

**NITROGEN REQUIREMENTS FOR CABBAGE (*BRASSICA OLERECEA
CAPITATA*) TRANSPLANTS AND CROP RESPONSE TO SPACING AND
NITROGEN TOP-DRESSING**

by

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DECLARATION

I declare that this dissertation, for the degree of M Inst Agrar: Horticultural Science at the University of Pretoria is my own work, except where acknowledged and that it has never before been submitted by myself for any degree at any university.

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Date

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Abstract

To determine the optimum nitrogen application level required for the production of good quality 'Drumhead' cabbage (*Brassica oleracea* var. *capitata*) transplants, a glasshouse experiment was conducted. Depending on water requirements, transplants were fertigated every two days (for the first four weeks) and every day (for the last two weeks) by floating trays in plastic tubs containing nutrient solution at 0, 30, 60, 90 and 120 mg·L⁻¹ N until field capacity was reached.

Increasing nitrogen from 0 to 120 mg·L⁻¹ increased shoot and root mass of cabbage transplants with more dry mass being partitioned to the shoot than to the roots. Nitrogen at 120 mg·L⁻¹ N produced greatest fresh and dry shoot mass, plant height, leaf area, leaf tissue nitrogen, net assimilation rate, relative growth rate and leaf mass ratio. Nitrogen at 90 mg·L⁻¹ improved dry root mass, pulling success, specific leaf area and leaf area ratio. Greatest values of root: shoot ratio and root mass ratio were obtained at 0 mg·L⁻¹ N.

Nitrogen at 90 mg·L⁻¹ was best as it produced transplants with more vigorous root growth which pulled out easily from the seedling trays.

To determine the best combination of spacing and nitrogen top-dressing for improved cabbage production under local conditions, a field experiment was conducted. Cabbage 'Copenhagen Market' transplants were spaced at 30 x 50 cm, 40 x 50 cm or 50 x 50 cm and fertilized with nitrogen as top-dressing at 50, 100 or 150 kg·ha⁻¹ N applied in two splits (fourth and eighth week after transplanting).

There were no interactions between spacing and nitrogen top-dressing for all measured variables. Nitrogen and spacing did not influence dry matter production and leaf tissue nitrogen. Furthermore, spacing did not affect core height and yield (per unit area) of trimmed cabbage heads. Nitrogen at 100 kg·ha⁻¹ produced the greatest head mass and yield for untrimmed cabbage heads. The 30 x 50 cm spacing produced the highest yield of untrimmed heads while 50 x 50 cm spacing produced heavier heads. For trimmed heads, 100 kg·ha⁻¹ N again produced the greatest head mass, head diameter, head height, core diameter and yield. Spacing did not affect the yield for trimmed heads. However, 40 x 50 cm spacing improved head diameter, head height and head mass while core diameter was larger with 50 x 50 cm spacing.

The split application of 100 kg·ha⁻¹ N as top-dressing was best for head mass and yield (per unit area) for trimmed and untrimmed heads. Choice of spacing would depend on whether trimmed or untrimmed heads are targeted.

Keywords: *Brassica oleracea* var. *capitata*, nitrogen, spacing, top-dressing, transplants

GENERAL INTRODUCTION

Cabbage (*Brassica oleracea* var. *capitata*) belongs to the family Cruciferae. It is generally believed to have originated from the wild, leafy, non-heading types, which are found growing in Europe (Splittstoesser, 1979; Phillips & Rix, 1993). It has been domesticated and used for human consumption since the earliest antiquity (Ware & McCollum, 1980; Yamaguchi, 1983; Smith, 1995).

Cabbage is a dicotyledonous biennial crop, but it is grown as an annual (Yamaguchi, 1983; Smith, 1995). There is much variation amongst cabbage types, ranging in colour from green to purple; in leaf character from smooth to savoy leaves; in head shape from flat to pointed; and in maturity from early to late maturing. The green, round headed types are the most common (Splittstoesser, 1979; Phillips & Rix, 1993).

Cabbage thrives best during cool, moist seasons (Ware & McCollum, 1980; Hemy, 1984; Smith, 1995; Tiwari, Singh & Mal, 2003). Even though it requires 500 mm of water for its growing period (Askew, 1999), good drainage is important, as too much water tends to split heads when they are mature (Splittstoesser, 1979; Ware & McCollum, 1980). Water should not be deficient from head formation until harvest time, as this will drastically limit yields (Askew, 1999). According to Hadfield (1995), it can be grown throughout the year in most parts of South Africa and its optimum soil pH ranges from 6.0 to 7.0. Its growth season is between 80 to 100 days (Lecuona, 1996).

A 100 g edible portion of cabbage contains 1.8 g protein, 0.1 g fat, 4.6 g carbohydrate, 0.6 g mineral, 29 mg calcium, 0.8 mg iron and 14.1 mg sodium (Singh & Naik, 1988). Moreover, it is a rich source of vitamins A and C (Prabhakar & Srinivas, 1990; Tiwari *et al.*, 2003). It may be served in slaw, salads or cooked dishes (Andersen, 2000).

According to the National Department of Agriculture (2003), cabbage is one of the most popular vegetables grown in South Africa. On the National Markets in 2001/2002, the total sales amounted to R 75 325 200.00 and total production was 153 100 t. About 20

to 40% of the total production is sold to the informal sector such as hawkers, small shops, etc (Lecuona, 1996).

In order to maintain or even improve cabbage production, some factors have to be considered. Production of vigorous transplants is one such necessary factor for successful vegetable production (Cantliffe & Karchi, 1992). Again, correct cultural practices such as adequate application of fertilizers (Everaarts, 1993a) and optimum plant population have to be adhered to in order to obtain good yields in cabbage production (Singh & Naik, 1988; Lecuona, 1996; Singh, 1996; Parmar, Maliwal, Kaswala & Patel, 1999; Sandhu, Chahai, Singh & Sandha, 1999; Kumar & Rawat, 2002).

Due to unpredictable climatic conditions in South Africa, most of the vegetables produced are propagated by means of transplanted seedlings (Strydom, 1997). Limited cell volume and high transplant densities of vegetable transplants grown in plug cells call for careful management of fertilizers (Dufault & Waters, 1985; Weston, 1988; Soundy, Cantliffe, Hochmuth & Stoffella, 2001a) as nutritional practices affect transplant size, quality and growth in the field (Garton & Widders, 1990; Dufault & Schultheis, 1994).

Adequate application of nitrogen fertilizer promotes vigorous vegetative growth and dark green colour of cabbage (Splittstoesser, 1979; Ware & McCollum, 1980; Peck, 1981; Hadfield, 1995). Nitrogen is important in the formation of chlorophyll and is also a component of proteins. Lack of nitrogen causes slow, spindly growth and pale foliage, resulting in limited production (Hadfield, 1995).

Spacing is another factor that was reported to be having an influence on cabbage production. Widders & Price (1989) defined spacing as the distance between the plants in the row and between the rows of planted crops. Ghanti, Sounda, Jana & Som (1982) observed maximum results of yield contributing characters (head diameter, gross and net mass of cabbage head) at 50 cm spacing and a decrease as spacing between plants decreased. In another study, Stepanovic, Bjelic & Dragicevic (2000) reported

increased yields in higher densities and highest cabbage head diameter value in the case of lowest crop densities.

Bearing in mind that nitrogen plays a good role in production of vigorous transplants and that spacing and nitrogen levels influence cabbage head size produced, it is important for the farmer to identify needs of his/her targeted market in order to meet them. Basically, the market demands either small cabbage heads or large heads, and in the market there are currently 30 or more cultivars, which makes it easy for the farmer to choose the most appropriate one for his/her area (Lecuona, 1996). However, within a chosen cultivar, spacing and nitrogen levels can be manipulated in accordance with the required head size.

Experiments using cabbage were conducted to investigate:

- the effect of nitrogen fertilizer on transplant production
- the optimum level of nitrogen top-dressing for different plant spacings suitable for local conditions

CHAPTER 1

LITERATURE REVIEW

1.1 Introduction

Brassica oleracea var. *capitata* (white cabbage) is one of the most important vegetables produced in South Africa. It is important in the human diet, especially in the poorer communities (Strydom, 1997). According to Salunkhe, Desai & Bhat (1987), most cruciferous vegetables are nutritionally low in calories, fat and carbohydrates, yet are rich in sources of protein and contain all the essential amino acids. They are good sources of minerals such as calcium, iron, magnesium, potassium and phosphorus in the available form. They contain substantial amounts of betacarotene (provitamin A), ascorbic acid, riboflavin, niacin and thiamin.

To produce optimum yields of good quality cabbages, often high amounts of nitrogen fertilizer are applied. The recommended total amounts of nitrogen fertilizer for cabbage are 160 to 260 kg·ha⁻¹ (The Fertilizer Society of South Africa, 2000). In reality, the amount of nitrogen fertilizer used is probably higher as farmers may apply more fertilizer than recommended to secure yields (Claassens, personal communication, 2004).

Nitrogen produces reliable and optimal yield and quality of vegetables. It is however, the most difficult element to manage in a fertilization system in order to ensure an adequate, yet not excessive, amount of available nitrogen within the rhizosphere from planting to harvest (Peck, 1981).

1.2 Transplant nutrition

Most of the vegetables produced in South Africa are propagated by means of transplanted seedlings, as climatic conditions are unpredictable. This makes the

transplant production industry important in the country (Strydom, 1997). For vegetable production to be a success, production of vigorous transplants for transplanted vegetables is necessary (Cantliffe & Karchi, 1992). Therefore, production of seedlings in individual cells within trays in glasshouse to give so-called modular transplants for transplanting into the field is a requirement (Powell, Thornton & Mitchell, 1991).

Nutritional practices affect vegetable transplant size and quality (Garton & Widders, 1990; Melton & Dufault, 1991; Dufault & Schultheis, 1994). The vegetable transplants grown in plug cells therefore, require careful management of fertilizers (Dufault & Waters, 1985; Weston, 1988) as cell volume is limited and seedling densities are high (Soundy *et al.*, 2001a). However, it is usually not feasible to supply sufficient concentrations of essential plant nutrient elements within media to sustain plant growth for an extended period (Garton & Widders, 1990).

The role of nitrogen in transplant growth has been investigated in a number of vegetable crops. Generally, vigorous transplant growth was attributed to higher nitrogen regimes. Melton & Dufault (1991) studied the effect of various rates of nitrogen, phosphorous and potassium on 'Sunny' tomato transplant growth and transplant quality. It was observed that nitrogen was a major factor affecting tomato transplant growth in both years of research. Plant height, leaf count, leaf area and shoot fresh and dry mass increased with nitrogen from 25 to 225 mg·L⁻¹. In 1988 root dry mass increased as nitrogen was increased from 25 to 225 mg·L⁻¹ and in 1989 it increased with nitrogen from 25 to 75 mg·L⁻¹ but decreased at 225 mg·L⁻¹. Growth did not seem to 'plateau' off even at the moderate (25 mg·L⁻¹) to high (225 mg·L⁻¹) nitrogen levels, except for root dry mass.

Fisher & Benson (1983) reported that as nitrogen levels were increased from 50 to 150 mg·L⁻¹, both shoot and root growth increased, subsequently resulting in increased total plant dry mass of asparagus transplants. They observed greater shoot growth than root growth and attributed that to more dry mass being partitioned to the shoot than to root. Increases in dry mass partitioning to the roots with low nitrogen levels were reported. Plants with higher total plant dry mass were produced from a 150 mg·L⁻¹ N. They

recommended a $150 \text{ mg}\cdot\text{L}^{-1}$ N to be applied especially when large transplants are targeted. However, a $100 \text{ mg}\cdot\text{L}^{-1}$ N may be more acceptable to some transplant producers. Adler, Dufault & Waters, Jr. (1984) noted similar results on asparagus transplants when nitrogen levels were increased from 100 to $200 \text{ mg}\cdot\text{L}^{-1}$ with phosphorus at $20 \text{ mg}\cdot\text{L}^{-1}$.

Dufault (1985) grew 'Utah 52-70R' celery transplants and fertilized them weekly with solutions containing nitrogen, phosphorus and potassium to determine the nutrient needs required to produce high quality transplants. It was observed that root and shoot growth increased with increasing nitrogen at any constant phosphorus rate. Plant height responded in a linear fashion while shoot number, dry shoot mass, leaf area, root dry mass and root to shoot ratios responded curvilinearly. With nitrogen increasing from 50 to 250 ppm leaf area, shoot dry mass and dry root mass more than doubled in a curvilinear fashion. They visually observed a change in colour of the foliage from pale, lime green to a dark, emerald green. In another experiment, Dufault & Schultheis (1994) reported increases in growth of bell pepper due to nitrogen and phosphorus preplant nutritional conditioning. It was observed that nitrogen accounted for more variation in shoot fresh and dry mass, leaf area and root dry mass than phosphorus while transplant height and leaf count were more affected by the main effect of phosphorus than nitrogen.

Tremblay & Sénécal (1988) conducted a study to determine the effect of potassium rate on growth of celery transplants when used in conjunction with high nitrogen rates. They compared the effects of nitrogen and potassium rate on transplants of broccoli, celery, lettuce and pepper grown in multicells. They reported increases in leaf area and shoot dry mass of all species with increasing nitrogen rates while root growth was reduced. Increasing nitrogen rate increased broccoli and pepper specific leaf area while celery specific leaf area was reduced. It was however, observed that lettuce specific leaf area was unaffected. As nitrogen rate increased, dry root mass for all species was reduced while pepper was unaffected. At higher nitrogen rates, root: shoot ratio of all species

was reduced and as suggested by Weston & Zandstra (1986), transplants with large root system appear to be more resistant to transplant shock.

Masson, Tremblay & Gosselin (1991) conducted a study on growth of celery, lettuce, broccoli and tomato transplants in multicellular trays to determine the effects of supplementary lighting of $100 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ in combination with four nitrogen rates (100, 200, 300 and $400 \text{ mg}\cdot\text{L}^{-1}$ N). As nitrogen rate was increased from $100 \text{ mg}\cdot\text{L}^{-1}$ to $400 \text{ mg}\cdot\text{L}^{-1}$ shoot dry mass of all species increased. It was observed that shoot dry mass for celery and broccoli increased curvilinearly while tomato increased linearly. Nitrogen rate at $100 \text{ mg}\cdot\text{L}^{-1}$ was observed to limit shoot growth under natural and supplementary lighting while the highest shoot dry mass was obtained with $400 \text{ mg}\cdot\text{L}^{-1}$ under supplementary lighting. Specific leaf area for lettuce, broccoli and tomato increased with nitrogen rate in a curvilinear fashion while celery was not affected. Broccoli and tomato leaf area ratio increased curvilinearly as nitrogen rate increased. Root dry mass of celery, lettuce and broccoli decreased with increasing nitrogen fertilization. For celery, lettuce and broccoli root : shoot dry ratio decreased curvilinearly with increasing nitrogen but decreased linearly for tomato.

In another study, Aloni, Pashkar, Karni & Daie (1991) studied the growth and carbohydrate partitioning of pepper transplants in the greenhouse and on their subsequent recovery and development after transplanting as affected by nitrogen nutrition. They found that as nitrogen application was increased, leaf count and mass increased while root fresh and dry mass were reduced at $200 \text{ mg}\cdot\text{L}^{-1}$ N compared to $30 \text{ mg}\cdot\text{L}^{-1}$ N. As nitrogen increased from 0 to $200 \text{ mg}\cdot\text{L}^{-1}$, total dry matter in the leaves increased progressively from 0.03 to 0.21 g. Roots grown with 30 to $100 \text{ mg}\cdot\text{L}^{-1}$ N were larger than those grown with $0 \text{ mg}\cdot\text{L}^{-1}$ N. Root : leaf ratio decreased with increasing nitrogen because total root growth was inhibited at $200 \text{ mg}\cdot\text{L}^{-1}$ N.

Soundy (1996) produced 'South Bay' lettuce transplants to evaluate how much nitrogen was necessary to produce high quality transplants and subsequent high quality crop in the field. In this study a high quality transplant was described as one that could be

produced within a short period of time and could pull with ease from the transplant flat. As nitrogen increased from 0 to 60 mg·L⁻¹, transplant shoot and root mass increased. Nonetheless, more dry mass was partitioned to shoot than roots, subsequently resulting in lower values of root to shoot ratio and root mass ratio. Transplant growth was improved as nitrogen applied increased and this was confirmed by increases in relative growth rate, specific leaf area, leaf area ratio and leaf mass ratio due to applied nitrogen. Furthermore, applied nitrogen increased leaf tissue nitrogen. The conclusion reached was that 60 mg·L⁻¹ N supplied via floatation irrigation was appropriate for production of high quality transplants. The reason being that bigger transplants were produced from this level compared to 15 mg·L⁻¹ N and that it resulted in improved head mass at harvest.

Soundy *et al.* (2001a) grew 'South Bay' lettuce transplants in a peat + vermiculite media in a greenhouse to determine optimum phosphorus concentration necessary and to investigate the interaction of nitrogen and phosphorus fertility and transplant growth during the winter season wherein temperature and light conditions are reduced. They reported no influence on root length, area or diameter of lettuce transplants by applied nitrogen, but observed that plants grown with 60 mg·L⁻¹ N had greater root: shoot ratio than plants grown with 100 mg·L⁻¹ N. Nitrogen did not influence relative growth rate, net assimilation rate, leaf area ratio, leaf mass ratio and root mass ratio at 28 days after sowing. It was however, observed that nitrogen influenced leaf area ratio through its interaction with phosphorus.

1.3 Pre-plant fertilizer application

Fertilizer placement some weeks to several days in the soil before sowing or planting is called base or basal dressing. It is mixed with the topsoil so that nutrients are immediately available for the young growing plants. Basal dressings usually have a high phosphorus content for root development, protein and chlorophyll formation and for the growth and colour of the plant. Fertilizer is spread uniformly over the soil surface (broadcasting). It is a common method for applying large quantities of bulk fertilizer

before planting (Tisdale & Nelson, 1975; Jones, 1982; Foth, 1990; Foth & Ellis, 1996). When fertilizer is broadcast on soil with low fertility, the aim is to increase soil fertility, especially phosphorus to levels of 25-35 mg·kg⁻¹ (Bray 2). Where the soil has high fertility and high yield potential, the maintenance application may not be applied all in a band but applied as broadcast and another small amount as pop-up at planting (The Fertilizer Society of South Africa, 2000).

It is vital to consider supplementing the fertilizer applied through broadcasting with starter or pop-up fertilizers at planting and side-dressing or top-dressing fertilizer later in the growing season. Pop-up fertilizers are applied at sowing or planting to supplement a regular fertilizer programme or a very fertile soil by providing a quick start or pop-up of the seedlings. These fertilizers often contain water-soluble ingredients high in phosphorus. Pop-up fertilizers stimulate early shoot and root growth, which allows for rapid development of the root system so that it can be in contact with more soil and as a result utilize broadcast fertilizer more efficiently (Jones, 1982).

In an experiment conducted by Welch, Tyler & Ririe (1985), it was observed that split application of nitrogen for celery, cauliflower and cabbage crops was more efficient than single application, as the yield increase was significantly higher. It is therefore, vital to have split application (pre-plant and top-dressing applications), especially in the areas where leaching of nutrients is high.

1.4 Top-dressing and side-dressing

Top-dressing is the application of fertilizer to a growing crop after it has emerged. Fertilizer is usually placed at the side of the plant as a side-dressing. The most important nutrient at this stage is nitrogen and it is therefore supplied in a nitrate form, which acts immediately. This fertilization method works rapidly when there is adequate moisture content in the soil. Top-dressings are usually valuable when there is evidence of deficiency of nitrogen due to insufficient early dressing or loss due to denitrification, leaching and volatilization. Denitrification of nitrogen occurs whenever the soil is

anaerobic. Nitrate is mobile and may be lost through leaching during periods of high rainfall and in areas with coarse sandy soils while volatilization occurs when NH_3 exists on the soil surface. Top-dressings are therefore, valuable when they are applied closer to the time when the growing plant is in maximum need of nutrients and with the least amount of time available for nitrogen loss (Tisdale & Nelson, 1966; Cooke, 1982; Finck, 1982; Jones, 1982; Foth, 1990).

Cabbages respond positively to top-dressings of nitrogen (Askew & Smith, 1995). Weather during the growing season plays a vital role in influencing the effects of top-dressing. That is, if high rainfall occurs after planting, fertilizer applied as basal dressing may be leached beyond the rooting zone of the plants and the effects of top-dressing may easily be observed (Everaarts, 1993b). Smith & Hapelt (1984) tried many different combinations of nitrogen and different top-dressing times in KwaZulu Natal and found that nitrogen applied 2/3 pre-plant and 1/3 at four weeks produced the highest cabbage yields. Smith, Demchak & Ferretti (1990) reported highest yields with banding and side-dressing of nitrogen in cabbage. Greater results were also reported by Neuvel (1990) in Brussels sprouts when base application was combined with top-dressing than when it was just a single base application. However, Cleaver, Greenwood, Whitwell & Wood (1971) observed that top-dressing was not important, provided sufficient nitrogen was applied at planting.

1.5 Crop response to nitrogen fertilization

Higher levels of nitrogen have often been found to induce optimum yields in *Brassica* vegetables. Zebarth, Freyman & Kowalenko (1991) observed a positive yield response up to $500 \text{ kg}\cdot\text{ha}^{-1} \text{ N}$, but that percentage nitrogen recovery was lower at the higher rates ($\pm 30\%$ lost at $500 \text{ kg}\cdot\text{ha}^{-1}$). Peck (1981) reported increased yields of cabbage heads to about $4 \text{ kg}\cdot\text{m}^2$ fresh mass more than plants grown without nitrogen fertilizer. As nitrogen was increased from $15 \text{ g}\cdot\text{m}^2$ to $30 \text{ g}\cdot\text{m}^2$ transplant fresh mass increased by 2 kg.

Parmar *et al.* (1999) recorded higher yields in cabbage with increased nitrogen rates. The application of 200 kg·ha⁻¹ N produced significantly higher yield over 150 kg·ha⁻¹ N but at par with 250 kg·ha⁻¹ N. This was attributed to the fact that higher nitrogen levels favoured the growth of plants with larger leaf area and it was more usefully utilized in head formation. Similar observations on cabbage were made by Ghanti *et al.* (1982), where yield contributing characters such as head diameter and gross mass of heads and number of marketable heads increased with increase in the levels of nitrogen up to 200 kg·ha⁻¹. Gupta (1987) observed significantly higher cabbage yields at 150 kg·ha⁻¹ N than yields at 0, 50 and 100 kg·ha⁻¹ N yet at par with yield at 200 kg·ha⁻¹ N. Increase in yield was attributed to increase in head mass.

Brussels sprout yields increased to 33.5 t·ha⁻¹ as nitrogen fertilizer was increased up to 90 kg·ha⁻¹. It was, however, observed that, even though yields increased significantly with increasing nitrogen fertilizer rate, the midrib NO₃-N levels did not always parallel these yield increases. Cauliflower yields were also observed to increase (21.3 t·ha⁻¹) as the nitrogen rates increased to 140 kg·ha⁻¹. As the midrib NO₃-N levels increased, it was observed that there was an increase in yield which suggested a close relationship in cauliflower between midrib NO₃-N levels and yield.

Everaarts & De Moel (1998) reported increasing uniformity with increasing amounts of nitrogen applied. In cabbage production uniformity of heads is important. Increase in relative core length was observed when nitrogen application rate increased, whereas dry matter content of the heads decreased. This was associated with softer head tissue at higher nitrogen availability, thereby having less physical resistance to stalk elongation. The lower the relative core length, the better the head quality (Aalbersberg & Stolk, 1993).

Peck (1981) observed decreases in percent dry mass of the heads, increased number of burst heads and increased tipburn in the heads with increasing fertilizer nitrogen rate. It was therefore concluded that high nitrogen fertilizer decreased the quality of cabbage heads.

1.6 Crop response to spacing

Stepanovic *et al.* (2000) reported highest cabbage head diameter values in the case of lowest crop density. It was observed that head diameter decreased in parallel with increasing crop density. In the contrary, higher cabbage yields per hectare were recorded in the case of higher plant densities. The higher crop densities were as a result recommended for cabbage production. It is, however, important to compare the issue of profitability of such a production with the high costs of transplants and manual labour. The most suitable crop density is that which ensures high yields, good quality and low production costs. For late cabbage varieties Stepanovic *et al.* (2000) recommended crop population of approximately 35 000 plants·ha⁻¹.

Dufault & Waters (1985) reported that broccoli head mass decreased linearly when plant populations were increased from 24 000 to 72 000 plants·ha⁻¹ with nitrogen kept constant at 112, 169 or 224 kg·ha⁻¹. It was however, observed that despite reduction of head mass, marketable yields increased due to increased numbers of heads. High broccoli yields were recorded at the highest plant populations of 72 000 plants·ha⁻¹. In cauliflower different results from those of broccoli were reported. It was observed that whenever plant populations were increased from 24 000 to 72 000 plants·ha⁻¹, marketable yield of cauliflower decreased. The explanation given was that increasing plant populations increased competition among plants resulting in reduced marketable yield.

Ghanti *et al.* (1982) studied the response of 'Pusa Drumhead' cabbage to nitrogen, phosphorus and spacing in order to find a suitable combination of nitrogen, phosphorus and spacing for obtaining higher yield. They observed significant effects of different spacings on the yield contributing characters such as head diameter, and gross and net mass of head. Maximum results of head diameter, head gross and head net mass were obtained at 50 x 70 cm spacing and decreased as intra-row spacing (40 x 70 cm and 30 x 70 cm) decreased. Closer spacing increased competition for water and nutrients and subsequently reduced vegetative growth which led to a decrease in the diameter as well

as mass of heads. Nonetheless, a closer spacing of 30 x 70 cm produced maximum number of marketable heads which was 55% more than that of 50 x 70 cm spacing. The maximum number of marketable heads from 30 x 70 cm spacing contributed to higher yields of about 35% and 18% more than that recorded under 50 x 70 cm spacing for the first and the second year, respectively.

Singh & Naik (1988) recorded significantly higher yields with closer spacing (45 x 30 cm) than wider spacings (45 x 45 cm and 45 x 60 cm) of cabbage. Yield from the closer spacing was approximately 49% and 45% more than yield recorded under 45 x 60 cm spacing in the first and second year, respectively. Furthermore, 63% and 92% more marketable heads were obtained from the closer spacing than the widest spacing. More number of marketable heads per unit area in the case of closer spacing was attributed to increases in yield. As spacing was increased there was no significant increase in head mass even though the widest spacing recorded maximum head mass. This was attributable to the fact that with closer spacing competition for the growth factors increased. Prabhakar & Srinivas (1990) recorded higher cabbage head yield ($11 \text{ t}\cdot\text{ha}^{-1}$) with closer spacing (50 x 30 cm) than wider spacings (50 x 40 cm and 50 x 50 cm). Parmar *et al.* (1999) noted higher head yield (16 to 43 %) in 30 x 30 cm over 45 x 30 cm during individual years of conducting experiments.

Singh (1996) tested nitrogen, phosphorus and spacing for their impact on cabbage (cv. Pusa Drumhead) under Chotanagpur conditions. It was observed that with the increase in plant spacing from 30 to 60 cm, there was a significant reduction in the number of marketable heads per unit area. The reductions were associated with higher plant densities in the closer spacings. Spacing did not have any significant influence on the head index, but an increasing trend was observed as spacing increased. Significant improvements in head volume were attained with an increase in spacing. Similar behavior was again observed with head mass as significantly higher mass was recorded at 60 cm spacing compared to 30 and 40 cm inter-row spacings. This behavior was attributable to availability of enough space and more nutrients at the widest spacings, which encouraged the growth and development of plants.

Tendaj & Kuzyk (2001) initiated a study to investigate the influence of greater plant density on the yield and head mass of red cabbage cultivars. They reported highest yield of marketable heads from 50 x 45 cm spacing. There was no significant difference between 50 x 45 cm spacing and the lower spacings (30 x 45 cm and 40 x 45 cm). As spacing was increased to 60 x 45 cm each cultivar used gave lower yields. Knavel & Herron (1981) observed that wide spacing increased head size while doubling plant population reduced it.

Kumar & Rawat (2002) conducted a study during 1997-98 at the Horticulture Farm, Rajasthan College of Agriculture, Udaipur, to determine the effects of nitrogen and spacing on the quality and yield of cabbage (*Brassica oleracea* L. var *capitata*). It was observed that spacing had no effect on dry matter percentage. Maximum head diameter and head mass were recorded at wider spacing. It was believed that wider spacing provided more sufficient space and less competition between available nutrients for plants. Therefore, there was increase in the head diameter and head mass.

In another study Guzman (1990) monitored the effect of 12, 13, 14 and 15 inch (30.5, 33.0, 35.6 and 38.0 cm) plant spacing in the row to maximize yield and quality of transplanted crisphead lettuce. Spacing did not have a significant influence on fresh mass and the number and percentage of marketable heads. This suggested that 12 to 15 inch (30.5 to 38.0 cm) plant spacing gave similar productivity. Nevertheless, it was evident that 12 or 13 inch (30.5 or 33.0 cm) spacing would probably maximize yields more than with wider spacings. All plant spacings under study provided good head mass and quality.

The literature indicates that production of vigorous transplants is necessary for successful vegetable production and that nitrogen fertilization is required for increased growth of the transplants. It is again evident that applied nitrogen and spacing influence cabbage head size and total yield per unit area.

CHAPTER 2

NITROGEN NUTRITION OF CABBAGE TRANSPLANTS

2.1 INTRODUCTION

Use of vigorous transplants at planting ensures successful vegetable production (Cantliffe & Karchi, 1992). Transplants are produced in individual cells within trays in glasshouses to give so-called modular transplants (Powel *et al.*, 1991). Due to limited cell volume and high transplant densities (Garton & Widders, 1990), an adequate supply of nitrogen, phosphorus and potassium to growing transplants is necessary (Melton & Dufault, 1991). However, it is usually not feasible to supply sufficient concentrations of essential plant nutrients within media to sustain plant growth for an extended period (Garton & Widders, 1990).

Melton & Dufault (1991) reported that nitrogen, phosphorus and potassium regimes affected tomato transplant growth. It was observed that nitrogen accounted for a higher percentage of variation in plant height, leaf count, leaf area, fresh shoot mass and dry shoot and root mass especially as nitrogen was increased from 25 to 225 mg·L⁻¹. Adler *et al.* (1984) found that as nitrogen was increased from 100 to 200 mg·L⁻¹ with phosphorus at 20 mg·L⁻¹, asparagus transplant shoot and root mass increased. Transplant growth for broccoli, lettuce, pepper and celery was greatest at 350 mg·L⁻¹ N but root growth decreased (Tremblay, Yelle & Gosselin, 1987). Soundy *et al.* (2001a) found that nitrogen rate at 100 mg·L⁻¹ improved shoot growth of lettuce transplants. It was, however, observed that root growth was reduced when compared to nitrogen at 60 mg·L⁻¹.

Literature cited suggests that the use of vigorous transplants at planting is necessary so as to ensure successful vegetable production. Based on this background, an experiment was conducted to determine the optimum nitrogen application level required for the production of good quality cabbage (Drumhead) transplants.

2.2 MATERIALS AND METHODS

A glasshouse experiment was conducted at the Hatfield Experimental Farm, University of Pretoria during July/August 2004. Trays with two hundred cavities were cut into four smaller trays, each having fifty cavities and were used for growing 'Drumhead' transplants. The growth medium was Culterra seedling soil. The trays were seeded and then covered with a thin layer of vermiculite. Depending on water requirements, plants were fertigated every 2 days (for the first four weeks) and every day (for the last two weeks) by floating trays in plastic tubs (Fig. 2.1) containing nutrient solution at 0, 30, 60, 90 and 120 mg·L⁻¹ N until field capacity was reached. Potassium and phosphorus were applied at a rate of 60 mg·L⁻¹ and 62 mg·L⁻¹ respectively, using KH₂PO₄. The experiment was laid out as a randomised complete block design with four replications.

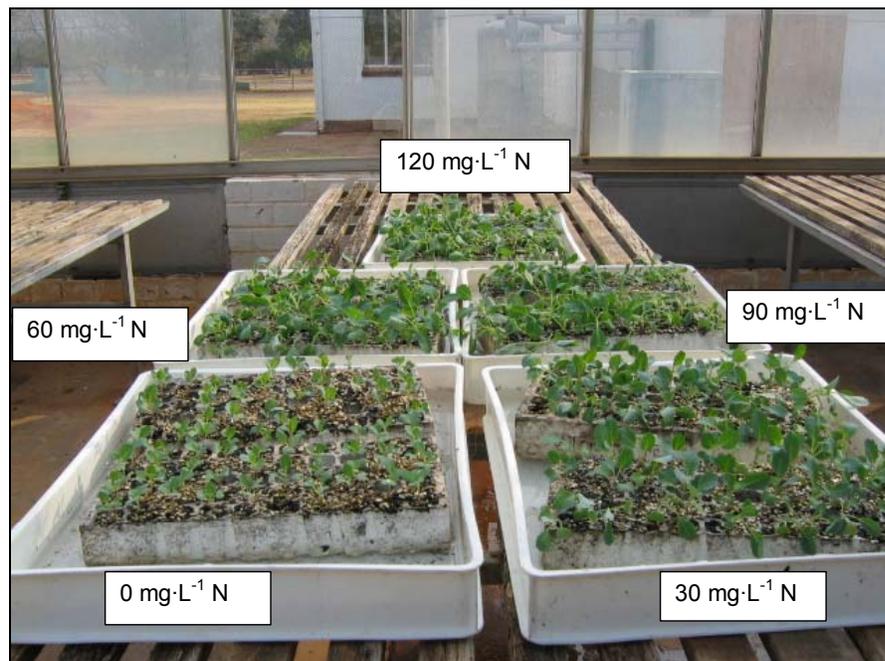


Fig. 2.1 Transplant trays floating in plastic tubs containing varying concentrations of nitrogen solution

Five plants were randomly sampled for each treatment, from week 3 to week 6 on a weekly basis, to monitor growth. Measurements included shoot and root fresh and dry mass, and leaf area (measured by a LI-3100 leaf area meter; LI-COR, Lincoln, Neb.).

Growth variables calculated were (Hunt, 1982; Gardner, 1985; Dubik, Krizek, Stimart & McIntosh, 1992; Nicola & Cantliffe, 1996):

- Root to shoot ratio (RSR = dry root mass ÷ dry shoot mass)
- Relative growth rate (RGR = $[\ln(\text{final total dry mass}) - \ln(\text{initial total dry mass})] \div (\text{final time} - \text{initial time})$)
- Net assimilation rate (NAR = $[\text{final total dry mass} - \text{initial total dry mass}] \div (\text{final time} - \text{initial time}) \times \{[\ln(\text{final leaf area}) - \ln(\text{initial leaf area})] \div (\text{final leaf area} - \text{initial leaf area})\}$)
- Specific leaf area (SLA = leaf area ÷ dry shoot mass)
- Leaf area ratio (LAR = leaf area ÷ total dry mass)
- Leaf mass ratio (LMR = dry shoot mass ÷ total dry mass)
- Root mass ratio (RMR = dry root mass ÷ total dry mass)

At the final sampling date, pulling success (%) was calculated from five plants sampled within each replicate that could be removed from the trays without breakage. Dried and ground plant material was digested according to Kjeldahl digestion method on a digester block to determine tissue nitrogen content (%) in the Soil Science Laboratory, University of Pretoria. Collected data were subjected to an analysis of variance using the SAS programme (Statistical Analysis Systems, 2003). Treatment sums of squares were

partitioned into linear and quadratic polynomial contrasts. Significant differences were taken at $P \leq 0.05$.

2.3 RESULTS AND DISCUSSION

2.3.1 Fresh and dry shoot mass

Fresh shoot mass increased in a linear fashion in response to increasing nitrogen application regardless of the sampling date (Fig. 2.2). Increasing nitrogen from 0 to 120 mg·L⁻¹ increased fresh shoot mass from 79 to 570 mg, 95 to 890 mg, 246 to 1 961 mg and 287 to 3 235 mg in transplants grown to 21, 28, 35 and 42 days after sowing (DAS), respectively. Therefore, fresh shoot mass was least with 0 mg·L⁻¹ N and greatest with 120 mg·L⁻¹ N regardless of the sampling date.

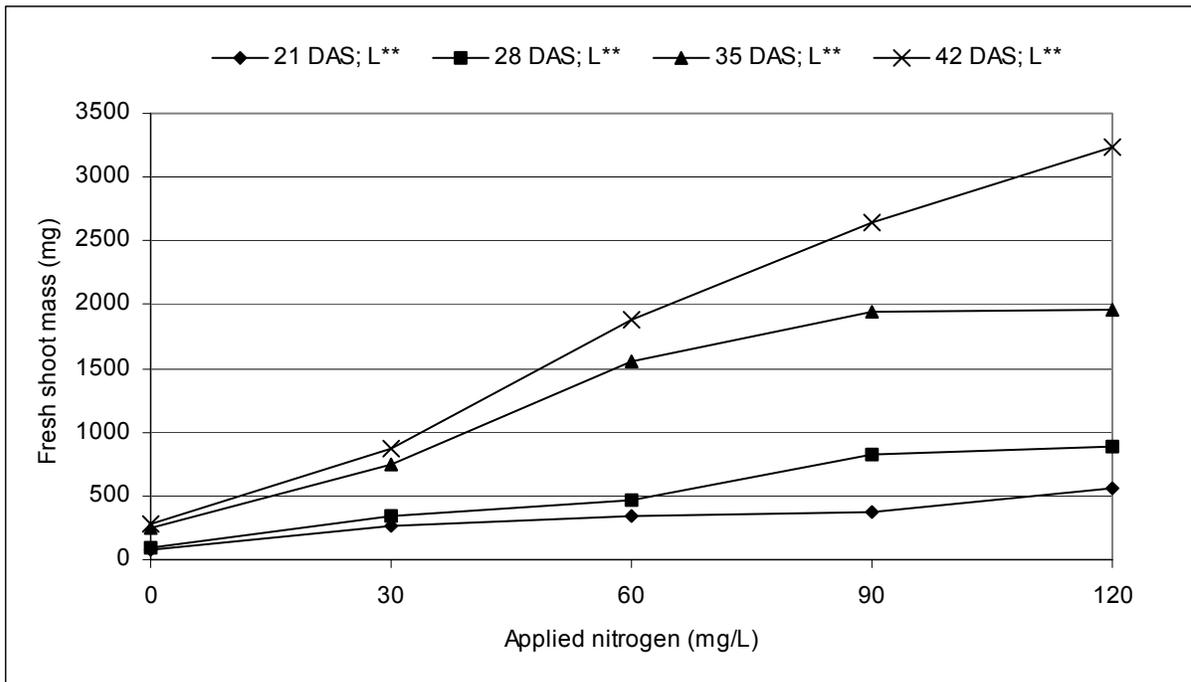


Fig. 2.2 Cabbage transplant fresh shoot mass response to nitrogen nutrition

Dry shoot mass increased in a linear fashion in response to increasing nitrogen applied throughout the growing period (Fig. 2.3). Increasing nitrogen from 0 to 120 mg·L⁻¹ increased dry shoot mass from 9 to 43 mg, 16 to 108 mg, 31 to 183 mg and 43 to 336 mg in transplants grown to 21, 28, 35 and 42 DAS, respectively.

Dry shoot mass was least with $0 \text{ mg}\cdot\text{L}^{-1}$ N and greatest with $120 \text{ mg}\cdot\text{L}^{-1}$ N regardless of the sampling date. Soundy (1996) also indicated that as nitrogen was increased from 0 to $60 \text{ mg}\cdot\text{L}^{-1}$ lettuce transplant shoot mass increased.

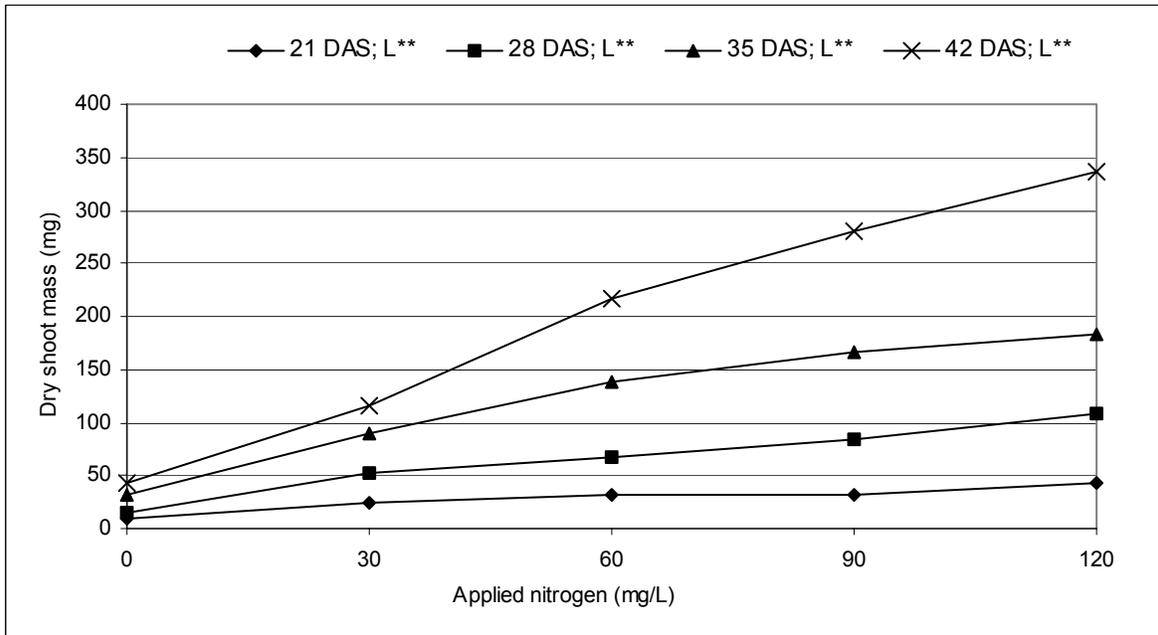


Fig. 2.3 Cabbage transplant dry shoot mass response to nitrogen nutrition

2.3.2 Fresh and dry root mass

Fresh root mass increased linearly with increasing nitrogen fertilization when transplants were sampled 21 and 28 DAS (Fig. 2.4). At 21 DAS, fresh root mass increased from 39 to 85 mg as nitrogen was increased from 0 to $120 \text{ mg}\cdot\text{L}^{-1}$ while for those sampled 28 DAS, fresh root mass increased from 84 to 166 mg.

For those sampled 35 and 42 DAS, fresh root mass increased in a quadratic fashion with increasing nitrogen application. Increasing nitrogen from 0 to $90 \text{ mg}\cdot\text{L}^{-1}$ increased fresh root mass for transplants grown to 35 and 42 DAS, beyond which it decreased. For transplants grown to 35 DAS, the increase was from 115 to 389 mg and for those grown to 42 DAS, it increased from 162 to 491 mg.

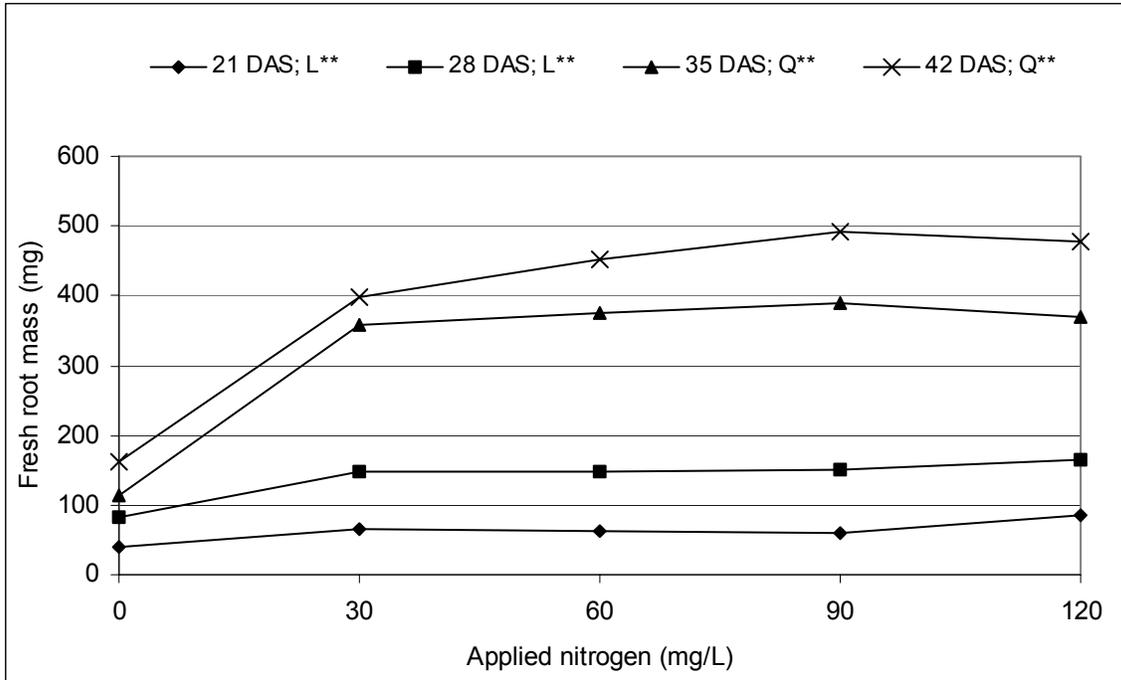


Fig. 2.4 Cabbage transplant fresh root mass response to nitrogen nutrition

Dry root mass of transplants sampled 21 and 28 DAS increased linearly with increasing nitrogen fertilization (Fig. 2.5) As nitrogen was increased from 0 to 120 mg·L⁻¹, average dry root mass for transplants sampled 21 DAS increased from 5 to 9 mg and increased from 10 to 15 mg for transplants grown to 28 DAS.

For transplants grown to 35 DAS, average dry root mass increased from 14 to 30 mg as nitrogen was increased from 0 to 60 mg·L⁻¹ beyond which it decreased. In the case of those grown to 42 DAS, average dry root mass increased from 14 to 40 mg as nitrogen was increased from 0 to 90 mg·L⁻¹ beyond which it decreased. Soundy (1996) observed that increasing nitrogen from 0 to 60 mg·L⁻¹ increased lettuce dry root mass. Tremblay & Sénécal (1988) reported reduced dry root mass with 350 mg·L⁻¹ N compared to 150 mg·L⁻¹ N for lettuce, broccoli and celery.

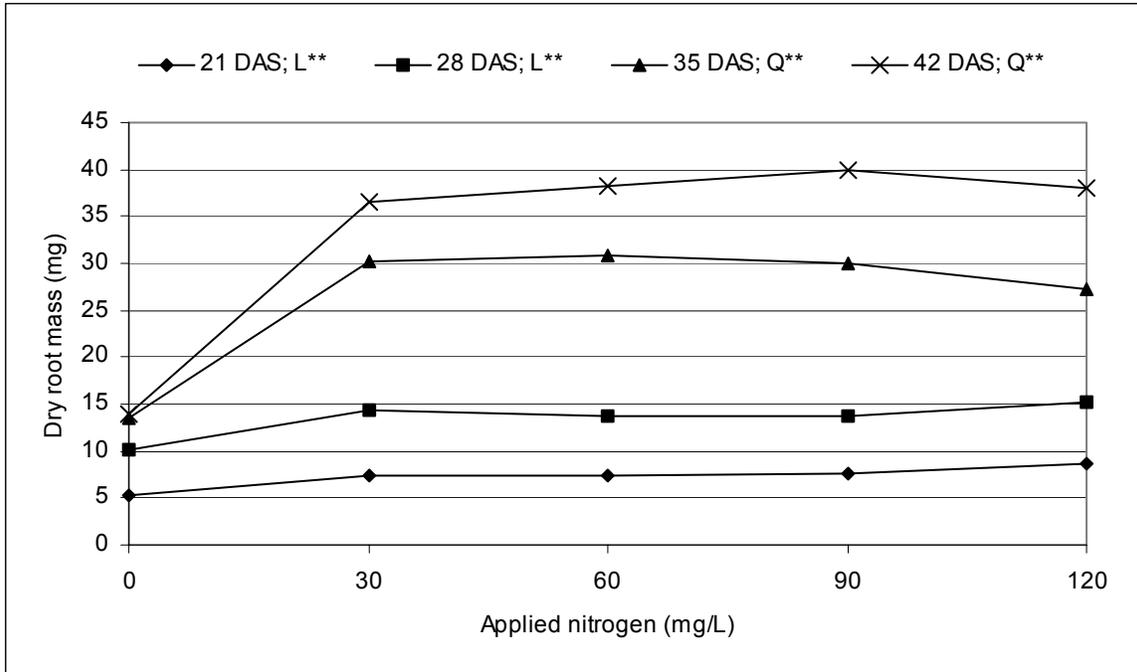


Fig. 2.5 Cabbage transplant dry root mass response to nitrogen nutrition

2.3.3 Leaf count

The higher nitrogen rates, relative to lower rates, increased leaf count regardless of the sampling date. Leaf count increased from 4 to 5, 4 to 6, 4 to 7, and 5 to 7, for transplants sampled 21, 28, 35 and 42 DAS, respectively as nitrogen was increased from 0 to 120 mg·L⁻¹. It was however, observed that for plants grown to 42 DAS, leaf counts obtained from 30 and 60 mg·L⁻¹ N were 5 and 6 respectively, which was lower than 6 and 7 obtained at 30 and 60 mg·L⁻¹ N for transplants grown to 35 DAS. The reason for the lower numbers in the case of transplants grown to 42 DAS was that the first leaves had fallen off, thereby reducing the leaf count. The tendency for the leaf count to increase in response to increasing nitrogen application is in agreement with the results of Melton & Dufault (1991). They observed increases in tomato leaf count as nitrogen was increased from 25 to 225 mg·L⁻¹ during both years of the study.

2.3.4 Plant height

Transplant height increased in a linear fashion with increasing nitrogen application regardless of the sampling date (Table 2.1). For transplants grown to 21, 28 and 35 DAS, transplant height increased more than three times and more than doubled in transplants grown to 42 DAS as nitrogen was increased from 0 to 120 mg·L⁻¹.

Throughout the growing period, the transplants grown with 30 to 120 mg·L⁻¹ N were taller than those grown with 0 mg·L⁻¹ N. Melton & Dufault (1991) reported increases in tomato transplant height as nitrogen rate was increased from 25 to 225 mg·L⁻¹.

2.3.5 Leaf area

Leaf area increased in a linear fashion with increasing nitrogen application for the whole growing period (Table 2.1). Increasing nitrogen from 0 to 120 mg·L⁻¹ increased leaf area from 1.29 to 9.9 cm², 2.63 to 23.61 cm², 4.34 to 45.91 cm² and 5.72 to 59.68 cm² for transplants grown to 21, 28, 35 and 42 DAS, respectively.

The high nitrogen rates, compared to low rates, increased the leaf area, with the least values obtained at 0 mg·L⁻¹ N and greatest values obtained at 120 mg·L⁻¹ N regardless of the sampling date. Melton and Dufault (1991) reported increases in tomato leaf area as nitrogen applied was increased from 25 to 225 mg·L⁻¹. Soundy (1996) also reported increases in lettuce leaf area with nitrogen from 0 to 60 mg·L⁻¹.

2.3.6 Root: shoot ratio

Root: shoot ratio decreased in a linear fashion in response to increasing nitrogen applied regardless of the sampling date (Table 2.1). Increasing nitrogen from 0 to 120 mg·L⁻¹ decreased root: shoot ratio from 0.57 to 0.20, 0.65 to 0.14, 0.43 to 0.15 and 0.33 to 0.11 for transplants grown to 21, 28, 35 and 42 DAS, respectively.

The greatest values of root: shoot ratio were obtained at 0 mg·L⁻¹ N while the least values were obtained at 120 mg·L⁻¹ N. The decrease in root: shoot ratio suggests that more growth occurred in the shoots than in the roots. The results are in agreement with the results reported by Soundy (1996). Root: shoot ratio of lettuce transplants decreased as nitrogen was increased from 0 to 60 mg·L⁻¹. Lettuce transplants grown with 0 mg·L⁻¹ N were, however, too small to be transplanted even though they had greatest root: shoot ratio. As suggested by Leskovar & Stoffella (1995), large root: shoot ratios are desirable, since transplants with large root systems are more resistant to transplant shock.

2.3.7 Pulling success

Higher nitrogen rates, compared to lower rates, increased pulling success in a quadratic fashion (Table 2.1). Increasing nitrogen from 0 to 90 mg·L⁻¹ improved pulling success from 15% to 100% and decreased with further nitrogen application. Soundy (1996) observed that lettuce transplants could not be pulled easily from the transplant trays regardless of the nitrogen treatment level used. More reduced pulling success was observed when mean dry mass was less than 20 mg. It was subsequently, suggested that nitrogen at 60 mg·L⁻¹ was probably not adequate with the irrigation programmes used.

2.3.8 Leaf tissue nitrogen

Leaf tissue nitrogen increased linearly with increasing nitrogen fertilization. As nitrogen applied was increased from 0 to 120 mg·L⁻¹, leaf tissue nitrogen increased from 1.18 to 3.75%. Soundy *et al.* (2001a) recorded higher leaf tissue nitrogen values from lettuce transplants grown with 100 mg·L⁻¹ N compared to those grown with 60 mg·L⁻¹ N. Widders (1989) suggested that leaf tissue nitrogen is important for plant establishment after planting.

Table 2.1 Root and shoot characteristics of cabbage transplants as affected by N nutrition, July/August 2004

Nitrogen applied (mg·L ⁻¹)	Plant height (mm)	Leaf area (cm ²)	Root: shoot ratio	Pulling success (%)	Leaf tissue N (%)
<i>21 Days After Sowing</i>					
0	22.40	1.29	0.57		
30	56.38	5.45	0.30		
60	63.73	7.33	0.23		
90	70.95	7.78	0.23		
120	76.93	9.90	0.20		
<i>Response</i>	L**	L**	L**		
<i>28 Days After Sowing</i>					
0	32.38	2.63	0.65		
30	77.75	10.78	0.28		
60	102.25	15.82	0.21		
90	112.05	20.97	0.17		
120	121.15	23.61	0.14		
<i>Response</i>	L**	L**	L**		
<i>35 Days After Sowing</i>					
0	45.98	4.34	0.43		
30	85.50	17.82	0.34		
60	117.40	32.25	0.22		
90	134.45	42.25	0.18		
120	138.85	45.91	0.15		
<i>Response</i>	L**	L**	L**		
<i>42 Days After Sowing</i>					
0	61.95	5.72	0.33	15.00	1.18
30	93.20	17.65	0.32	50.00	1.93
60	127.80	36.48	0.18	70.00	2.88
90	151.48	51.83	0.15	100.00	3.48
120	153.20	59.68	0.11	70.00	3.75
<i>Response</i>	L**	L**	L**	Q**	L**

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*) or 0.01 (**)

2.3.9 Relative growth rate

Relative growth rate of transplants grown to 28 and 35 DAS increased in a quadratic fashion in response to increasing nitrogen and increased linearly for transplants sampled 42 DAS (Table 2.2). With transplants grown to 28 DAS, relative growth rate increased from 0.57 to 0.88 $\text{mg}\cdot\text{mg}^{-1}\cdot\text{wk}^{-1}$ as nitrogen was increased from 0 to 90 $\text{mg}\cdot\text{L}^{-1}$ after which it decreased. For the transplants grown to 35 DAS, relative growth rate increased from 0.54 to 0.74 $\text{mg}\cdot\text{mg}^{-1}\cdot\text{wk}^{-1}$ with nitrogen from 0 to 60 $\text{mg}\cdot\text{L}^{-1}$ beyond which it decreased. At 42 DAS, relative growth rate increased from 0.25 to 0.58 $\text{mg}\cdot\text{mg}^{-1}\cdot\text{wk}^{-1}$ with nitrogen from 0 to 120 $\text{mg}\cdot\text{L}^{-1}$.

Gardner (1985) explained growth rate as dry mass gain over a given time interval in relation to the initial mass. The present results suggest that most dry mass accumulation took place in first 28 days, after which the rate decreased. The present results are in agreement with those of Soundy (1996) where relative growth rate was reported to have increased as a result of increasing nitrogen application.

2.3.10 Net assimilation rate

Net assimilation rate decreased in a quadratic fashion in response to applied nitrogen for transplants grown to 28 DAS and decreased in a linear fashion for transplants grown to 35 DAS (Table 2.2). For transplants grown to 42 DAS, net assimilation rate increased in a quadratic fashion in response to applied nitrogen.

As defined by Gardner (1985), net assimilation rate is the net gain in mass per unit leaf area. For plants grown to 28 DAS, net assimilation rate was greatest in transplants grown with 0 $\text{mg}\cdot\text{L}^{-1}$ N, but the total production of dry matter over the same period was greater in transplants grown with added nitrogen. In transplants grown to 42 DAS, net assimilation rate was greatest at 120 $\text{mg}\cdot\text{L}^{-1}$ N. It was however, observed that production efficiency declined as transplants grew older.

Soundy, Cantliffe, Hochmuth & Stoffella (2001b) reported greater net assimilation rate values in lettuce transplants grown with $60 \text{ mg}\cdot\text{L}^{-1}$ N compared to transplants receiving $100 \text{ mg}\cdot\text{L}^{-1}$ N.

2.3.11 Specific leaf area

Specific leaf area increased in a quadratic fashion in response to applied nitrogen (Table 2.2). In transplants sampled 21 DAS, specific leaf area increased from 0.14 to $0.24 \text{ cm}^2\cdot\text{mg}^{-1}$ with nitrogen from 0 to $60 \text{ mg}\cdot\text{L}^{-1}$. It was observed that specific leaf area obtained from $60 \text{ mg}\cdot\text{L}^{-1}$ N was equal to specific leaf area obtained at $90 \text{ mg}\cdot\text{L}^{-1}$ N and that beyond $90 \text{ mg}\cdot\text{L}^{-1}$ N specific leaf area decreased. At 28 DAS, specific leaf area increased from 0.17 to $0.25 \text{ cm}^2\cdot\text{mg}^{-1}$ as nitrogen was increased from 0 to $90 \text{ mg}\cdot\text{L}^{-1}$ after which it decreased. For transplants grown to 35 and 42 DAS, specific leaf area increased from 0.14 to $0.25 \text{ cm}^2\cdot\text{mg}^{-1}$ and from 0.13 to $0.18 \text{ cm}^2\cdot\text{mg}^{-1}$ respectively, as nitrogen was increased from 0 to $90 \text{ mg}\cdot\text{L}^{-1}$ after which it decreased. Tremblay & Senécal (1988) reported increases in specific leaf area for broccoli and pepper transplants as nitrogen was increased to $350 \text{ mg}\cdot\text{L}^{-1}$ compared to nitrogen at $150 \text{ mg}\cdot\text{L}^{-1}$. Soundy (1996) observed increases in specific leaf area of lettuce transplants as nitrogen was increased from 0 to $60 \text{ mg}\cdot\text{L}^{-1}$.

Low specific leaf area values were obtained at $0 \text{ mg}\cdot\text{L}^{-1}$ N regardless of the sampling date. Hunt (1990) explained specific leaf area as a measure of the relative thickness of the leaves. Dubik, Krizek & Stimart (1990) suggested that low specific leaf area values reflect that leaf size and assimilate production are low. In the present experiment it can be deduced that transplants grown with $0 \text{ mg}\cdot\text{L}^{-1}$ N were thinner and had low assimilate production compared to the transplants grown with any level of nitrogen.

2.3.12 Leaf area ratio

Leaf area ratio of transplants grown to 21 and 28 DAS increased in a quadratic fashion in response to increasing nitrogen while for transplants sampled 35 and 42 DAS, it

increased linearly (Table 2.2). Transplants sampled 21 DAS had leaf area ratio ranging from 0.09 to 0.19 $\text{cm}^2 \cdot \text{mg}^{-1}$ as nitrogen was increased from 0 to 60 $\text{mg} \cdot \text{L}^{-1}$ beyond which there was no effect. At 28 DAS, leaf area ratio increased from 0.10 to 0.22 $\text{cm}^2 \cdot \text{mg}^{-1}$ with nitrogen from 0 to 120 $\text{mg} \cdot \text{L}^{-1}$ while at 42 DAS, leaf area ratio increased from 0.10 to 0.16 $\text{cm}^2 \cdot \text{mg}^{-1}$ with nitrogen from 0 to 90 $\text{mg} \cdot \text{L}^{-1}$ after which there was no effect. Low leaf area ratio values were obtained from plants grown with 0 $\text{mg} \cdot \text{L}^{-1}$ N.

The present results are in agreement with the results reported by Masson *et al.* (1991) where leaf area ratio of broccoli and tomato transplants increased in a curvilinear fashion. According to Gardner (1985) leaf area ratio is the ratio between photosynthesizing tissue and the total respiring plant tissues. Dubik *et al.* (1990) suggested that low values of leaf area ratio reflect reduction in leafiness of a plant and assimilate production. The current results suggest that transplants grown with 0 $\text{mg} \cdot \text{L}^{-1}$ N had reduced leafiness and reduced assimilate production.

2.3.13 Leaf mass ratio

Leaf mass ratio increased linearly in response to increasing nitrogen application regardless of the sampling date (Table 2.2). Increasing nitrogen from 0 to 120 $\text{mg} \cdot \text{L}^{-1}$ increased leaf mass ratio from 0.64 to 0.83, 0.61 to 0.88, 0.70 to 0.87 and 0.75 to 0.90 for transplants sampled 21, 28, 35 and 42 DAS respectively. Favourable leaf mass ratio was obtained at 120 $\text{mg} \cdot \text{L}^{-1}$ N. As Soundy (1996) increased nitrogen from 0 to 60 $\text{mg} \cdot \text{L}^{-1}$ leaf mass ratio of lettuce transplants increased.

According to Hunt (1990) leaf mass ratio expresses how leafy a plant is, based on the dry mass. It measures the productive investment of the plant. The results from the present experiment suggest that productive investment was least with 0 $\text{mg} \cdot \text{L}^{-1}$ N and greatest in transplants grown with 120 $\text{mg} \cdot \text{L}^{-1}$ N.

Table 2.2 Influence of N nutrition on growth characteristics of cabbage transplants, July/August 2004

Nitrogen applied (mg·L ⁻¹)	Relative growth rate (mg·mg ⁻¹ ·wk ⁻¹)	Net assimilation rate (mg·cm ⁻² ·wk ⁻¹)	Specific leaf area (cm ² ·mg ⁻¹)	Leaf area ratio (cm ² ·mg ⁻¹)	Leaf mass ratio	Root mass ratio
<i>21 Days After Sowing</i>						
0			0.14	0.09	0.64	0.36
30			0.22	0.17	0.77	0.23
60			0.24	0.19	0.81	0.19
90			0.24	0.19	0.81	0.19
120			0.23	0.19	0.83	0.17
<i>Response</i>			Q**	Q**	L**	L**
<i>28 Days After Sowing</i>						
0	0.57	6.01	0.17	0.10	0.61	0.39
30	0.73	4.38	0.21	0.16	0.78	0.22
60	0.74	3.84	0.24	0.20	0.83	0.17
90	0.88	4.33	0.25	0.22	0.86	0.14
120	0.86	4.59	0.22	0.19	0.88	0.12
<i>Response</i>	Q**	Q**	Q*	Q**	L**	L**
<i>35 Days After Sowing</i>						
0	0.54	5.46	0.14	0.10	0.70	0.30
30	0.60	3.88	0.20	0.15	0.75	0.25
60	0.74	3.85	0.23	0.19	0.82	0.18
90	0.70	3.36	0.25	0.21	0.85	0.15
120	0.53	2.59	0.25	0.22	0.87	0.13
<i>Response</i>	Q**	L**	Q**	L**	L**	L**
<i>42 Days After Sowing</i>						
0	0.25	2.51	0.13	0.10	0.75	0.25
30	0.23	1.75	0.15	0.12	0.76	0.24
60	0.42	2.56	0.17	0.14	0.85	0.15
90	0.49	2.70	0.18	0.16	0.88	0.12
120	0.58	3.15	0.18	0.16	0.90	0.10
<i>Response</i>	L**	Q**	Q**	L**	L**	L**

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*) or 0.01 (**)

2.3.14 Root mass ratio

Root mass ratio decreased in a linear fashion in response to increasing nitrogen applied throughout the growing period (Table 2.2). Increasing nitrogen from 0 to 120 mg·L⁻¹ decreased RMR from 0.36 to 0.17, 0.39 to 0.12, 0.30 to 0.13 and 0.25 to 0.10 for transplants sampled 21, 28, 35 and 42 DAS, respectively, as nitrogen was increased from 0 to 120 mg·L⁻¹. The transplants grown with 0 mg·L⁻¹ N had greatest root mass ratio compared to the transplants grown with 120 mg·L⁻¹ N regardless of the sampling date.

2.4 CONCLUSIONS

Nitrogen fertilization had pronounced influence on transplant shoot and root growth. More dry mass was, however, partitioned to the shoot than the roots. At the end of the sixth week, transplants grown with 90 mg·L⁻¹ N had the greatest dry root mass and pulled out easily from the transplant trays. It can, therefore, be concluded that nitrogen at 90 mg·L⁻¹ supplied through floatation irrigation, was required to improve transplant root dry mass for plants grown in a Culterra seedling soil covered with vermiculite.

Quality transplants produced at 90 mg·L⁻¹ N were about 152 mm tall, had seven leaves, had dry shoot mass of approximately 280 mg, dry root mass of approximately 40 mg, leaf area of about 52 cm² and leaf tissue nitrogen of approximately 3.5 %. Dry mass accumulation (RGR) for the quality transplants was about 0.49 mg·mg⁻¹·wk⁻¹ while production efficiency (NAR) was about 3.15 mg·cm⁻²·wk⁻¹. Assimilation production (SLA) was about 0.18 cm²·mg⁻¹ and leafiness (LAR) about 16 cm²·mg⁻¹. Even for quality transplants, productive investment was only 12 % towards the roots and 88 % towards the shoots.

2.5 SUMMARY

An experiment was conducted to determine the optimum nitrogen application level required for the production of good quality 'Drumhead' cabbage transplants. Depending

on water requirements, transplants were fertigated every two days (for the first four weeks) and every day (for the last two weeks) by floating trays in plastic tubs containing nutrient solution at 0, 30, 60, 90 and 120 mg·L⁻¹ N until field capacity was reached.

As nitrogen was increased from 0 to 120 mg·L⁻¹ transplant shoot and root mass increased. More dry mass was, however, partitioned to the shoot than the roots. Root: shoot ratio and root mass ratio were, as a result, low. Applied nitrogen furthermore increased relative growth rate, specific leaf area, leaf area ratio and leaf mass ratio. Leaf tissue nitrogen and pulling success were improved by increasing nitrogen applied.

Nitrogen at 90 mg·L⁻¹ proved to be ideal for production of good quality cabbage transplants. Transplants grown with 90 mg·L⁻¹ N were easily pulled out of the seedling trays and had the largest dry root mass.

CHAPTER 3

PLANT POPULATION AND NITROGEN TOP-DRESSING INFLUENCE CABBAGE PRODUCTION

3.1 INTRODUCTION

In South Africa, cabbage is one of the most popular vegetables grown. On the sixteen major fresh produce markets, total sales and production were R 75 325 200.00 and 153 100 tons in 2001/2002, respectively (National Department of Agriculture, 2003). Approximately 20 to 40% of the total production is sold to the informal sector such as hawkers, small shops, etc. (Lecuona, 1996). It can be grown almost throughout the year in most parts of South Africa (Hadfield, 1995) and its growing season is between 80 to 100 days (Lecuona, 1996).

Increasing pressure on agriculture creates a need to improve agricultural production (Tiwari *et al.*, 2003). It has been reported that appropriate plant density and nutrition assume great importance in maximising yield of any given crop (Gupta, 1987; Peck, 1981; Prabhakar & Srinivas, 1990; Singh, 1996; Parmar *et al.*, 1999; Kumar & Rawat, 2002). It is, therefore, important to determine the optimal combination of plant population and nitrogen that could increase the yield and quality of cabbage heads produced (Kumar & Rawat, 2002).

Peck (1981) reported increased cabbage yield with increased nitrogen application, even though the positive yield response due to the first increment of 15 g·m² nitrogen fertilizer compared to no nitrogen fertilizer, was twice the positive yield response due to an additional 15 g·m² nitrogen fertilizer. Parmar *et al.* (1999) reported significant increases in cabbage head mass at 200 kg·ha⁻¹ N which was higher than at 150 kg·ha⁻¹ N but at par with 250 kg·ha⁻¹ N. The increase was attributed to the fact that higher nitrogen levels favoured the growth of plants with larger leaf area and it was more usefully used in head formation.

In a study conducted by Lecuona (1996) on various cabbage cultivars, it was concluded that increasing plant spacing increased head mass. It was, however, observed that at 60 x 60 cm spacing a peak was reached, after which, head mass decreased. Stepanovic *et al.* (2000) reported higher cabbage yields in the case of 70 x 30 cm spacing compared to 70 x 70 cm. They, however, suggested that the issue of profitability should be considered, taking into account high costs of seedlings and labour.

Sandhu *et al.* (1999) reported higher head yields in medium nitrogen levels and closer spacing. Under intermediate levels of nitrogen, they reported more number of plants per unit area, which resulted in maximum yield of cabbage heads with good head compactness. Singh & Naik (1988) reported significant effect of spacing and nitrogen interaction on yield during the year 1985-86. The highest yield of 274.15 quintals per ha ($27.4 \text{ t}\cdot\text{ha}^{-1}$) was obtained from a nitrogen application of $240 \text{ kg}\cdot\text{ha}^{-1}$ at 45 x 30 cm plant spacing. Statistically, similar yield was obtained when nitrogen fertilization was reduced to $180 \text{ kg}\cdot\text{ha}^{-1}$ while spacing was kept at 45 x 30 cm plant spacing. It was observed that with increasing plant spacing there was a reduction in yield, especially at higher levels of nitrogen fertilization than at lower levels. From these results a combination of $180 \text{ kg}\cdot\text{ha}^{-1}$ nitrogen fertilization and 45 x 30 cm spacing was recommended.

It is evident from the literature that for cabbage head production to be successful, knowledge of a combination of optimum plant density and suitable nitrogen levels is vital as it can be used to improve production of cabbage. It is against this background that 'Copenhagen Market' cabbage was studied at varying intra-row spacings and varying nitrogen levels in order to determine the best combination of spacing and nitrogen top-dressing for improved production under local conditions.

3.2 MATERIALS AND METHODS

A field experiment was carried out at Hatfield Experimental Farm, University of Pretoria, South Africa (Lat. 25°45'S, Long. 28°16'E, Alt. 1370 m) on a sandy clay loam soil. The average annual rainfall is about 600-700 mm occurring from October to March. Frost is frequently experienced during winter months (June-July). The experiment was conducted during the months of March-June 2004. Weather data on rainfall and temperature were collected from the Experimental Farm Weather Station during these months to provide a picture of the conditions under which the crop was grown (Fig. 3.1).

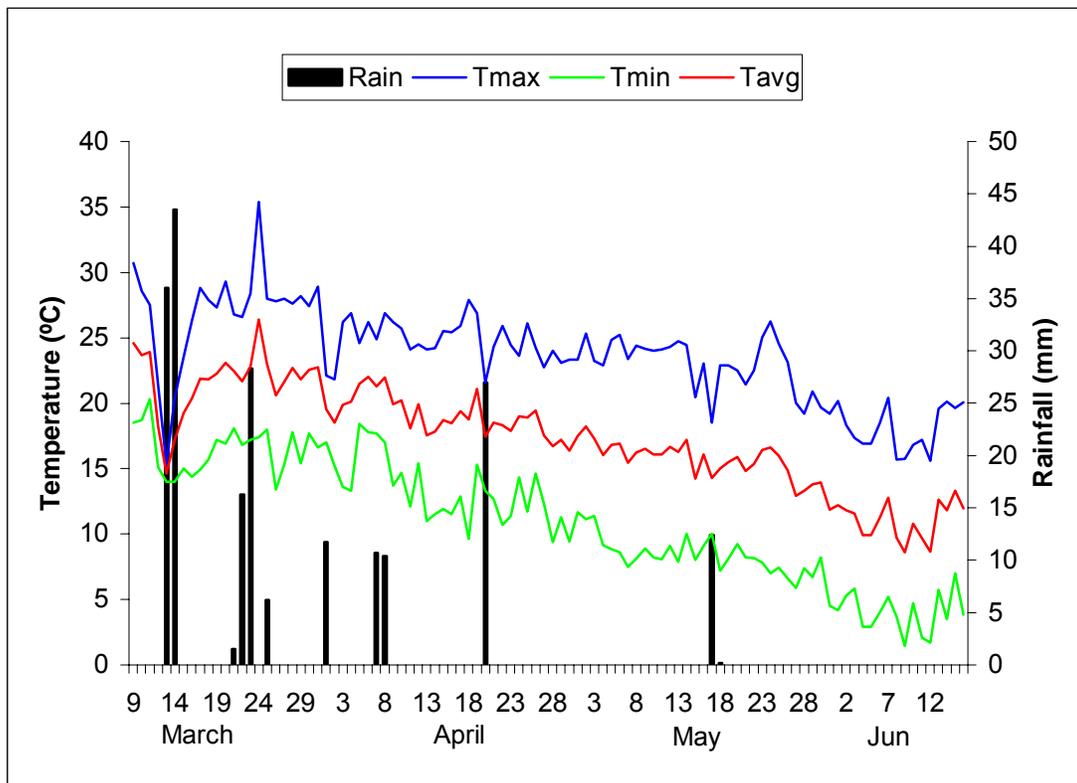


Fig. 3.1 Meteorological data for Hatfield Experimental Farm depicting daily maximum, minimum and average temperatures (°C) and rainfall (mm), 09 March to 16 June, 2004

The soil was characterized by analysis of pH, extractable cations and extractable phosphorus using 1:1 water, ammonium acetate and Bray-1 methods respectively (Table 3.1).

Table 3.1 Chemical analysis of soil at Hatfield Experimental Farm

Depth (cm)	Phosphorus (mg·kg ⁻¹)	Potassium (mg·kg ⁻¹)	Calcium (mg·kg ⁻¹)	Sodium (mg·kg ⁻¹)	Soil pH
0-30	13.9	28.5	463	16.5	7.1
30-60	22.9	35.5	459	8.5	6.8

Five week old transplants were planted on 5 m² plots. Treatments included three intra-row spacings (30, 40, and 50 cm) at an inter-row spacing of 50 cm, as well as three nitrogen topdressings (50, 100 and 150 kg·ha⁻¹). Nitrogen top-dressings were applied in two splits (four weeks and eight weeks after transplanting). The nine treatment combinations were arranged in a 3 x 3 factorial experiment laid out in a randomized complete block design and replicated four times (Fig. 3.2). A week before transplanting, nitrogen, phosphorus and potassium were broadcast by hand and incorporated into the soil at a rate of 50, 30 and 40 kg·ha⁻¹ respectively, using 3:2:1 (25), LAN (28% N) and potassium chloride (50% K). Pests were controlled by spraying crops with Metasystox, while weeds were hoed and hand-weeded whenever necessary. Plants were irrigated every three days by supplying 25 mm water on each occasion via overhead sprinkler irrigation.

On the basis of six plants from each experimental unit, head mass (kg) was measured on untrimmed and trimmed heads and measurements converted into tons per hectare. Heads trimmed to marketable form were cut open in the middle and used to determine head diameter (mm), head height (mm), core height (mm) and core diameter (mm). Slices were cut from three heads from each experimental unit and dried at 60°C to determine percentage dry matter content. Dried and ground plant leaf material were digested according to the Kjeldahl digestion method on a digester block to determine leaf tissue nitrogen content (%). Data for each variable measured were analysed as 3 x 3 factorial within the ANOVA directive language SAS (Statistical Analysis System, 2003). Statistical tests were evaluated at P ≤ 0.05.



Fig. 3.2 Plot layout of the field trial

3.3 RESULTS AND DISCUSSION

3.3.1 Influence of spacing and nitrogen on cabbage

Even though lines depicting yield from the 30 x 50 cm spacing and 40 x 50 cm seemed to cross over, there were no interactions detected between spacing and nitrogen on cabbage yield at $P \leq 0.05$ (Figs 3.3 and 3.4).

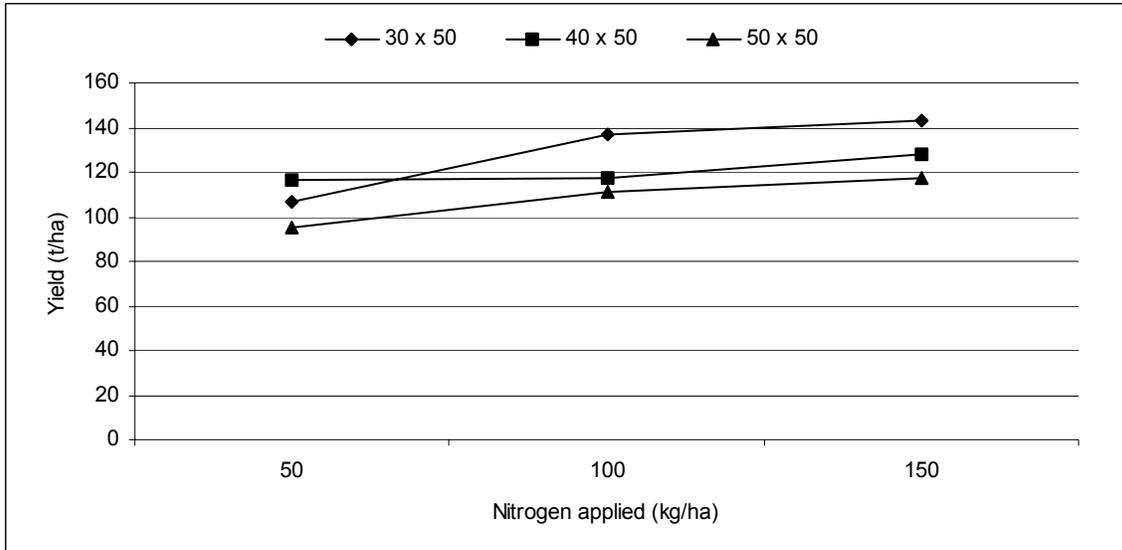


Fig. 3.3 Untrimmed cabbage head yield as influenced by spacing and nitrogen fertilizer

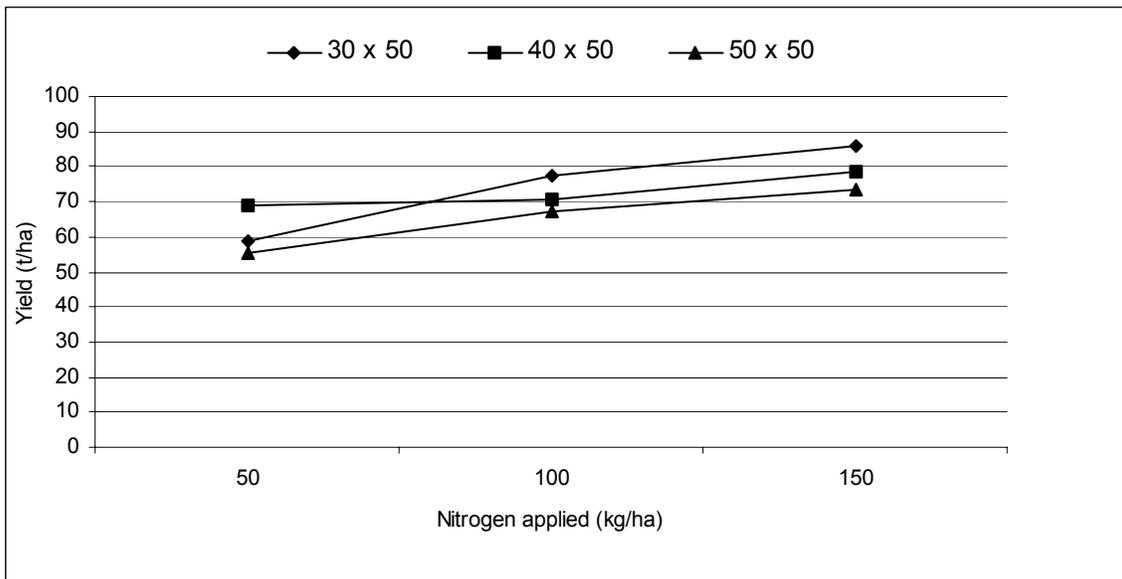


Fig. 3.4 Trimmed cabbage head yield as influenced by spacing and nitrogen fertilizer

3.3.2 Yield as influenced by nitrogen

Nitrogen application had a pronounced effect on the yield and yield contributing characters of cabbage (Table 3.2). Nitrogen at 150 kg·ha⁻¹ produced the greatest head mass and yield for untrimmed cabbage heads. For trimmed heads, nitrogen at 150 kg·ha⁻¹ again maximized head diameter, head height, head mass and yield. It was however, found that yield improvements from 100 to 150 kg·ha⁻¹ were not significantly different. Gupta (1987) reported maximum cabbage head mass at 150 kg·ha⁻¹ N. The maximum yields from 150 kg·ha⁻¹ N were attributed mainly to increase in head mass. For the current experiment higher yields at higher nitrogen doses could be attributed to great head height, diameter and mass obtained at higher nitrogen doses. Westerveld, McDonald, McKeown & Scott-Dupree (2003) reported increases in head width (diameter) and height as nitrogen application was increased up to 255 kg·ha⁻¹.

Ghanti *et al.* (1982) attributed the increase in diameter to the fact that nitrogen favoured more vegetative growth with more number of leaves and larger leaf area which are usefully utilized in the formation of heads. Kumar & Rawat (2002) reported increases in head mass and yield up to 150 kg·ha⁻¹ N, beyond which there was a reduction in yield. The reason suggested for such a response was that nitrogen significantly increased growth parameters, which in return synthesized more plant metabolites thereby increasing yield. The same reason could be attributed to the response observed in the present study.

Table 3.2 Nitrogen fertilization on mean head diameter, height, mass and yield of cabbage

Nitrogen (kg·ha ⁻¹)	Trimmed head				Untrimmed head	
	diameter (mm)	height (mm)	mass (kg·plant ⁻¹)	yield (t·ha ⁻¹)	mass (kg·plant ⁻¹)	yield (t·ha ⁻¹)
50	161.78 ^a	154.28 ^a	1.21 ^a	61.04 ^a	2.11 ^a	106.29 ^a
100	175.19 ^b	165.53 ^b	1.42 ^{ab}	71.75 ^b	2.39 ^{ab}	121.76 ^b
150	176.00 ^b	170.47 ^b	1.57 ^b	79.31 ^b	2.55 ^b	129.81 ^b
MEANS	170.99	163.43	1.40	70.70	2.35	119.29
LSD _{Tukey}	11.12	7.22	0.20	10.51	0.29	14.88

Trimmed head mass = Untrimmed – wrapper leaf mass

Means within the same columns followed by the same letter are not significantly different at $P \leq 0.05$

3.3.3 Quality as influenced by nitrogen

Nitrogen fertilization influenced core diameter and height but did not significantly influence dry matter production and leaf tissue nitrogen (Table 4.3). However, there was a tendency for greater leaf tissue nitrogen concentration with increasing nitrogen rate. On the contrary, dry matter decreased with increasing nitrogen rate. The non-significance could be attributed to the fact that nitrogen availability per plant in this experiment was such that no great differences in dry matter and leaf tissue nitrogen concentration within one treatment developed. Contrary to these results, Sanderson & Ivany (1999) reported higher leaf tissue nitrogen concentration at 120 kg·ha⁻¹ N than 90 kg·ha⁻¹ N for cabbage, Brussels sprouts and broccoli. Everaarts & De Moel (1998) reported decreases in cabbage dry matter content as nitrogen was increased while Kumar & Rawat (2002) observed maximum cabbage dry matter percentage at 200 kg·ha⁻¹ N.

Highest measurements for core height and core diameter were obtained at 150 kg·ha⁻¹ nitrogen level. It was, however, found that core diameter measurements at 150 kg·ha⁻¹ nitrogen level were not significantly different from measurements at 100 kg·ha⁻¹ nitrogen rate. Singh, Singh & Quadeer (2002) reported maximum stem thickness near the crown (core diameter) at 150 kg·ha⁻¹ N.

Table 3.3 Influence of nitrogen on the quality of cabbage

Nitrogen (kg·ha ⁻¹)	Trimmed head core		Dry matter (%)	Leaf tissue N (%)
	diameter (mm)	height (mm)		
50	37.75 ^a	72.71 ^a	8.53 ^a	2.69 ^a
100	39.19 ^{ab}	77.50 ^a	8.09 ^a	2.86 ^a
150	39.83 ^b	83.14 ^b	7.84 ^a	2.91 ^a
MEANS	38.93	77.78	8.16	2.82
LSD _{Tukey}	1.56	5.32	0.79	0.23

Means within the same columns followed by the same letter are not significantly different at $P \leq 0.05$

3.3.4 Yield as influenced by spacing

Yield of untrimmed heads and yield contributing characters were significantly influenced by varying intra-row spacings while yield for trimmed heads was not (Table 3.4). Larger and heavier heads were obtained with 50 x 50 cm spacing and decreased with a decrease in intra-row spacing. It was, however, observed that as intra-row spacing was decreased from 50 cm to 40 cm, there were no significant differences in head diameter, head height and head mass (for both trimmed or untrimmed heads). It is possible that as intra-row spacing was reduced, competition for nutrients, light, air and moisture increased which would have resulted in decreased diameter and mass of cabbage heads. Stoffella & Fleming (1990) reported quadratic increases in the cabbage head height and head width as intra-row spacing was increased from 8 to 38 cm.

As intra-row spacing was increased the total yield for both trimmed and untrimmed heads decreased. Even though there were no significant differences concerning trimmed head yield, there was a tendency for decreased yield as intra-row spacing was increased. It was observed that even though the larger and heavier individual cabbage heads were obtained from 50 x 50 cm spacing, the maximum yield per unit area was obtained from 30 x 50 cm spacing. However, there was no significant difference in yield between 30 x 50 cm spacing and 40 x 50 cm spacing. This suggests that the greatest cabbage head mass resulting from increased intra-row spacing failed to compensate for the decreased number of heads that resulted from such spacing. Higher yields from 30 x 50 cm spacing in the current study

are in agreement with the results of Prabhakar & Srinivas (1990) whereby 30 x 50 cm was superior to 40 x 50 cm spacing and 50 x 50 cm spacing. Lal (1996) reported similar yield

Table 3.4 Influence of intra-row spacing on mean head diameter, height and mass of cabbage

Intra-row spacing (cm)	Trimmed head				Untrimmed head	
	diameter (mm)	height (mm)	mass (kg·plant ⁻¹)	yield (t·ha ⁻¹)	mass (kg·plant ⁻¹)	yield (t·ha ⁻¹)
30	159.89 ^a	154.19 ^a	1.11 ^a	74.14 ^a	1.94 ^a	129.00 ^a
40	171.33 ^b	165.03 ^b	1.45 ^b	72.65 ^a	2.41 ^b	120.67 ^{ab}
50	181.75 ^b	171.06 ^b	1.63 ^b	65.31 ^a	2.70 ^c	108.17 ^b
MEANS	170.99	163.43	1.40	70.70	2.35	119.29
LSD _{Tukey}	11.12	7.22	0.20	10.51	0.29	14.88

Untrimmed head mass = Trimmed head mass + wrapper leaf mass

Means within the same columns followed by the same letter are not significantly different at $P \leq 0.05$

results on cabbage and attributed such behavior to higher plant population per unit area at narrower spacings.

3.3.5 Quality as influenced by spacing

Core diameter was significantly influenced by varying intra-row spacings (Table 3.5). The largest core diameter was recorded in plants from the 50 x 50 cm spacing. These results are in agreement with results observed by Stoffella & Fleming (1990) who reported linear increase of core diameter in cabbage as intra-row spacing was increased. In the current experiment leaf tissue nitrogen, dry matter and core height were not significantly affected by varying intra-row spacings. The findings on dry matter are in agreement with results of Kumar & Rawat (2002) who observed no influence of spacing on cabbage dry matter.

Table 3.5 Influence of spacing on quality of cabbage

Intra-row spacing (cm)	Trimmed head core		Dry matter (%)	Leaf tissue N (%)
	diameter (mm)	height (mm)		
30	36.61 ^a	75.79 ^a	8.59 ^a	2.78 ^a
40	38.97 ^b	78.47 ^a	7.99 ^a	2.88 ^a
50	41.19 ^c	79.08 ^a	7.89 ^a	2.80 ^a
MEANS	38.93	77.78	8.16	2.82
LSD _{Tukey}	1.56	5.32	0.79	0.23

Means within the same column followed by the same letter are not significantly different at $P \leq 0.05$

3.4 CONCLUSIONS

Cultivation aspects such as plant population and nitrogen nutrition are vital in maximization of cabbage head yields. It is therefore, important for the farmer to determine the best combination of optimum plant spacing and suitable nitrogen levels. The heaviest trimmed cabbage head of $1.42 \text{ kg}\cdot\text{plant}^{-1}$ and highest yield of $71.75 \text{ t}\cdot\text{ha}^{-1}$ were produced at $100 \text{ kg}\cdot\text{ha}^{-1}$ N. Head diameter was 175.19 mm , head height was 165.53 mm and the core diameter was 39.19 mm at this level of nitrogen. For untrimmed cabbage heads the heaviest heads and greatest yield were also produced at $100 \text{ kg}\cdot\text{ha}^{-1}$ N. The head mass was $2.39 \text{ kg}\cdot\text{plant}^{-1}$ while total yield (per unit area) was $121.76 \text{ t}\cdot\text{ha}^{-1}$. The split application of $100 \text{ kg}\cdot\text{ha}^{-1}$ N as top-dressing was, therefore, best for head mass and yield (per unit area) for trimmed and untrimmed heads.

For trimmed heads, the heaviest cabbage heads of about $1.45 \text{ kg}\cdot\text{plant}^{-1}$ were obtained from $40 \times 50 \text{ cm}$ spacing, even though the total yield (per unit area) from $40 \times 50 \text{ cm}$ spacing was not significantly different from $30 \times 50 \text{ cm}$ spacing or $50 \times 50 \text{ cm}$ spacing. For untrimmed heads, the heaviest heads of about $2.7 \text{ kg}\cdot\text{plant}^{-1}$ were obtained from $50 \times 50 \text{ cm}$ spacing while the greatest yield of about $120.67 \text{ t}\cdot\text{ha}^{-1}$ was obtained from $40 \times 50 \text{ cm}$ spacing. The choice of spacing would, therefore, depend on whether the farmer is targeting trimmed or untrimmed heads.

3.5 SUMMARY

An experiment was conducted to determine the best combination of spacing (30 x 50, 40 x 50 and 50 x 50 cm) and nitrogen top-dressing (50, 100 and 150 kg·ha⁻¹) for cabbage cultivar Copenhagen Market produced on a sandy clay loam during the months of March-June 2004. Treatments consisted of all combinations of three intra-row spacings and three levels of nitrogen.

The interaction effect of spacing and nitrogen was non-significant on the variables measured. Influence of nitrogen application on dry matter production and leaf tissue nitrogen was non-significant. Furthermore, spacing did not influence core height and yield per unit area of trimmed cabbage heads. Nitrogen at 100 kg·ha⁻¹ produced the greatest head mass and yield for untrimmed heads. The 40 x 50 cm spacing produced heavier heads and highest yield of untrimmed heads. For trimmed heads, 100 kg·ha⁻¹ nitrogen again produced greatest head mass, head diameter, head height, core diameter and yield. Spacing did not affect yield for trimmed heads. However, 40 x 50 cm spacing improved head diameter, head height and head mass while core diameter was larger with 50 x 50 cm spacing.

Therefore, split application of 100 kg·ha⁻¹ N as top-dressing was best for head mass and yield (per unit area) for trimmed and untrimmed heads. For trimmed heads, a spacing of 40 x 50 cm was ideal for cabbage head mass, while a spacing of 50 x 50 cm was ideal for untrimmed head mass.

GENERAL DISCUSSION AND CONCLUSIONS

In the greenhouse experiment (Chapter 2), it was found out that higher nitrogen rates compared to lower rates, improved transplant shoot and root growth. However, more dry mass was partitioned to shoots than to the roots, resulting in lower values of root: shoot and root mass ratios. Furthermore, applied nitrogen increased relative growth rate, net assimilation rate, specific leaf area, leaf area ratio and leaf mass ratio, indicating improved growth.

It was also observed that leaf tissue nitrogen and pulling success were improved by increasing nitrogen applied. Nitrogen at $90 \text{ mg}\cdot\text{L}^{-1}$ resulted in production of good quality cabbage transplants with largest dry root mass that pulled easily from the transplant trays. Reduced pulling success was observed when mean dry root mass was less than 40 mg.

Understanding the importance of nitrogen on cabbage transplant growth has provided new insight into the production of cabbage transplants. The effects of pre-transplant fertilization on survival of cabbage transplants following transplanting into sub-optimal field environments were not determined in this study. It would, therefore, be appropriate to conduct studies to find the effect of good root development of transplants on further plant growth, taking into account transplant shock, plant establishment and yield.

In the field experiment (Chapter 3), the results confirmed the fact that higher nitrogen levels improve cabbage yields. However, use of excessive amounts of nitrogen fertilizer may result in luxurious growth with no increases in yield. In the experiment, it was found out that nitrogen top-dressing influenced cabbage head mass and cabbage head yield per unit area. A split application of $100 \text{ kg}\cdot\text{ha}^{-1}$ N as top-dressing produced the greatest head mass and yield for untrimmed heads. This amount of nitrogen again improved yield-contributing characters of cabbage for trimmed heads.

Furthermore, the study revealed that plant spacing has a pronounced influence on cabbage head mass and yield per unit area. As intra-row spacing was decreased, the cabbage head mass decreased, while yield per unit area increased. The reduction in head mass could probably have been due to the fact that as intra-row spacing decreased, more plants per unit area resulted in more competition for soil water and nutrients between individual plants. An increase in yield per unit area with a decrease in intra-row spacing could be attributed to the higher numbers of plants attained at lower plant densities.

For untrimmed heads the highest yield was produced from 30 x 50 cm plant spacing while larger and heaviest heads were produced from the 50 x 50 cm spacing. Plant spacing did not seem to have much influence on the quality of cabbage. Only the head diameter was influenced, with flat heads obtained at the 50 x 50 cm spacing.

Basically, the market demands either small or large cabbage heads. The smaller heads are mainly used as salads while the larger ones are either fried or boiled and eaten together with *papa* (stiff maize porridge) as the main course especially in poor communities. Depending on the targeted market, the farmer may manipulate his/her nitrogen application levels or intra-row spacing in accordance with the required cabbage head size.

Issues pertaining to nitrogen costs, nitrogen leaching into water supplies and high nitrate levels in food were not addressed in the current experiment. These issues may need to be considered in subsequent studies.

GENERAL SUMMARY

A glasshouse experiment was conducted to determine the optimum nitrogen application level required for the production of good quality 'Drumhead' cabbage transplants. Good quality transplants are those with large root system that can easily pull from the transplant trays. Depending on water requirements, transplants were fertigated every two days (for the first four weeks) and every day (for the last two weeks) by floating trays in plastic tubs containing nutrient solution at 0, 30, 60, 90 and 120 mg·L⁻¹ N until field capacity was reached. The experiment was arranged as a randomized complete block design (RCBD) with four replications.

As nitrogen was increased from 0 to 120 mg·L⁻¹ transplant shoot and root mass increased. Dry mass was least with 0 mg·L⁻¹ N throughout the growing period. The dry shoot mass was greatest in transplants that received 120 mg·L⁻¹ N regardless of sampling date. For transplants grown to 21 and 28 DAS, the greatest values of dry root mass were obtained at 120 mg·L⁻¹ N while for those sampled 35 and 42 DAS, greatest values were obtained at 60 and 90 mg·L⁻¹ N, respectively. More dry mass was, however, partitioned to the shoot than the roots. Root: shoot ratio and root mass ratio were as a result low. The greatest root: shoot ratio values were obtained at 0 mg·L⁻¹ N and least values at 120 mg·L⁻¹ N.

Applied nitrogen furthermore increased relative growth rate, specific leaf area, leaf area ratio and leaf mass ratio. The highest concentration of leaf tissue nitrogen was obtained from transplants which received 120 mg·L⁻¹ N. This could have been due to the fact that more nitrogen was available to the transplants at this treatment level. At termination of the experiment, only transplants grown with 90 mg·L⁻¹ N could easily pull from the transplant trays.

The study demonstrated that nitrogen at 90 mg·L⁻¹ produced transplants with more vigorous root growth that could easily pull from the transplant trays.

To determine the best combination of spacing and nitrogen top-dressing for improved production under local conditions a field experiment was conducted. Treatments consisted of 30, 40 and 50 cm intra-row and 50 cm inter-row spacings and 50, 100 and 150 kg·ha⁻¹ N top-dressing applied in two splits (four and eight weeks after transplanting). Treatments were arranged in a factorial experiment and laid out in a randomized complete block design and replicated four times.

There were no interactions between spacing and nitrogen top-dressing for all measured variables. Nitrogen did not influence dry matter production and leaf tissue nitrogen. The greatest head mass and yield (per unit area) for untrimmed cabbage heads were obtained at 100 mg·L⁻¹ N. For trimmed heads 100 mg·L⁻¹ N again produced greatest head mass, head diameter, head height, core diameter and yield.

Spacing did not influence dry matter production, leaf tissue nitrogen, core height and yield of trimmed heads. For trimmed heads a 50 x 50 cm spacing produced heavier heads but yield was not affected. However, 40 x 50 cm spacing improved head diameter, head height and head mass while core diameter was larger with 50 x 50 cm spacing.

The results indicated that split application of 100 kg·ha⁻¹ N top-dressing was best for head mass and yield (per unit area) for trimmed and untrimmed heads. Choice of spacing would depend on whether trimmed or untrimmed heads are targeted.

REFERENCES

- AALBERSBERG, I.J.W. & STOLK, J.H. (Eds.). 1993. 38e Descriptive list of varieties of vegetables for field cultivation 1994 (in Dutch). CPRO-DLO, Wageningen, The Netherlands, 259 pp. (cited by EVERAARTS & DE MOEL, 1998).
- ADLER, P. R., DUFAULT, R. J. & WATERS, L. Jr, 1984. Influence of nitrogen, phosphorous and potassium on asparagus transplant quality. *HortScience* 19, 565-566.
- ALONI, B., PASHKAR, T., KARNI, L. & DAIE, J., 1991. Nitrogen supply influences carbohydrate partitioning of pepper seedlings and transplant development. *J. Amer. Soc. Hort. Sci.* 116(6), 995-999.
- ANDERSEN, C. R., 2000. Cabbage home gardening series. University of Arkansas.
Website: http://www.uaex.edu/Other_Areas/publications/HTML/FSA-6006.asp
- ASKEW, D., 1999. Cabbage series: Part V: Plant population, transplanting, irrigation and crop rotation. Hygrotech Forum. Newsletter of Hygrotech Seed (Pty) Ltd, Pretoria.
- ASKEW, D. & SMITH, I.E., 1995. A study of fertilization practices on cabbage in the Umlaas River Valley, KwaZulu-Natal. *In*: D. ASKEW. A multi-factor study of cabbage production in the Umlaas River Valley. Ph.D. Thesis. University of Natal, Pietermaritzburg.
- CANTLIFFE, D. J. & KARCHI. Z., 1992. Performance of crisphead lettuce cultivars on polyethylene-mulched, drip-irrigated sandy soils in Florida. *Proc. Fla. State. Hort. Soc.* 105, 340-342. (Cited by SOUNDY *et al.*, 2001a).

- CLAASSENS, A.S., 2004. Personal communication. Department of Plant Production and Soil Science. University of Pretoria, Pretoria.
- CLEAVER, T.J., GREENWOOD, D.J., WHITWELL, J.D. & WOOD, M.B., 1971. Nitrogen and potassium fertilizer requirements of Brussels sprouts. *J. Hort. Sci.* 46, 17-31.
- COOKE, G.W., 1982. Fertilizing for maximum yield. Third edition. Granada Publishing Ltd, London.
- DUBIK, S.P., KRIZEK, D.T. & STIMART, D.P., 1990. Influence of root zone restriction on mineral element concentration, water potential, chlorophyll concentration, and partitioning of assimilate in spreading *Euonymus* (*E. Kiautschvica* Loes. 'Sieboldiana'). *J. Plant Nutr.* 13, 677-699.
- DUBIK, S.J. KRIZEK, D.T. STIMART, D.P. & MCINTOSH, M.L., 1992. Growth analysis of spreading euonymous subjected to root restriction. *J. Plant Nutr.* 15, 469-486.
- DUFAULT, R.J., 1985. Relationship among nitrogen, phosphorus, and potassium fertility regimes on celery transplant growth. *HortScience* 20(6), 1104-1106.
- DUFAULT, R.J. & WATERS, L., 1985. Container size influences broccoli and cauliflower transplant growth but not yield. *HortScience* 20, 682-684.
- DUFAULT, R. J. & SCHULTHEIS, J.R., 1994. Bell pepper seedling growth and yield following pre-plant nutritional conditioning. *HortScience* 29(9), 999-1001.
- EVERAARTS, A.P., 1993a. General and quantitative aspects of nitrogen fertilizer use in the cultivation of *Brassica* vegetables. *Acta Hortic.* 339, 149-160.
- EVERAARTS, A.P., 1993b. Strategies to improve the efficiency of nitrogen fertilizer use in the cultivation of *Brassica* vegetables. *Acta Hortic.* 339, 161-173.

- EVERAARTS, A.P. & DE MOEL, C.P., 1998. The effect of nitrogen and the method of application on yield and quality of white cabbage. *European J. Agron.* 9, 203-211.
- FINCK, A., 1982. Fertilizers and fertilization: Introduction and practical guide to crop fertilization. Verlag Chemie, New York.
- FISHER, K.J. & BENSON, B.L., 1983. Effects of nitrogen and phosphorus nutrition on the growth of asparagus seedlings. *Sci. Hortic.* 21, 105-112.
- FOTH, H.D., 1990. Fundamentals of soil science. Eighth edition. John Wiley and Sons, Inc., New York.
- FOTH, H.D. & ELLIS, B.G., 1996. Soil fertility. Second edition. Lewis Publishers, New York.
- GARDNER, F.P., 1985. Physiology of crop plants. First edition. Ames: The Iowa State University Press, Iowa.
- GARTON, R.W. & WIDDERS, I.E., 1990. Nitrogen and phosphorus preconditioning of small-plug seedling influence processing tomato productivity. *HortScience* 25, 655-657.
- GHANTI, P., SOUNDA, G., JANA, P. K. & SOM, M. G., 1982. Effect of levels of nitrogen, phosphorus and spacing on yield characters of cabbage. *Veg. Sci.* 9, 1-4.
- GUPTA, A., 1987. Effect of nitrogen and irrigation on cabbage production. *Indian J. Hort.* 44, 241-244.
- GUZMAN, V.L., 1990. Effect of plant spacing on yield and quality of transplanted South Bay lettuce. Belle Glade EREC Research Report. pp 109.

- HADFIELD, J., 1995. Vegetable gardening in South Africa. Struikhof Publishers, Cape Town, South Africa.
- HEMY, C., 1984. Growing vegetables in South Africa. Macmillan, South Africa (Publishers) (Pty) Ltd, Johannesburg, South Africa.
- HUNT, R., 1982. Plant growth curves. The functional approach to plant growth analysis. Edward Arnold, London.
- JONES, U.S., 1982. Fertilizer and soil fertility. Second edition. Reston Publishing Company, Virginia.
- KNAVEL, D.E. & HERRON, J.W., 1981. Influence of tillage system, plant spacing and nitrogen on head weight, yield, and nutrient concentration of spring cabbage. *J. Amer. Soc. Hort. Sci.* 106 (5), 540-545.
- KUMAR, M. & RAWAT, T.S., 2002. Effect of nitrogen and spacing on the quality and yield of cabbage (*Brassica oleracea* L. var. *capitata*). *Agric. Sci. Digest* 22(2), 90-92.
- LAL, G., 1996. Effect of nitrogen and spacing on yield and quality of cabbage (*Brassica oleracea* L. var. *capitata*). *Ann. Biol.* 12(2), 242-244.
- LECUONA, A., 1996. The influence of various spacings on yields and head mass of six cabbage cultivars. Roodeplaat Bulletin No. 46.
- LESKOVAR, D.I. & STOFFELLA, P.J., 1995. Vegetable seedling root system: Morphology, development and importance. *HortScience* 30(6), 1153-1159.

- MASSON, J., TREMBLAY, N. & GOSSELIN, A., 1991. Nitrogen fertilization and HPS supplementary lighting influence vegetable transplant production. I. Transplant growth. *J. Amer. Soc. Hort. Sci.* 116(4), 594-598.
- MELTON, R.R. & DUFAULT, R.J., 1991. Nitrogen, phosphorus and potassium fertility affect tomato transplant growth. *HortScience* 26(2), 141-142.
- NATIONAL DEPARTMENT OF AGRICULTURE, 2003. Abstract of Agricultural Statistics. South Africa.
- NEUVEL, J., 1990. Nitrogen fertilization of Brussel sprouts (in Dutch). Report 102. PAGV, Lelystad. 35 pp. (Cited by EVERAARTS, 1993a).
- NICOLA, S. & CANTLIFFE, D.J., 1996. Increasing cell size and reducing medium compression enhances lettuce transplant quality and field production. *HortScience* 31(2), 184-189.
- PARMAR, H.C., MALIWAL, G.L., KASWALA, R.R. & PATEL, M.L., 1999. Effect of irrigation, nitrogen and spacing on yield of cabbage. *Indian J. Hort.* 56 (3), 256-258.
- PECK, N.H., 1981. Cabbage plant response to nitrogen fertilization. *Agron. J.* 73, 679-684.
- PHILLIPS, R. & RIX, M., 1993. Vegetables. Random House, Inc. New York, USA.
- POWELL, A.A., THORNTON, J.M. & MITCHELL, J.A., 1991. Vigour differences in *Brassica* seed and their significance to emergence and seedling variability. *J. Agric. Sci.* 116, 369-373.

- PRABHAKAR, B.S. & SRINIVAS, K., 1990. Effect of spacing and fertilizer on head yield of cabbage. *Prog. Hort.* 22(1-4), 112-116.
- SALUNKHE, D.K., DESAI, B.B. & BHAT, N.R., 1987. Vegetable and flower seed production. Agricole Publishing Academy, New Delhi.
- SANDERSON, K.R. & IVANY, J.A., 1999. Cole crop yield response to reduced nitrogen rates. *Can. J. Plant* 79, 149-151.
- SANDHU, K.S., CHAHAI, B. S., SINGH, D. & SANDHA, M.S., 1999. Effect of population density and nitrogen on growth characters and yield of cabbage (*Brassica oleracea* var. *capitata*). *Veg. Sci.* 26 (2), 146-148.
- SINGH, R.V., 1996. Response of cabbage to N, P fertilization and spacing under Chotanagpur conditions. *Indian J. Hort.* 53 (1), 59-63.
- SINGH, R.V. & NAIK, L.B., 1988. Response of cabbage to plant spacing, nitrogen and phosphorus levels. *Indian J. Hort.* 45, 325-328.
- SINGH, D.K., SINGH, Y. & QUADEER, A., 2002. Response of nitrogen on the productivity of cabbage cultivars. *Ann. Agric. Res. New Series* 23(1), 33-37.
- SMITH, K., 1995. Classic vegetable catalogue. Thomas C. Lothian Pty. Ltd. Victoria, Australia.
- SMITH, C.B., DEMCHAK, K.T. & FERRETTI, P.A., 1990. Fertilizer placement effects on growth responses and nutrient uptake of sweet corn, snapbeans, tomatoes and cabbage. *Commun. Soil Sci. Plant Anal.* 21, 107-123.
- SMITH, I.E. & HAPELT, D., 1984. Nitrogen fertilization and spacing of cabbages. *In*: I.E. SMITH & M.D. LAING (ed). Cabbage growing in Natal. Proceedings of a

symposium on cabbage production held on the 27th March, 1984 at the Baynesfield Recreation Hall. Pietermaritzburg, University of Natal.

SOUNDY, P., 1996. Lettuce transplant root and shoot growth and development in relation to nitrogen, phosphorus, potassium and water management. Ph.D. Dissertation. University of Florida, Gainesville, FL.

SOUNDY, P. CANTLIFFE, D. J. HOCHMUTH, G. J. & STOFFELLA, P. J., 2001a. Nutrient requirements for lettuce transplants using floatation irrigation system. I. Phosphorus. *HortScience*. 36 (6), 1066-1070.

SOUNDY, P. CANTLIFFE, D. J. HOCHMUTH, G. J. & STOFFELLA, P. J., 2001b. Nutrient requirements for lettuce transplants using floatation irrigation system. II. Potassium. *HortScience* 36 (6), 1071-1074.

SPLITTSTOESSER, W. E., 1979. Vegetable growing handbook. The AVI Publishing Company, Inc., USA.

STATISTICAL ANALYSIS SYSTEM, 2003. SAS User's Guide: Statistics Version 8.2. SAS Institute Inc., Cary NC, USA.

STEPANOVIC, M.V., BJELIC, V.V. & DRAGICEVIC, V.D., 2000. Effect of crop density on morphological characteristics and yield of cabbage. *Acta Horti*. 533, 205-207.

STOFFELLA, P.J. & FLEMING, M.F., 1990. Plant population influences yield variability of cabbage. *J. Amer. Soc. Hort. Sci.* 115(5), 708-711.

STRYDOM, A.W., 1997. Seed vigour tests for cabbage. M.Sc. Dissertation. University of Pretoria, Pretoria.

- TENDAJ, M. & KUZYK, K., 2001. Effect of plant density on yielding of cabbage. *Veg. Crops Res. Bulletin* 54(2), 35-39.
- THE FERTILIZER SOCIETY OF SOUTH AFRICA, 2000. Fertilizer handbook. Beria Printers. Lynwood Ridge, South Africa.
- TISDALE, S.L. & NELSON, W.L., 1966. Soil fertility and fertilizers. Second edition. The Macmillan Company, New York.
- TISDALE, S.L. & NELSON, W.L., 1975. Soil fertility and fertilizers. Third edition. The Macmillan Company, New York.
- TIWARI, K.N., SINGH, P.K. & MAL, P.K., 2003. Effect of drip irrigation on yield of cabbage (*Brassica oleracea* L. var. *capitata*) under mulch and non-mulch conditions. *Agric. Water Manag.* 58,19-28.
- TREMBLAY, N. & SENÉCAL, M., 1988. Nitrogen and potassium in nutrient solution influence seedling growth of four vegetable species. *HortScience* 23(6), 1018-1020.
- TREMBLAY, N., YELLE, S. & GOSSELIN, A., 1987. Effects of CO₂ enrichment, nitrogen and phosphorous fertilization on growth and yield of celery transplants. *HortScience* 22, 875-876.
- WARE, G.W. & McCOLLUM, J.P., 1980. Producing vegetable crops. The Interstate Printers and Publishers, Inc. Illinois, USA.
- WELCH, N.C., TYLER, K.B. & RIRIE, D., 1985. Nitrogen rates and nitrapyrin influence on yields of Brussels sprouts, cabbage, cauliflower and celery. *HortScience* 20(6), 1110-1112.

- WESTERVELD, S.M., MCDONALD, M.R., MCKEOWN, A.W. & SCOTT-DUPREE, C.D., 2003. Optimum nitrogen fertilization of summer cabbage in Ontario. *Acta Hortic.* 627, 211-215.
- WESTON, L.A., 1988. Effect of flat cell size, transplant age, and production site on growth and yield of pepper transplants. *HortScience* 23, 709-711.
- WESTON, L.A. & Zandstra, B.H., 1986. Effect of root container size and location of production on growth and yield of tomato transplants. *J. Amer. Soc. Hort. Sci.* 111, 498-501.
- WIDDERS, I.E., 1989. Pretransplant treatments of N and P influence growth and elemental accumulation in tomato seedlings. *J. Amer. Hort. Sci.* 114(3), 416-420.
- WIDDERS, I.E. & PRICE, H.C., 1989. Effects of plant density on growth and biomass partitioning in pickling cucumbers. *J. Amer. Soc. Hort. Sci.* 114, 751-755.
- YAMAGUCHI, M., 1983. World vegetables. The AVI Publishing Company, Inc. USA.
- ZEBARTH, B.J., FREYMAN, S. & KOWALENKO, C.G., 1991. Influence of N fertilization on cabbage yield, head nitrogen content and exchangeable soil organic N at harvest. *Can. J. Plant Sci.* 71, 1275-1280.

APPENDICES

APPENDIX A: GREENHOUSE EXPERIMENT

Table A 1 Analysis of variance for root and shoot characteristics of cabbage transplants as affected by nitrogen application, July/August 2004

Sources of variation	Df	Mean Squares ^z								
		Fresh shoot mass (10 ³ mg)	Dry shoot mass (mg)	Fresh root mass (10 ² mg)	Dry root mass (mg)	Plant height (cm)	Leaf area (cm ²)	Root : shoot ratio (10 ⁻³)	Pulling success (%)	Leaf tissue nitrogen (%)
<i>21 Days After Sowing</i>										
Treatment	4	123.00**	624.39**	10.85**	6.21**	1828.61**	41.98**	88.43**		
Replication	3	0.45 ^{NS}	0.47 ^{NS}	0.34*	0.16 ^{NS}	2.22 ^{NS}	0.03 ^{NS}	0.17 ^{NS}		
Error	12	0.46	0.19	0.07	0.05	3.21	1.22	0.27		
<i>28 Days After Sowing</i>										
Treatment	4	446.53**	4781.52**	40.40**	14.62**	5073.37**	280.88**	173.28**		
Replication	3	0.23 ^{NS}	3.66 ^{NS}	0.41 ^{NS}	0.16 ^{NS}	19.26 ^{NS}	1.15 ^{NS}	0.01 ^{NS}		
Error	12	1.02	3.78	0.54	0.26	25.65	7.53	0.16		
<i>35 Days After Sowing</i>										
Treatment	4	2335.99**	15169.10**	538.29**	214.65**	6029.49**	1204.10**	55.57**		
Replication	3	1.30 ^{NS}	19.93 ^{NS}	0.04 ^{NS}	38.61 ^{NS}	20.68 ^{NS}	45.66 ^{NS}	1.54 ^{NS}		
Error	12	0.93	14.83	0.04	12.27	10.57	17.30	0.57		
<i>42 Days After Sowing</i>										
Treatment	4	5944.31**	57026.95**	738.15**	472.69**	6211.17**	2050.57**	40.14**	3920.00**	4.64**
Replication	3	10.03 ^{NS}	33.25 ^{NS}	0.09 ^{NS}	3.44 ^{NS}	64.83 ^{NS}	51.39 ^{NS}	0.42 ^{NS}	20.00 ^{NS}	0.20 ^{NS}
Error	12	3.91	60.79	0.06	5.16	79.43	39.76	0.65	120.00	0.30

^zF-values significant (*), highly significant (**) or non-significant (NS) at 5% level of probability

Table A 2 Analysis of variance for nitrogen nutrition on growth characteristics of cabbage transplants July/August 2004

Sources of variation	Df	Mean Squares ^z					
		Relative growth rate (10 ⁻⁴ mg·mg ⁻¹ ·wk ⁻¹)	Net assimilation rate (10 ⁻¹ mg·cm ⁻² ·wk ⁻¹)	Specific leaf area (10 ⁻⁵ cm·mg ⁻¹)	Leaf area ratio (10 ⁻⁵ cm ² ·mg ⁻¹)	Leaf mass ratio (10 ⁻⁵)	Root mass ratio (10 ⁻⁵)
<i>21 Days After Sowing</i>							
Treatment	4			714.12**	805.05**	2447.00**	2449.25**
Replication	3			6.42 ^{NS}	3.39 ^{NS}	11.33 ^{NS}	7.17 ^{NS}
Error	12			95.26	60.32	6.33	5.92
<i>28 Days After Sowing</i>							
Treatment	4	634.59**	26.61**	414.83**	795.50**	4698.00**	4698.00**
Replication	3	19.42 ^{NS}	2.99 ^{NS}	26.77 ^{NS}	19.33 ^{NS}	1.83 ^{NS}	1.83 ^{NS}
Error	12	8.7	4.15	90.02	65.47	4.33	4.33
<i>35 Days After Sowing</i>							
Treatment	4	55.03**	441.60**	914.00**	1047.12**	2040.75**	2040.75**
Replication	3	61.98**	26.45 ^{NS}	172.75*	108.86 ^{NS}	84.50*	84.50*
Error	12	13.98	1.54	47.08	31.59	20.75	20.75
<i>42 Days After Sowing</i>							
Treatment	4	915.12**	10.18**	166.94*	288.69**	1853.25**	1853.25**
Replication	3	27.60 ^{NS}	1.29 ^{NS}	63.77 ^{NS}	40.48 ^{NS}	16.50 ^{NS}	16.50 ^{NS}
Error	12	14.71	1.04	31.96	25.97	23.58	23.58

^zF-values significant (*), highly significant (**) or non-significant (NS) at 5% level of probability

APPENDIX B: FIELD EXPERIMENT

Table B 1 Effects of N top-dressing and plant spacing on cabbage head mass, yield and quality characteristics

Sources of variation	Df	Mean squares ^z									
		Head diameter	Head height	Core diameter	Core height	Dry matter	Leaf tissue nitrogen	Trimmed head mass	Untrimmed head mass	Trimmed head yield	Untrimmed head yield
		(mm)	(mm)	(mm)	(mm)	(%)	(%)	(kg·plant ⁻¹)	(kg·plant ⁻¹)	(t·ha ⁻¹)	(t·ha ⁻¹)
Nitrogen (N)	2	765.86**	826.54*	13.67**	327.11**	1.45 ^{NS}	0.15 ^{NS}	0.37**	0.61**	1011.45**	1714.46**
Spacing (S)	2	1434.78**	875.98**	63.04**	36.79 ^{NS}	1.74 ^{NS}	0.04 ^{NS}	0.84**	1.81**	268.09 ^{NS}	1319.41**
N x S	4	259.69 ^{NS}	97.41 ^{NS}	1.75 ^{NS}	49.06 ^{NS}	1.65 ^{NS}	0.09 ^{NS}	0.03 ^{NS}	0.06 ^{NS}	99.41 ^{NS}	243.35 ^{NS}
Replications	3	903.99**	242.70**	7.33*	178.24**	4.4**	0.21*	0.43**	0.51**	1121.98**	1310.55**
Error	24	119.01	50.14	2.33	27.25	0.60	0.05	0.04	0.08	106.19	212.88

^zF-values significant (*), highly significant (**) or non-significant (NS) at 5% level of probability