of the effect of nitrate / ammonium ratio and concentration on shoot dry weight of dry bean cv Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 42.7 | | |
| Ratio (R) | 1 | 22.7 | 22.7 | 10.27* |
| Concentration (C) | 1 | 2.0 | 2.0 | 0.92ns |
| R x C | 1 | 0.2 | 0.2 | 0.08ns |
| Error | 8 | 17.7 | 2.2 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 5E** ANOVA of the effect of nitrate / ammonium ratio and concentration on root dry weight of dry bean cv Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 0.3 | | |
| Ratio (R) | 1 | 0.1 | 0.06 | 1.81ns |
| Concentration (C) | 1 | 0.002 | 0.002 | 0.09ns |
| R x C | 1 | 0.008 | 0.01 | 0.25ns |
| Error | 8 | 0.26 | 0.03 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 5F** ANOVA of the effect of nitrate / ammonium ratio and concentration on number of pods per plant of dry bean cv Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 38.9 | | |
| Ratio (R) | 1 | 0.8 | 0.8 | 0.22ns |
| Concentration (C) | 1 | 4.1 | 4.1 | 1.20ns |
| R x C | 1 | 6.8 | 6.8 | 1.98ns |
| Error | 8 | 27.3 | 3.4 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 5G** ANOVA of the effect of nitrate / ammonium ratio and concentration on number of seeds per pod of dry bean cv Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 1.2 | | |
| Ratio (R) | 1 | 0.003 | 0.003 | 0.02ns |
| Concentration (C) | 1 | 0.003 | 0.003 | 0.02ns |
| R x C | 1 | 0.08 | 0.1 | 0.61ns |
| Error | 8 | 1.1 | 0.1 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 5H** ANOVA of the effect of nitrate / ammonium ratio and concentration on hundred seed mass of dry bean cv Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 424.8 | | |
| Ratio (R) | 1 | 88.6 | 88.6 | 2.16ns |
| Concentration (C) | 1 | 2.8 | 2.8 | 0.07ns |
| R x C | 1 | 5.3 | 5.3 | 0.13ns |
| Error | 8 | 328.1 | 41.0 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 5I** ANOVA of the effect of nitrate / ammonium ratio and concentration on seed yield per plant of dry bean cv Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 910.8 | | |
| Ratio (R) | 1 | 122.9 | 122.9 | 2.57ns |
| Concentration (C) | 1 | 229.9 | 229.9 | 4.81ns |
| R x C | 1 | 175.9 | 175.9 | 3.68ns |
| Error | 8 | 382.2 | 47.8 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 5J** ANOVA of the effect of nitrate / ammonium ratio and concentration on harvest index of dry bean cv Kranskop (Experiment 1)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 11 | 16.8 | | |
| Ratio (R) | 1 | 4.7 | 4.7 | 3.19ns |
| Concentration (C) | 1 | 0.2 | 0.2 | 0.13ns |
| R x C | 1 | 0.2 | 0.2 | 0.13ns |
| Error | 8 | 11.7 | 1.5 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 6A** ANOVA of the effect of nitrate / ammonium ratio and concentration on fresh biomass of dry bean cultivar Kranskop 40 DAE (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 26 | 3180.8 | | |
| Ratio (R) | 2 | 244.3 | 122.2 | 1.49ns |
| Concentration (C) | 2 | 1201.5 | 600.8 | 7.30** |
| R x C | 4 | 254.2 | 63.6 | 0.77ns |
| Error | 18 | 1480.7 | 82.3 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 6B** ANOVA of the effect of nitrate / ammonium ratio and concentration on leaf area of dry bean cultivar Kranskop 40 DAE (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 26 | 2376514.1 | | |
| Ratio (R) | 2 | 382753.8 | 191376.9 | 4.86* |
| Concentration (C) | 2 | 1041375.8 | 520687.9 | 13.22* |
| R x C | 4 | 243649.6 | 60912.4 | 1.55ns |
| Error | 18 | 708734.8 | 39374.1 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 6C** ANOVA of the effect of nitrate / ammonium ratio and concentration on dry biomass of dry bean cultivar Kranskop 40 DAE (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 26 | 279.0 | | |
| Ratio (R) | 2 | 22.7 | 11.4 | 1.53ns |
| Concentration (C) | 2 | 94.8 | 47.4 | 6.38** |
| R x C | 4 | 27.6 | 6.9 | 0.93ns |
| Error | 18 | 133.8 | 7.4 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 6D** ANOVA of the effect of nitrate / ammonium ratio and concentration on shoot dry weight of dry bean cultivar Kranskop 40 DAE (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 26 | 58.5 | | |
| Ratio (R) | 2 | 5.6 | 2.8 | 2.07ns |
| Concentration (C) | 2 | 20.3 | 10.2 | 7.45** |
| R x C | 4 | 7.9 | 2.0 | 1.45ns |
| Error | 18 | 24.6 | 1.4 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 6E** ANOVA of the effect of nitrate / ammonium ratio and concentration on root dry weight of dry bean cultivar Kranskop 40 DAE (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 26 | 5.9 | | |
| Ratio (R) | 2 | 0.3 | 0.2 | 0.65ns |
| Concentration (C) | 2 | 0.4 | 0.2 | 0.71ns |
| R x C | 4 | 0.4 | 0.1 | 0.38ns |
| Error | 18 | 4.8 | 0.3 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 6F** ANOVA of the effect of nitrate / ammonium ratio and concentration on seed mass per plant of dry bean cultivar Kranskop at maturity (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 35 | 2206.3 | | |
| Ratio (R) | 2 | 1340.6 | 670.3 | 44.74** |
| Concentration (C) | 2 | 3.1 | 1.6 | 0.10ns |
| R x C | 4 | 458.3 | 114.6 | 7.65** |
| Error | 27 | 404.5 | 15.0 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 6G** ANOVA of the effect of nitrate / ammonium ratio and concentration on number of pods per plant of dry bean cultivar Kranskop at maturity (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 35 | 351.0 | | |
| Ratio (R) | 2 | 142.1 | 72.0 | 28.95** |
| Concentration (C) | 2 | 2.4 | 1.2 | 0.49ns |
| R x C | 4 | 140.3 | 35.1 | 14.29** |
| Error | 27 | 66.2 | 2.4 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 6H** ANOVA of the effect of nitrate / ammonium ratio and concentration on number of seeds per pod of dry bean cultivar Kranskop at maturity (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 35 | 8.2 | | |
| Ratio (R) | 2 | 0.8 | 0.40 | 1.55ns |
| Concentration (C) | 2 | 0.03 | 0.01 | 0.05ns |
| R x C | 4 | 0.32 | 0.08 | 0.30ns |
| Error | 27 | 7.06 | 0.26 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 6I** ANOVA of the effect of nitrate / ammonium ratio and concentration on hundred seed mass of dry bean cultivar Kranskop at maturity (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 35 | 6074.2 | | |
| Ratio (R) | 2 | 1969.6 | 984.8 | 12.35** |
| Concentration (C) | 2 | 470.1 | 235.0 | 2.95ns |
| R x C | 4 | 1482.1 | 370.5 | 4.65** |
| Error | 27 | 2152.4 | 79.7 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 6J** ANOVA of the effect of nitrate / ammonium ratio and concentration on harvest index of dry bean cultivar Kranskop at maturity (Experiment 2)

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 35 | 2130.6 | | |
| Ratio (R) | 2 | 553.4 | 276.7 | 6.79** |
| Concentration (C) | 2 | 105.2 | 52.6 | 1.29ns |
| R x C | 4 | 372.6 | 93.1 | 2.29ns |
| Error | 27 | 1099.4 | 40.7 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 7A** ANOVA of the effect of cultivar and growth regulator on seed mass per plant of dry bean

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 17 | 239.6 | | |
| Cultivar (C) | 1 | 87.6 | 87.6 | 7.32* |
| Growth regulator (GR) | 2 | 4.1 | 2.1 | 0.17ns |
| C x GR | 2 | 4.4 | 2.2 | 0.18ns |
| Error | 12 | 143.5 | 12.0 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 7B** ANOVA of the effect of cultivar and growth regulator on number of pods per plant of dry bean

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 17 | 273.1 | | |
| Cultivar (C) | 1 | 186.9 | 186.9 | 42.05** |
| Growth regulator (GR) | 2 | 11.1 | 5.6 | 1.25ns |
| C x GR | 2 | 21.8 | 10.9 | 2.45ns |
| Error | 12 | 53.3 | 4.4 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 7C** ANOVA of the effect of cultivar and growth regulator on number of seeds per pod of dry bean

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 17 | 7.4 | | |
| Cultivar (C) | 1 | 4.3 | 4.3 | 19.31** |
| Growth regulator (GR) | 2 | 0.3 | 0.1 | 0.61ns |
| C x GR | 2 | 0.2 | 0.1 | 0.44ns |
| Error | 12 | 2.7 | 0.2 | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 7D** ANOVA of the effect of cultivar and growth regulator on hundred seed mass of dry bean

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 17 | 3005.8 | | |
| Cultivar (C) | 1 | 2518.1 | 2518.1 | 82.88** |
| Growth regulator (GR) | 2 | 50.3 | 25.2 | 0.83ns |
| C x GR | 2 | 72.7 | 36.4 | 1.20ns |
| Error | 12 | 364.6 | | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant

**Table 8. 7E** ANOVA of the effect of cultivar and growth regulator on harvest index of dry bean

| Source | df | SS | MS | F- Value |
|---|---|---|---|---|
| Total | 17 | 1951.8 | | |
| Cultivar (C) | 1 | 26.9 | 26.9 | 0.61ns |
| Growth regulator (GR) | 2 | 1042.1 | 521.0 | 11.88** |
| C x GR | 2 | 356.5 | 178.2 | 4.06* |
| Error | 12 | | | |

*, **, = significantly different from zero at P≤0.05, P≤0.01 respectively
ns = not significant