RESPONSE OF CABBAGE (*BRASSICA OLERACEA VAR CAPITATA)* TRANSPLANTS TO NITROGEN, PHOSPHORUS AND POTASSIUM NUTRITION

KETSEEMANG MORE

RESPONSE OF CABBAGE (*BRASSICA OLERACEA VAR CAPITATA)* TRANSPLANTS TO NITROGEN, PHOSPHORUS AND POTASSIUM NUTRITION

by

KETSEEMANG MORE

Submitted in partial fulfilment of the requirements for the degree MSc (Agric) Horticulture
Department of Plant Production and Soil Science
in the Faculty of Natural and Agricultural Sciences
University of Pretoria
Pretoria

Supervisor: Dr P. Soundy
Co-supervisor: Dr D. Marais

November, 2006

DECLARATION

I declare that this thesis, for the degree of MSc (Agric.) Horticulture at the University of Pretoria is my work, except where duly acknowledged and that it has never been submitted before by myself for any degree at any university.

……. …….

Ketseemang More Date

ACKNOWLEDGEMENTS

I would like to acknowledge the support and dedication of the following people who have contributed in making this project a success:

My supervisor, Dr P. Soundy whose continual guidance, assistance, patience and constructive criticism have given me the courage to go on.

Dr D. Marais, my co-supervisor, whose assistance, encouragement and advice gave me the will to continue to the finish.

I would like to extend my sincere gratitude to the men and women who work at the University of Pretoria Experimental Farm, for assisting me during the greenhouse and field experiments.

I would have made a mistake if I could forget my fellow students and friends; Didimalang Futho, Laurinda Nobela, Samuel Mudau, Kingsley Kwenani, Yibekal and Abby (Soil Science) for their constant support.

My fiancée, Dr Guy Roger wa Safi Safi, my mother, Mrs Gakeitsape Keikanetswe, my stepfather, Mr Keeme Keikanetswe and my children Lame and Kaone for being so understanding, loving and supporting me emotionally and spiritually.

Finally, to the Almighty God for always protecting and supporting me. Just believe and everything will be okay.

DEDICATION

This thesis is dedicated to my late grandfather Mr BONANG MORUELE- A-MABUDI who taught me to hope, believe and have faith.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

RESPONSE OF CABBAGE TRANSPLANTS TO NITROGEN, PHOSPHORUS AND POTASSIUM NUTRITION

by

K. More

Supervisor: Dr P. Soundy

Co-supervisor: Dr D. Marais

Department: Plant Production and Soil Science

Degree: MSc (Agric) Horticulture

Abstract

Poor root development is a problem in transplants that are produced in cavity trays, as transplants tend to break when being pulled out of the cavity trays during transplanting. Cabbage transplants were propagated at different levels of nitrogen, phosphorus and potassium in separate experiments to determine the amount of nitrogen, phosphorus and potassium that could optimise shoot and root development. The transplants from the nitrogen experiments were then planted into the field to determine the effect of pretransplant nitrogen on the yield and head quality of cabbage.

To determine the amount of nitrogen that could optimise shoot and root development, cabbage 'Drumhead' transplants were propagated at 0, 30, 60, 90 and 120 mg·Ü$^{-1}$ N. Nitrogen application enhanced shoot and root growth regardless of season. Leaf nitrogen and pulling success also improved as nitrogen increased during the two seasons. Leaf nitrogen content in transplants that were propagated during autumn increased from 10.3 to 28.3 g·kg^{-1} while during spring, leaf nitrogen increased from 13.0 to 43.7 g·kg^{-1} as applied nitrogen increased from 0 to 120 mg·Ł$^{-1}$.

In autumn, quality transplants were obtained from transplants that were propagated at 90 mg·L^{-1} N, as a result the transplants gave the highest cabbage yield. In spring, quality transplants were obtained from transplants that received 60 mg·L^{-1} N, which in turn gave the highest cabbage yield. Pretransplant nitrogen increased head diameter and head height but did not affect core diameter and core height during autumn. During spring pretransplant nitrogen increased head diameter but did not affect head height. Core diameter was increased by pretransplant nitrogen while core height was not affected. Pretransplant nitrogen applied at 90 mg·L^{-1} in autumn and 60 mg·L^{-1} in spring is enough to give quality transplant that would give high yield.

Potassium was applied at 0, 15, 30, 45 and 60 mg·L^{-1} during cabbage transplant production to evaluate the effect of potassium nutrition on cabbage transplant shoot and root development. Applied potassium improved fresh shoot and root mass, plant height, leaf potassium content, pulling success and net assimilation rate. Dry shoot and root mass, leaf number, leaf area, root: shoot ratio, root mass, leaf mass ratio, specific leaf area, relative growth rate and leaf area ratio were not affected by applied potassium. Applying at least 15 mg·L^{-1} K during cabbage transplant production gave quality transplants.

Cabbage transplants were propagated at 0, 15, 30, 45 and 60 mg·L^{-1} P, to determine the impact of phosphorus nutrition on shoot and root growth of cabbage transplants. Applied phosphorus improved leaf area, fresh and dry shoot mass, fresh and dry root mass, pulling success and leaf phosphorus content. Most of the increases in growth were achieved with 15 mg·L^{-1} P. Therefore, application of at least 15 mg·L^{-1} P during cabbage transplant production was enough to give quality transplants.

Keywords: Nitrogen, transplants, phosphorus, potassium

GENERAL INTRODUCTION

Cabbage is scientifically known as *Brassica oleracea* var. *capitata*. It belongs to the Brassicaceae family which includes kale (*Brassica oleracea* var *acephala*), chinese cabbage (*Brassica pekinensis* (Lour Rapr.) and Brussels sprouts (*Brassica oleracea* var. *gemmifera* DC). Initially cabbage was used for medicinal purposes such as treatment for gout, stomach problems, headache and deafness, while today it is mainly used as a fresh market crop and for processing. Fresh market cabbage is used for cooking (as main dish or mixed with other vegetables in stews) and making of salads (e.g. cole slaw). There are three types of heading cabbage, namely green, red and savoy. They contain different amounts of nutrients with savoy being more superior (Peirce, 1987). For processing, cabbage can be mixed with other vegetables or sold as stir-fry and for making sauerkraut (Shoemaker, 1949; Ryder, 1979; Smith, 1995).

Cabbage is a biennial crop that is grown as an annual, unless it is grown for seed production (Ryder, 1979; Pierce, 1987). The transition from vegetative to reproductive growth is triggered by temperature. It is a cool season crop, therefore, it will produce flowers if grown in areas of mild winters. The optimum temperature for growth is 15-18 ^{o}C. Cabbage can tolerate freezing temperatures but is less tolerant to high temperatures. However, there are some varieties that have been bred for heat tolerance (Tindall, 1979; Hemy, 1984; Pierce, 1987).

Cabbage is a dicotyledonous crop that has fibrous and finely branched roots. It is widely cultivated in South Africa because it is easy to grow and performs well in a wide range of soil and climatic conditions (Hemy, 1984; Gilbert & Hadfield, 1992). Cabbage is a heavy nitrogen and potassium feeder (Tindall, 1979; Hemy, 1984; Gilbert & Hadfield, 1992) and therefore prefers deep, fertile soil with pH (KCl) 5.5 – 6.5 (Askew, 1999a). When soils are infertile, higher amounts of nitrogen and potassium should be applied compared to phosphorus.

Vegetables can be propagated either by direct seeding or by transplants. Direct seeded plants normally have more balanced root, stem, leaf, and fruit dry matter partitioning than transplants but in overall, transplants give higher and early yield than direct seeded plants (Leskovar & Cantliffe, 1993). Transplants can be produced in beds, containers, or in plug

trays. Transplants grown in plug trays have an advantage over those grown on beds as they undergo less root injury during transplanting. The other reason for using transplants is that, the crop tends to mature uniformly and in cabbage, this is important as at least 70 % of the total heads should be harvested at first cut in order for the farmer to reduce production costs (Askew, 1999b).

Cabbage is not rich in nutrients but based on the volume consumed, it contributes a lot to the daily nutrient requirements of an average adult (Ryder, 1979; Peirce, 1987). Cabbage is low in calories and protein content, but is a good source of many minerals, particularly potassium, and is relatively high in sulphur, calcium, vitamins A, C, B1 and B2 (Smith, 1995; Tiwari, Singh & Mal, 2003). Sulphur contributes to the cooking smell of cabbage (Smith, 1995). Green cabbage cultivars tend to have more vitamin A than red cultivars, and savoy types tend to have more vitamin A than smooth types. The National Science and Development Board (1980) found out that 100 g edible portion of cabbage contains 74 mg calcium, 28 mg phosphorus, 0.8 mg iron, 11 mg sodium and 212 mg potassium. According to Singh & Naik (1988), 100 g of edible portion of cabbage contains 1.8 g protein, 0.1 g fat, 4.6 g carbohydrate, 29 mg calcium, 0.8 mg iron and 14.1 mg sodium.

Other than nutritional value, cabbage is widely consumed and in the rural communities of South Africa and Botswana, it plays a major role as relish due to its longer shelf life (at room temperature) compared to other leafy vegetables. In South Africa, cabbage is the fourth most important vegetable after potato, tomato, and onion based on amount consumed. The amount of cabbage that was sold at the sixteen major fresh produce markets around South Africa during 2002 was 148 700 tonnes. Preliminary results from the Department of Agriculture revealed that production of cabbage and red cabbage at July-June 2002/03 was 178 000 tonnes (National Department of Agriculture, 2004).

However, the production (yield and quality) of cabbage is affected by the amount of nutrients that is provided to transplants during propagation and in the field. Soundy (1996) acknowledged that lettuce transplants grown with floatation irrigation system tend to have poor root system resulting in them not being able to pull out of cavity trays. Vegetable transplant production in cavity trays requires precise nutrient management (Biernbaum & Versluys, 1998) due to their limited cell volume and high transplant densities. Production of vigorous transplants is a prerequisite for improved vegetable yields (Cantliffe & Karchi,

1992). Improved nutrient regimes would contribute to efficient high quality transplant development (Tremblay & Senécal, 1988).

Irrigation methods also affects root and shoot growth of vegetables. Pepper transplant basal root elongation and root mass were improved by overhead irrigation compared to floatation irrigation. Floatation irrigation system enhanced water use efficiency, reduced shoot: root ratio of pepper (*Capsicum annuum* L.) transplants (Leskovar & Heineman, 1994). When using floatation irrigation system, fertilizer management is crucial since high rates of fertilizer especially nitrogen has been reported to increase shoot growth at the expense of root growth (Tremblay, Yelle & Gosselin, 1987; Tremblay & Senècal, 1988; Masson, Tremblay & Gosselin, 1991a). Nitrogen, phosphorus and potassium applied through floatation irrigation can minimise nutrient leaching from excess irrigation.

The role of nitrogen, phosphorus and potassium has been investigated in most vegetables. Semuli (2005) tested the effect of nitrogen nutrition on cabbage transplants and recommended that application of 90 mg·Ł$^{-1}$ N during cabbage transplant production. Soundy *et al.* (2005) propagated lettuce transplants at 0, 30, 60, 90 and 120 mg·ħ$^{-1}$N. The authors reported that increasing nitrogen, increased dry shoot mass and leaf nitrogen but decreased root: shoot ratio. Yield and head quality were optimised with 60 to 90 mg·Đ$^{-1}$ N.

Phosphorus applied to lettuce transplants improved relative growth rate and pulling success while net assimilation rate was reduced (Soundy *et al.*, 2001b). Melton & Dufault (1991a) reported that increasing phosphorus from 5 to 45 mg·ħ$^{-1}$ increased tomato (*Lycopersicon esculentum* Mill.) transplant height, stem diameter, leaf number, leaf area and fresh shoot mass but reduced dry shoot and root mass.

Potassium applied at 25, 75, or 225 mg·kg^{-1} three times per week did not affect transplant height, stem diameter, leaf number, leaf area, fresh shoot mass or dry shoot and root mass. However, the growing medium contained 103 mg·Ł$^{-1}$ K (Melton & Dufault, 1991a). Soundy *et al.* (2001a) reported that applying potassium at 0, 15, 30, 45 and 60 mg·Ł$^{-1}$ did not influence fresh and dry shoot mass, leaf area, relative growth rate, leaf mass ratio and root mass ratio regardless of the initial K concentration in the growing medium.

However, data is still lacking on the response of cabbage transplants to nitrogen, phosphorus and potassium nutrition. A study was conducted with the aim of producing an ideal transplant

that has a well developed root system and could easily pull out of cavity trays without breaking. In order to achieve this, experiments were conducted to determine a) the amount of nitrogen that can optimise cabbage transplant shoot and root development, b) the effect of pre-transplant nitrogen nutrition on yield and head quality of cabbage. c) the impact of phosphorus nutrition on shoot and root growth of cabbage transplants, d) the effect of potassium nutrition on cabbage transplant shoot and root development.

CHAPTER 1

LITERATURE REVIEW

1.1 Introduction

Crop species differ in their nutrient requirements depending on the stage of development and part of the plant that is of economic importance. Most leafy vegetables have a high requirement for nitrogen while large amounts of potassium are a requisite for good growth of crops of which the marketable part is the underground organ (e.g. sweet potato and Irish potato) (Preece & Read, 2005). Cabbage is a heavy feeder and, therefore, takes up high amounts of nutrients especially nitrogen and potassium from the soil (Hemy, 1984; Salunkhe, Desai & Bhat., 1987).

Nutrient management is important in transplant growth, as the quality of transplants in terms of shoot and root growth determines their performance in the field and, therefore, affect yield. High levels of nitrogen, lead to increased partitioning of dry matter to the shoots than the roots. Shoot growth is sustained by how well the roots have developed. Roots are important for absorption of water and nutrients from the growth medium (Mengel & Kirkby, 2001; Havlin *et al*., 2005). However, besides root development, nutrient uptake is also affected by various factors such as environmental conditions, irrigation method and frequency, temperature, amount and duration of light, type of fertilizer used and methods of application.

1.2 Nitrogen

1.2.1 The role of N in plants

Nitrogen is required by plants in large quantities and, therefore, its deficiency symptoms are common in crops (Tisdale *et al*., 1993; Mengel & Kirkby, 2001). Plants take up nitrogen as NH_4^+ and NO_3^- ions from organic matter, inorganic materials and fixation of free nitrogen by microorganisms (Pierce, 1987). Nitrogen plays a major role in protein formation and is a component of chlorophyll. Chlorophyll is required for light energy absorption by the process of photosynthesis. Therefore, adequate N supply will enhance the amount of chlorophyll as a result increase photosynthesis. A deficiency of N reduces the formation of chlorophyll, as a

result plants lose their green colour leading to reduction in the rate of photosynthesis. In addition, when dry matter accrual is decreased, plant growth declines. However, excess N in relation to P, K and S can delay crop maturity as it tends to extend the period of vegetative growth (Salisbury & Ross, 1992; Tisdale *et al*., 1993; Mengel & Kirkby, 2001).

1.2.2 Effect of N on vegetable transplant growth

There have been many reports on how N impacts on vegetable transplant growth. Dry shoot mass and leaf N content increased, while root: shoot ratios of lettuce (*Lactuca sativa* L.) 'South Bay' transplants was reduced as nitrogen increased from 0 to 120 mg·L^{-1} (Soundy *et al*., 2005). Other authors such as Dufault (1986) have reported that increasing N from 10 to 250 mg·L^{-1} increased shoot and root growth of muskmelon transplants. Increasing N also increased shoot: root ratio of muskmelon transplants indicating that dry matter partitioning was more to the shoots than to the roots.

Nitrogen was found to contribute more to differences in fresh and dry shoot mass, leaf area and root dry mass than phosphorus in bell pepper transplants. At 75 mg·L^{-1} or 225 mg·L^{-1} N, fresh and dry shoot mass, transplant height, leaf area and number increased linearly with increasing N. For quality transplants, P should be applied at 15 to 45 mg·L^{-1} and N at 25 to 75 mg·L^{-1} (Dufault & Schultheis, 1994).

Melton & Dufault (1991a) studied the effect of nitrogen, phosphorus and potassium on 'sunny' tomato (*Lycopersicon esculentum* Mill.) transplant growth and quality, and reported that N played a major role in transplant growth during the two years of the study. Increasing N from 25 to 225 mg·L^{-1}, increased fresh shoot mass, plant height, stem diameter, leaf number, leaf area, shoot and root mass and total chlorophyll. The optimum amount of N for tomato transplants was 225 mg·L^{-1}. In 1988, the tomato dry root mass increased as nitrogen increased from 25 to 225 mg·L^{-1} but in 1989 dry root mass increased with nitrogen from 25 to 75 mg·L^{-1} but declined as N increased to 225 mg·L^{-1}. Dufault (1986) previously obtained similar results on muskmelon as nitrogen was increased from 10 to 250 mg·L^{-1}.

Tremblay *et al*. (1987) propagated celery transplants at 200, 400 and 600 mg·Â$^{-1}$ N supplied from urea. Nitrogen increased leaf area, dry mass, leaf area ratio, dry matter content of transplant shoots as well as the root: shoot ratio.

Tremblay & Senécal (1988) conducted a study to determine the influence of nitrogen and potassium on transplant growth of broccoli (*Brassica oleracea* italica L.), celery (*Apium graveolens* L.), lettuce (*Lactuca sativa* L.), and pepper (*Capsicum annuum* L., cv. Maor). Application of high nitrogen levels enhanced shoot growth of all species but decreased root growth. Increasing N, increased leaf area and shoot mass of all species but reduced the percentage of shoot dry matter for all species except celery, which was not affected. The specific leaf area of broccoli and pepper was improved by increasing N but specific leaf area of celery was decreased while lettuce was not affected. Dry root mass of all species, except pepper, decreased as N increased. The root: shoot ratio of all species was reduced as N increased. This is an undesirable response since transplants with poor root systems tend to suffer more transplanting shock (Weston & Zandstra, 1986) when taken to the field. Similar findings of increased leaf area and dry shoot mass with reduced dry root mass and root: shoot ratio in celery transplants have been reported when nitrogen was increased (Tremblay *et al*., 1987; Tremblay & Gosselin, 1989).

Masson *et al*. (1991a) studied the effect of supplementary light of 100 µmol·s^{-1}·án^{-2} (PAR) combined with nitrogen at 100, 200, 300 and 400 mg·Ò$^{-1}$on growth of celery, lettuce, broccoli and tomato transplants. Supplementary light compared to natural light alone increased dry shoot mass of celery, lettuce, broccoli, and tomato transplants. It also increased percentage dry matter of broccoli and tomato, leaf area of lettuce and broccoli and root: shoot ratio of celery and broccoli. Nitrogen at 400 mg·Ł$^{-1}$ increased the dry shoot mass of celery, lettuce, broccoli and tomato transplants by 37%, 38%, 61% and 38%, respectively. High nitrogen increased shoot growth at the expense of root growth except for tomato where there was a 16% increase in root mass.

According to Aloni Pashkar & Karni.(1991) nitrogen levels below 100 mg•L^{-1} reduced pepper (*Capsicum annuum* L., cv. Maor) shoot growth and chlorophyll content. Nitrogen supply had a negative effect on root growth but at low N, root: shoot ratio was improved. The supply of nitrogen also influences carbohydrate utilisation (Havlin *et al*., 2005). Starch accumulation in leaves plus increased translocation and export of assimilates from the leaves to the roots are

changes that occur in plants that did not receive N, resulting in increased root: shoot ratio (Browwer, 1962; Ingestad, 1979). In addition, Aloni *et al*. (1991) reported accumulation of starch and sugars in leaves of pepper that did not receive N. At low N levels no substantial amounts of starch accumulated in the shoots, as sucrose exported to the roots was rapidly hydrolysed to support growth. Therefore nitrogen deficient seedlings were slower to recover even when sufficient N was applied after transplanting.

Increasing N from 50 to 150 mg·H^{-1} increased both shoot and root growth of asparagus transplants resulting in increased total dry mass. There was more dry matter partitioning to the shoots than the roots as nitrogen increased and more dry matter partitioning to the roots at low N. Nitrogen at 100 - 150 mg·L^{-1} produced suitable transplants for commercial production (Fisher & Benson, 1983; 1984).

Asparagus transplant production increased as nitrogen increased from 100 - 200 mg·L^{-1}. However, partitioning of dry matter into crowns was more than to the shoots. Root: shoot ratio was not affected by increasing nitrogen while the crown: shoot mass ratio (fresh and dry) decreased with increasing nitrogen (Adler, Dufault & Waters, 1984). In another study, Fisher & Benson (1983; 1984) reported that increasing N increased shoot growth in asparagus transplants.

Plants need minimal N during the first phase of growth i.e. 0 - 15 days after emergence because photosynthetic activity is low. However, during the second phase (15 – 31 days), nitrogen is needed in increased amounts due to increased photosynthetic activity. Widders (1989) proposed the use of low N during early stages of transplant growth and high N before transplanting while Garton & Widders (1990) suggested that giving low N during early stages and increasing N before transplanting could reduce stem elongation and enhance tissue N. This was later confirmed by Bassoccu & Nicola (1992) who reported that tomato transplant height can be controlled by varying N in the first phase of growth i.e. from the earliest true leaves to half of the nursery period.

In another study, Nicola & Bassoccu (2000) reported that N fertilization should be limited during the first phase (0 - 15 days) of transplant growth and increased during the second phase (16 - 31 days). They indicated that at the second phase, N utilisation by transplants will be

optimised, leading to transplants with sufficient root mass to overcome transplanting shock in the field. In addition, tissue N content will be enhanced (Widders, 1989) leading to rapid stand establishment and improved nutrient uptake from the soil. Reducing N during the first phase and increasing it in the second phase improved transplant quality in terms of dry matter accumulation and partitioning.

Vavrina *et al*. (1998) conducted a study to determine the impact of N fertilization on tomato transplant production and response to seasonal variation. Transplants were propagated at 0, 15, 30, 45, 60 and 75 mg·L^{-1} N. The authors reported that increasing N in both seasons increased stem diameter, leaf area, leaf number and dry root and shoot mass. However, stem diameter, leaf area and number, root: shoot ratio and the ratio of dry shoot mass: leaf area responded quadratically in the fall and this was attributed to high greenhouse temperature and light. Increasing transplant N fertilisation in spring increased total fruit yield and production of extra large fruits while the opposite trend occurred in the fall.

1.2.3 Influence of pretransplant N on crop performance in the field

Lettuce transplants propagated at 60 to 90 mg·L^{-1} N had optimum root systems to achieve the highest pulling success rate from cavity trays. In the field, these transplants resulted in optimum yields and head quality (Soundy *et al*., 2005).

Tremblay *et al*. (1987) tested N on celery transplants at 200, 400 and 600 mg·L^{-1} supplied from urea. Nitrogen applied at 400 mg·L^{-1} during transplant production significantly increased total marketable yield and side shoot mass of celery at harvest. However, Liptay, Nicholls & Skkemma (1992) reported that pepper transplant growth was influenced by nitrogen especially accumulation and distribution of dry matter between leaves, stems and roots. Moreover, total yield was not affected by nitrogen applied during transplant production. Early yield on the hand was enhanced by nitrogen. Nitrogen applied at 30 meq·L^{-1} gave the highest early yield and highest number of fruits compared to 4 meq·L^{-1}.

Nitrogen supplied during transplant production affects growth in the greenhouse and has an after-effect when transplants are taken to the field (Weston & Zandstra, 1986; Widders, 1989; Garton & Widders, 1990; Melton & Dufault, 1991b). Increasing N in the nutrient solution during transplant production lead to increased early shoot growth in the field and reduced days to maturity. Nitrogen applied to tomato transplants at 100 - 200 mg·L^{-1} in 1988 increased total yield, however, in 1989 total yield increased when nitrogen was applied at 50 to 100

mg·Â$^{-1}$. N applied over 100 mg·Â$^{-1}$ did not contribute to yield increase in tomato (Melton & Dufault, 1991b).

In cauliflower, Wurr, Cox & Fellows, (1986) reported that 'low' nutrient feed containing 52 mg·L^{-1} N increased cauliflower number of leaves and transplants had high percentage dry matter at transplanting. However, the difference was not observed in the field as final number of leaves formed, time to 50% curd maturity and curd marketable yield were not affected. However, Masson *et al.* (1991a; 1991b) reported heavier cauliflower heads when transplants were propagated at 400 mg·ß$^{-1}$ N than those given lower N rates.

When tomato transplants were grown under natural light combined with nitrogen at 8 to 15 mmol·ß$^{-1}$, high and early yield were obtained. However, total yield was not affected by transplant nutrition and maximum yield was recorded at 15 mmol·È$^{-1}$ N. There was also no interaction between N and light (Bassoccu & Nicola, 1995).

Weston & Zandstra (1986) conducted a study to determine the effect of root container size and location of production on growth and yield of tomato. Transplants grown in the state of Michigan were dark green at 4 weeks from seeding while those from Florida were chlorotic and had reduced leaf area. The practice of applying 30 mg·Ł$^{-1}$ N and withdrawing nutrients during the last week of production to harden transplants could have contributed to the small transplant size and reduced early yields of Florida plants.

Vavrina *et al*. (1998) reported that transplants grown in Florida during fall should be getting 20 – 30 mg·ß$^{-1}$ N and for spring transplant fertilisation should be 45 - 60 mg·ß$^{-1}$ N. This difference in nitrogen requirement was attributed to air temperature and light conditions. In Florida air temperatures and light are more like those of fall in the north and therefore if nitrogen is not adjusted, tomato yield in the north could be affected. However, small, slow growing transplants generally give total yields similar to large, vigorous plants.

Liptay & Nicholls (1993) reported that application of 5 - 350 mg·Ł$^{-1}$ N during tomato transplant production in the greenhouse increased transplant growth in a sigmoid pattern up to 200 mg·Ä$^{-1}$ N. Despite this, in the field, root growth increased exponentially as N applied during transplant production increased from 50 to 350 mg·L^{-1}. Moreover, for maximum survival, growth and early yield in the field N should be applied at 100 to 200 mg·Ł$^{-1}$ during transplant production. Establishment in the field was highly correlated with transplant stem strength.

Bar-Tal, Bar-Yosef & Kafkafi, (1990) reported that applying nitrogen at 1.0 to 5.0 mM combined with phosphorus at 0.1 mM to 1.0 mM lead to an increase in vegetative growth of pepper (*Capsicum annuum* L., cv. Maor) transplants and resulted in early fruit ripening. The nitrogen content in the plant tissue at transplanting significantly affected field performance. Transplants that had nitrogen content of < 3.1 $mg \cdot kg^{-1}$ in their plant tissue had retarded vegetative development during the first 2 to 4 weeks in the field. This also delayed fruit ripening resulting in lower yield in the first 18 weeks but total yield was not significantly decreased.

1.3 Phosphorus

1.3.1 The role of P in plants

Phosphorus is taken up by plants as $H_2PO_4^-$ and HPO_4^{2-} ions. Phosphorus play a role in plants during energy storage and transfer through adenosine diphosphate and adenosine triphosphate. Energy obtained during photosynthesis and carbohydrates are stored in phosphate compounds for use in vegetative and reproductive growth (Tisdale *et al*., 1993).

1.3.2 Effect of P on vegetable transplant growth

Soundy *et al*. (2001b) reported that nitrogen at 60 $mg \cdot L^{-1}$ combined with P enhanced both shoot and root growth in a study where lettuce transplants were grown at different P concentrations with floatation irrigation. Phosphorus application enhanced pulling success from 30% to ~ 90%. Tissue phosphorus content of 3.0 to 4.0 $g \cdot kg^{-1}$ in the lettuce transplants grown with floatation irrigation was necessary to optimize plant size, root growth and therefore increased crop yield. Phosphorus as low as 15 to 30 $mg \cdot L^{-1}$ coupled with irrigation frequency of 2 to 3 days during any season was enough to optimise lettuce transplant growth.

Tomato transplants were propagated at 10, 40 and 70 $mg \cdot L^{-1}$ P (Melton & Dufault, 1991b) and 5, 15 and 45 $mg \cdot L^{-1}$ P (Melton & Dufault, 1991a). Phosphorus at 45 $mg \cdot L^{-1}$ increased tomato fresh shoot mass, plant height, stem diameter, leaf area and leaf number compared to phosphorus at 5 to 15 $mg \cdot L^{-1}$ (Melton & Dufault, 1991a). Melton & Dufault (1991b) found that increasing phosphorus reduced the total chlorophyll of tomato transplants. Stem diameter, leaf number, leaf area, fresh shoot mass, dry shoot and root mass were higher at 40 $mg \cdot L^{-1}$ P compared to 10 $mg \cdot L^{-1}$ P with no further increases at 70 $mg \cdot L^{-1}$ P. Plant height increased as

phosphorus increased. However, the effect of phosphorus on transplant growth differed across the two years of study.

Phosphorus applied at 5 to 125 mg·Ü$^{-1}$ increased celery transplant diameter, height, dry shoot and root mass and leaf area but dry root mass and shoot number were not affected. Nitrogen interacted with phosphorus for all growth variables measured. Phosphorus at 5 to 125 mg·L^{-1} combined with at least 250 mg·Ł$^{-1}$ N significantly increased celery shoot number, diameter, height and dry shoot and root mass. However, dry shoot mass, leaf area and root: shoot mass (dry) ratios increased with phosphorus combined with at least 50 mg·Ţ$^{-1}$ N (Dufault, 1985). Moreover, Dufault (1986) reported that muskmelon transplant height, stem diameter, leaf area, dry shoot and root mass, leaf number and shoot: root ratio of 27 day old muskmelon transplants increased at low phosphorus rates (5 to 25 mg·Ī$^{-1}$) while phosphorus at 25 to 125 mg·L^{-1} reduced these growth variables. Again in celery, transplant shoot number, height and leaf area were highest at 2.5 mg·Ë$^{-1}$ P (Dufault, 1987). Contrary to this, Tremblay *et al*. (1987) reported no significant effect of phosphorus on celery transplants.

Asparagus transplants were propagated at 7.5, 15 and 22.5 mg·Ł$^{-1}$ P combined with 50, 100 and 150 mg·Ł$^{-1}$ N. Phosphorus increased dry shoot mass by increasing the mean dry mass and number of shoots. Low level of phosphorus increased dry matter partitioning to the roots. However, phosphorus combined with 50 mg·L^{-1} N had no effect on shoot growth and this could mean that lower N was limiting the impact of P. Moreover, at high N levels there was a positive response to increasing P. Phosphorus in plant tissue increased as phosphorus in the nutrient solution increased (Fisher & Benson, 1983).

Increasing phosphorus from 0.1 to 0.5 mM in combination with 1.0 to 5.0 mM N increased shoot and root dry mass of 27 day old pepper (*Capsicum annuum* L.) transplants but increasing to 1.0 mM had no further effect on transplant mass. Transplant development was retarded when leaf phosphorus content of plant tissue was < 3.1 mg·ß$^{-1}$ P on a dry matter basis (Bar-Tal *et al*., 1990). Increasing phosphorus from 5 to 45 mg·Ł$^{-1}$ increased fresh and dry shoot mass, leaf area and leaf count of pepper (*Capsicum annuum* L.) transplants when combined with 75 or 225 mg·L^{-1} N but not with 25 mg·L^{-1} N. However, phosphorus did not influence dry root mass (Dufault & Schultheis, 1994).

1.3.3 Influence of pretransplant P on crop performance in the field

Tomato transplants given 100 to 200 mg·L^{-1} N combined with P levels of less than 2 mg·L^{-1} could affect growth and survival but higher levels did not appear to have a negative impact on transplant performance (Liptay *et al*., 1992; Rideout and Overstreet, 2003; Rideout, 2004), therefore, excess P is wasteful.

Rideout (2004) reported that in tomato, delayed fertilization or delayed fertilization with brushing together with low P fertilisation resulted in little change in overall field performance of tomato transplants grown under low P fertilization and height control cultural practices. Also there was no yield response to low P applications, suggesting that P cannot negatively affect total yield or economic returns. Contrary to this, Melton & Dufault (1991b) reported that pretransplant conditioning of tomato transplants with phosphorus, contributed considerably to variation during the last harvest. At the third harvest, phosphorus at 40 mg·L^{-1} produced higher yields compared with 10 mg·L^{-1} but increasing phosphorus to 70 mg·L^{-1} did not increase yield further.

Bar-Tal *et al*. (1990) reported that applying phosphorus from 0.1 mM to 1.0 mM to pepper transplants lead to increased vegetative growth and as a result early fruit ripening. In the field, plant mass and fruit ripening increased when transplant dry mass at transplanting increased from 63 to 285 mg·Plant $^{-1}$. However, plant relative growth rate and total fruit yield were not affected by phosphorus nutrition in the nursery.

1.4 Potassium

1.4.1 The role of K in plants

Potassium is used as an activator in many enzymatic reactions in the plant. Potassium also controls guard cell turgor thereby controlling the opening and closing of the stomata and as a result the transpiration rate. Transpiration is the loss of moisture through the stomata (Tisdale *et al*., 1993; Hochmuth, 2001). Potassium is taken up as K^+.

1.4.2 Effect of K on vegetable transplant growth

Soundy *et al*. (2001a) reported that fresh and dry shoot mass, leaf area, root to shoot ratio, relative growth rate, leaf mass ratio and root mass ratio were not affected by applied potassium when lettuce transplants were propagated at 15, 30, 45 or 60 $mg \cdot L^{-1}$ K. However, growth parameters may not have been affected because the medium already contained 24 $mg \cdot E^{-1}$ available K.

Melton & Dufault (1991a) propagated tomato transplants with 25, 75, and 225 $mg \cdot kg^{-1}$ K applied three times per week. Potassium did not affect transplant height, stem diameter, leaf number, leaf area, total chlorophyll, fresh and dry shoot mass and dry root mass but the initial K in the medium was 103 $mg \cdot kg^{-1}$. The amount of potassium in the medium, therefore, could have been enough to meet the requirements for transplant growth.

Tremblay & Senécal (1988) conducted a study on lettuce, broccoli, pepper and celery transplants grown in Metromix growing medium and varying nitrogen and potassium levels applied daily. They found that potassium increased broccoli leaf area and dry shoot mass curvilinearly with a maximum at 200 $mg \cdot L^{-1}$ K. Celery leaf area increased linearly as potassium increased. The effect of potassium on growth characteristics, however, was a function of nitrogen status and differed among species, with celery being the least affected. Under high nitrogen, maximum percentage of shoot dry matter, root dry mass and root: shoot ratio (dry) and minimum specific leaf area of broccoli were obtained with an intermediate potassium rate. Increasing potassium under high nitrogen levels enhanced both lettuce leaf area and dry matter accumulation.

Dufault (1985) reported that potassium had no influence on growth of celery transplants, however, the medium contained 40 $mg \cdot kg^{-1}$ HCl extractable potassium. In contrast Dufault (1986) reported an increase in shoot growth of muskmelon transplant when propagated at 10 to 250 $mg \cdot K^{-1}$ potassium.

1.4.3 Influence of K on vegetable production and fruit quality

In tomato, potassium is not required for increasing yield but is required for uniform ripening and increasing acidity in the fruits. When NaCl is applied to partially replace KNO_3, this should be done with care as Na reduces uptake of potassium, resulting in the reduction of

potassium content in the fruits. Consequently, tomato quality and taste will be reduced (Adams & Ho, 1989; Adams, 1991) when potassium content of the fruits is reduced. However, Adams (1991) reported that inducing salinity by using major nutrient elements like NO_3^- - N, K and Ca compared to NaCl affected vegetative growth, reduced the size, dry mass and sugar content of tomato fruits at 12 $mS \cdot cm^{-1}$. The acidity of the fruit juices was higher with added major nutrients than with NaCl and this showed that increased acidity was not necessarily due to K but was due to reduction in water content of the fruits due to salinity.

1.5 Interaction of nitrogen, phosphorus, and potassium on transplant growth

The optimal concentration of nitrogen and phosphorus in solution for pepper transplant production was 5 mM and 0.5mM respectively, and tissue content of less than 25 $mg \cdot kg^{-1}$N and less than 3.1 $mg \cdot kg^{-1}$ P in the shoot reduced 'Maor' pepper transplant development two to four weeks after transplanting. It also delayed ripening, resulting in lower early yield but total yield was not affected. Plant mass and fruit ripening increased for plants that had a shoot mass increase of 63 to 285 mg per plant before transplanting. Optimal quality transplants had shoot mass of 285 mg and 48 mg root mass with a N, P and K content of 39, 5.5 and 67 $g \cdot kg^{-1}$, respectively (Bar-Tal *et al*., 1990).

High quality celery transplants could be obtained by applying N, P and K in the ratio 250:125:10 using a medium containing low N, P and K. Increasing P combined with low N lead to improved leaf area, dry shoot mass, root to shoot ratio but shoot number, diameter, height and shoot and root mass increased with highest P and N (Dufault, 1985).

Shoot growth of broccoli, celery, lettuce and pepper was increased while root growth was reduced at high N. Broccoli leaf area and shoot dry mass were highest at 200 $mg \cdot L^{-1}$ K while celery was not affected by K. For lettuce and pepper, percentage of shoot dry matter was increased with K and low N but was reduced with high N. Increasing K at high N improved lettuce leaf area and dry matter accumulation while in pepper it resulted in plants that were more succulent. Tremblay & Senécal, (1988) concluded that K should be applied at 350 $mg \cdot L^{-1}$ for lettuce, for broccoli at 200 $mg \cdot L^{-1}$ and 50 $mg \cdot L^{-1}$ for pepper while celery growth was not affected by K.

CHAPTER 2

GROWTH OF CABBAGE TRANSPLANTS AS AFFECTED BY PRETRANSPLANT NITROGEN NUTRITION AND SUBSEQUENT CROP PERFORMANCE IN THE FIELD

2.1 Introduction

Cabbage belongs a group of crops that are referred to as 'heavy feeders' and this is because it removes more nutrients in the soil than other crops like legumes (Peirce, 1987). Nitrogen is one of the macronutrients that is required by plants in large quantities and as a result, its deficiency is common in plants. Plants take up nitrogen in the form of NO_3^- and NH_4^+ ions (Tisdale *et al.*, 1993; Mengel & Kirkby, 2001). Nitrogen plays a major role in protein formation and is a component of chlorophyll. Chlorophyll is required for light energy absorption by the process of photosynthesis that generally leads to growth in plants. Therefore, deficiency of nitrogen could result in reduced growth and pale green leaves and stems (Tisdale *et al.*, 1993; Mengel & Kirkby, 2001).

Nitrogen has been reported to enhance shoot growth at the expense of root development in most vegetables (Tremblay *et al.*, 1987). Enhanced plant height, stem diameter, leaf area, leaf number, total chlorophyll and fresh and dry shoot mass have been attributed to nitrogen application (Melton & Dufault, 1991). The amount of nitrogen required by a transplant during propagation, is affected by method of irrigation used, crop, location and greenhouse factors which depend on the season (Vavrina *et al.*, 1998). Excess nitrogen encourages more vegetative growth and crops tend to take long to reach maturity. However, there has been reports of increased yield when transplants were propagated at high level of nitrogen (Masson *et al.*, 1991). This could be because starch accumulates in the roots of transplants that receive high nitrogen and therefore sustains the transplant before the roots can start absorbing nutrients from the soil while the opposite is true for transplants propagated at low nitrogen (Aloni *et al.*, 1991).

Nitrogen increases the utilisation of carbon dioxide for photosynthesis and as a result, causes an increase in production of assimilates for plant growth (Weerakoon, Olszyk & Moss, 1999).

A lot of research has been done on the impact of nitrogen nutrition on vegetable transplants. However, most of the work has been on tomato, lettuce, pepper, celery and little on cabbage transplants.

The objectives of the study were to:

(i) determine the amount of nitrogen that could optimise transplant shoot and root development

(ii) evaluate the impact of seasonal variation on nitrogen requirement of cabbage transplants

(iii) assess the impact of pretransplant nitrogen on yield and yield components of cabbage

2.2 MATERIALS AND METHODS

2.2.1 Greenhouse experiment

The experiment was conducted during autumn-winter and spring-summer seasons at University of Pretoria Experimental Farm (altitude: 26° 12'S, 28° 10'E). The transplant production experiment was carried out in a greenhouse. Seeds of cabbage 'Drumhead' were sown on 16 March 2005 and the experiment was terminated on 2 May 2005. The spring-summer experiment was initiated on 15 August 2005 and was terminated on 21 September 2005. The layout of the experiment was a randomized complete block design with four replications. Each replication had 100 plants of which 50 were for the transplant production experiment whereas the other 50 plants were for the field experiment. The transplant trays used were 200 inverted pyramid cavity trays that are commonly used in South Africa for transplant production. Cavity trays were filled with 'Cultera' growing medium (Figure 2.1 A) and three seeds were sown per cavity. Thereafter, the trays were covered with a thin layer of vermiculite (Figure 2.1B). The growth medium had no added fertilizer. Irrigation was done with a watering can until treatment application was initiated. Transplants were thinned to leave one plant per cavity.

Nitrogen levels were 0, 30, 60, 90 and 120 mg·Á$^{-1}$ supplied as NH_4NO_3. Potassium and phosphorus were each applied at 30 mg·Ł$^{-1}$ supplied from KCl and NaH_2PO_4, respectively. Other nutrients like Ca, Mg, S, B, Mn, Mo Cu and Zn were applied at half strength Hoagland's solution. Application of treatments started 5 - 6 days after emergence. The

nutrient solutions were prepared in 150 L containers and were replaced every week. Irrigation was done by floating cavity trays in nutrient solution until the medium reached field capacity (Figure 2.2), after which the cavity trays were removed and put back on benches. After each irrigation, the solutions were put back into the containers. During the autumn-winter experiment, irrigation was done every day because the temperatures were high and transplants wilted if irrigation was delayed. Greenhouse temperature was recorded from a wall mounted thermometer (Johnson controls, Penn F010). During the autumn-winter experiment, the minimum and maximum greenhouse day temperature was 20 to 35 ^{o}C respectively while during the spring-summer experiment the average minimum and maximum temperature was 15 to 33 ^{o}C, respectively.

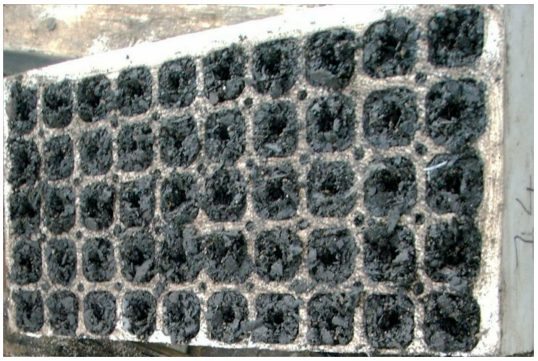
(A)  (B) 

Figure 2. 1 50-cavity trays after being filled with 'Cultera' growth medium (A) and covered with vermiculite (B)

Figure 2. 2 Transplants being floated in white rectangular plastic tubs during an irrigation event

2.2.1.1 Sampling

Sampling for the autumn-summer experiment started on 12 April 2005 and continued weekly until 2 May 2005. The spring-summer greenhouse experiment was first sampled on 8 September 2005 and continued weekly until 21 September 2005. Measurements of plant height, number of expanded true leaves (leaves with a clearly visible petiole), leaf area (using leaf area meter, model Ll-3100, Ll-COR, Lincoln, Nebraska), root and shoot (fresh and dry) mass were recorded from five transplants sampled every week from each replication. Shoot and root dry mass were obtained by drying samples at 65 °C for 48 hours. After being removed from cavity trays, transplants were washed with tap water until all the growing had been removed and then divided into shoot and roots before measurements were taken. The experiments were terminated when at least one treatment across all replications could easily pull out of tray cells. At termination of the experiments, five plants were pulled from each replicate and their pulling success recorded. Pulling success (%) was the number of plants that could be removed from the cells without breakage. The remaining plants were harvested and shoots dried in the oven for 48 hours at 65 ^{o}C before being submitted to the University of Pretoria Soil Science Laboratory for tissue analysis of total N.

Growth parameters calculated were (Hunt, 1982; Gardner, Pearce & Mitchell, 1990; Nicola & Cantliffe, 1996):

- Root to shoot ratio (RSR = dry root mass ÷ dry shoot mass)
- Relative growth rate (RGR = [ln(final total dry mass – ln(initial total dry mass) ÷ (final time – initial time)])
- Net assimilation rate (NAR = (final total dry mass – initial total dry mass) ÷ (final time – initial time) × [(ln(final leaf area) – ln(initial leaf area)])
- Specific leaf area (SLA = leaf area ÷ dry shoot mass)
- Leaf area ratio (LAR = leaf area ÷ total dry mass)
- Root mass ratio (RMR = dry root mass ÷ total dry mass)
- Pulling Success (PLS = Percentage of transplants that could easily pull out of trays without breaking)

2.2.2 Field experiment

Transplants that were raised during the greenhouse experiment were transplanted into the field at termination of the greenhouse experiment. The soil was analysed before transplanting. Nitrogen, phosphorus and potassium were applied at 200, 80, 180 kg·ha^{-1} respectively. Potassium and phosphorus were applied as basal dressing while nitrogen was applied as topdressing. Nitrogen application was split into three equal proportions that were applied at one week, five weeks, and eight weeks after transplanting. The experimental layout was a randomized complete block design with four replications. Transplanting was done on 16 May 2006. At termination of the greenhouse experiment, the plants from the autumn-winter experiment were not immediately transplanted into the field due to a delay in field preparation. Plants from the spring–summer experiment were transplanted on 27 September 2005. All plants received the same amount of fertilizers and all other agronomic practices during the two experiments were the same. Plants were spaced at 0.5 m within rows and 0.5 m between rows. The plot area was 3.0 m by 3.0 m and the effective plot area was 2.5 m by 2.5 m. The field experiments were terminated when at least one treatment had reached maturity which was 114 and 111 days after transplanting for autumn–winter and spring summer experiments, respectively.

2.2.2.1 Harvesting

At harvest, total mass and number of marketable heads (with and without wrapper leaves), head diameter, head height, core diameter and core height were recorded. The diameter and height of the head and the core were obtained by cutting the head longitudinally (Figure 2.3) before taking the measurements. Head mass was recorded as untrimmed head mass and trimmed head mass. Untrimmed head is one with wrapper leaves while trimmed is a head without wrapper leaves. In South Africa, the hawker market prefers the head with some wrapper leaves while chain stores require the head without wrapper leaves (Askew, 1999b). Wrapper leaves were sampled, dried and analysed for total nitrogen.

Figure 2. 3 Cabbage heads after being cut horizontally to enable recording of head quality parameters

Data was subjected to analysis of variance using the Statistical Analysis System (SAS Institute Inc., 2003) software. Treatment sums of squares were partitioned into linear and quadratic polynomial contrasts.

2.3 RESULTS AND DISCUSSION

2.3.1 Autumn -winter season experiment

2.3.1.1 Shoot development

Plant height

Nitrogen caused a linear increase in plant height at 21 and 28 days after sowing. At 35 and 42 days after sowing, plant height increased quadratically with an increase in nitrogen (Figure 2.4). At 21 days after sowing, plant height was 16, 23, 37, 46 and 46 mm for transplants that were propagated with 0, 30, 60, 90 and 120 mg·Ł$^{-1}$ N, respectively. As nitrogen increased from 0 to 120 mg·L^{-1}, plant height of transplants sampled 28, 35 and 42 days after sowing also increased from 27 to 112 mm, 33 to 153 mm and 35 to 157 mm, respectively. In pepper (Dufault & Schultheis, 1994) and tomato (Melton & Dufault, 1991a) increasing nitrogen increased plant height and Tremblay *et al*. (1987) reported an increase in transplant growth in general in response to application of nitrogen.

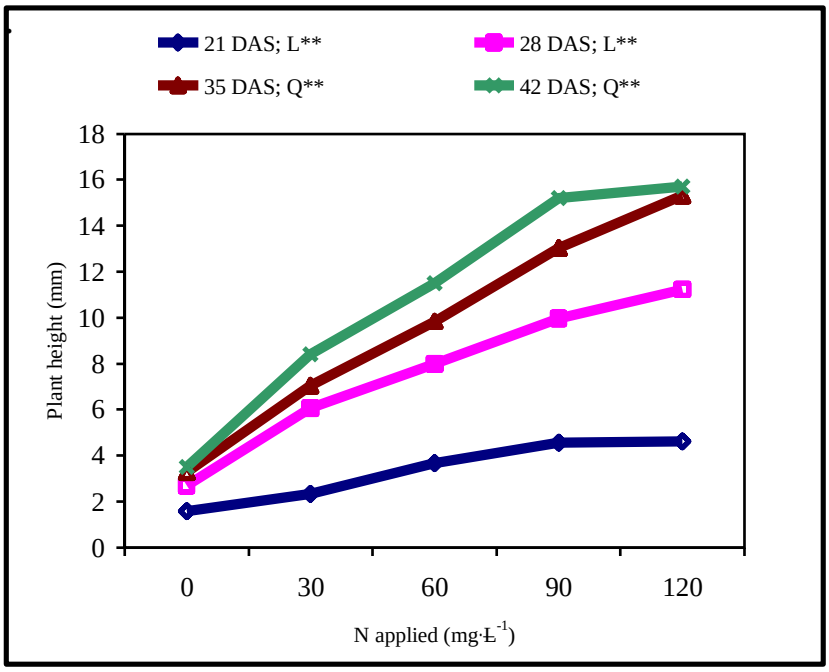


Figure 2. 4 Plant height of cabbage transplants as affected by nitrogen nutrition [Linear (L) or quadratic (Q) effects significant at P=0.05 (*), 0.01 (**) or nonsignificant (NS)]

Leaf number

At 21, 28, 35, and 42 days after sowing, the number of leaves increased in a quadratic fashion as nitrogen increased. This showed that increasing level of nitrogen during transplant growth increased leaf development (Table 2.1). Transplants that did not receive nitrogen during propagation were stunted, spindly, with small and pale reddish green leaves (Figure 2.5). According to Waring *et al* (1985), when nitrogen is a limiting nutrient, leaf development is reduced. In tomato, Melton & Dufault (1991a) reported an increase in transplant leaf number as nitrogen increased.

Figure 2. 5 Shoots and roots of cabbage transplants at 42 days after sowing

Leaf area

Nitrogen increased the leaf area of cabbage transplants irrespective of sampling date(Table 2.1). When transplants are not given nitrogen during production, leaf size is reduces and they become chlorotic and necrotic (Huang *et al*., (2002). There was minimal increase in leaf area of transplants that did not receive N across sampling dates. At 21 days after sowing, the leaf area was 1.6, 6.0, 10.3, 16.9, and 20.84 cm^2 for transplants that were propagated at 0, 30, 60, 90 and 120 $mg \cdot B^{-1}$ N, respectively. Increasing nitrogen during 21 and 28 days after sowing, increased leaf area linearly as nitrogen was increased from 0 to 120 $mg \cdot Ł^{-1}$. However, at 35 and 42 days after sowing, leaf area increased in a quadratic fashion as nitrogen increased from 0 to 120 $mg \cdot L^{-1}$ (Figure 2.6). Application of nitrogen caused an increase in leaf area during transplant production of broccoli, cauliflower, lettuce and celery (Tremblay *et al*., 1987; Tremblay & Senécal, 1988; Dufault, 1987). However, Dufault (1987) reported that even though nitrogen application increased the leaf area and other shoot related parameters, nitrogen above 10 $g \cdot kg^{-1}$ of growing medium caused a decrease in shoot parameters. Transplants that received 0 $mg \cdot Đ^{-1}$ had small dull leaves while those that were propagated at 90 and 120 $mg \cdot Ł^{-1}$ had dark green, big leaves with greater leaf area showing that nitrogen played a mayor role in leaf expansion.

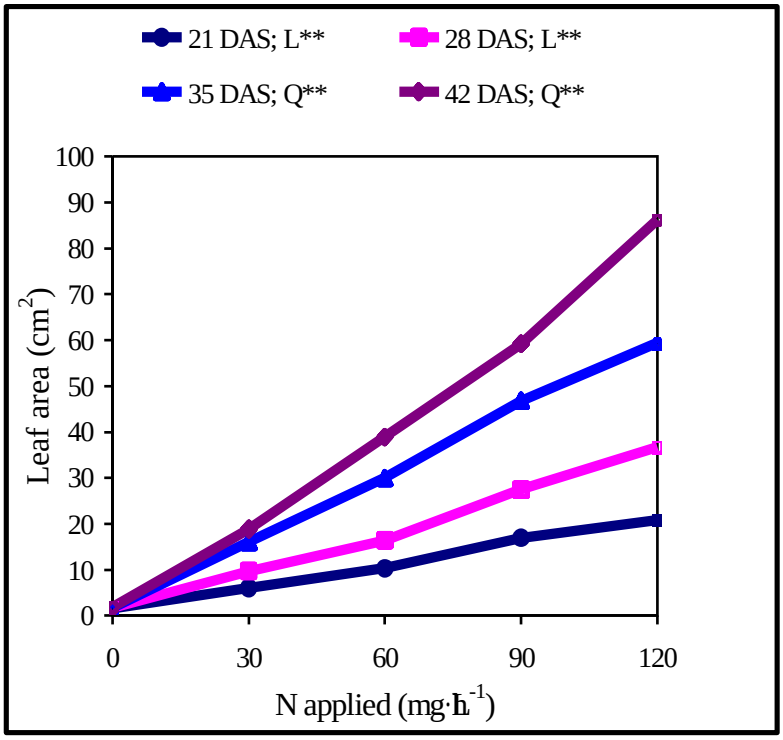


Figure 2. 6 Leaf area of cabbage transplants as affected by nitrogen nutrition [Linear (L) or quadratic (Q) effects significant at P=p0.05 (*), 0.01 (**) or nonsignificant (NS)]

Table 2. 1 Shoot characteristics of cabbage transplants in response to nitrogen nutrition, March/May 2005

Nitrogen applied ($mg \cdot L^{-1}$)	Fresh shoot mass (mg)	Dry shoot mass (mg)	Leaf number	Leaf area (cm^2)	Leaf nitrogen ($g \cdot kg^{-1}$)
21 days after sowing (1st sampling)					
0	9.2	8.7	1.0	1.62	
30	124.5	32.7	2.2	5.99	
60	326.5	51.7	2.0	10.27	
90	493.9	65.5	2.3	16.93	
120	644.0	70.8	2.7	20.84	
Response	Q**	Q**	Q**	L**	
28 days after sowing (2nd sampling)					
0	20.7	11.2	1.3	1.74	
30	338.5	58.9	2.6	9.65	
60	647.5	89.2	3.7	16.38	
90	982.8	112.9	4.0	27.46	
120	1367.0	140.6	4.2	36.74	
Response	Q**	Q**	Q**	L**	
35 days after sowing (3rd sampling)					
0	34.5	14.0	1.7	1.78	
30	697.0	89.5	3.9	16.11	
60	1253.7	136.0	4.6	29.95	
90	1966.4	191.0	4.8	46.83	
120	2523.7	198.0	5.4	59.41	
Response	Q**	Q**	Q**	Q**	
42 days after sowing (4th sampling)					
0	38.5	15.2	1.8	1.83	10.3
30	858.6	124.5	4.0	18.82	16.1
60	1841.9	202.5	4.8	38.90	17.4
90	2806.5	283.5	5.4	59.23	19.5
120	3899.5	355.0	5.7	86.24	28.3
Response	Q**	Q**	Q**	Q**	L**

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

Fresh and dry shoot mass

Increasing nitrogen from 0 to 120 $mg \cdot L^{-1}$, increased fresh shoot mass from 9 to 644 mg, 21 to 1367 mg, 35 to 2524 mg in transplants sampled at 21, 28 and 35 days after sowing, respectively (Table 2.1). In addition, transplants that were propagated with high N (90 and

120 mg·Â$^{-1}$) were succulent compared to transplant that received low N (30 and 60 mg·Â$^{-1}$) across sampling dates. Regardless of date of sampling, the greatest fresh shoot mass was recorded from transplants that were propagated at 120 mg·Ł$^{-1}$ N. The level of nitrogen supply affects carbohydrates utilisation. Under favourable and adequate nitrogen, less carbohydrates are deposited in the vegetative cells (Havlin *et al*., 2005). As a result more protoplasm is formed and because the protoplasm is highly hydrated, the plants become succulent.

Nitrogen application increased dry shoot mass in a quadratic fashion irrespective of sampling date. At 21 days after sowing, dry shoot mass was 9, 33, 52, 66, and 71 mg for transplants that were propagated at 0, 30, 60, 90 and 120 mg·Ł$^{-1}$ N, respectively (Table 2.1). As nitrogen increased from 0 to 120 mg·Ł$^{-1}$, dry shoot mass increased from 11 to 141 mg, 14 to 198 mg and 15 to 355 mg for transplants that were sampled 28, 35 and 42 days after sowing, respectively.

Leaf nitrogen content

The nitrogen content in the transplant tissues increased as the concentration of nitrogen in the nutrient solution increased. Transplants that had tissue nitrogen content of <16 g·kg^{-1} on a dry matter basis were spindly thin and stunted with small leaves. Tissue nitrogen was significantly affected by amount of nitrogen applied during transplant production. Leaf nitrogen was 10.3, 16, 17, 20 and 28 g·kg^{-1} for transplants that were propagated with 0, 30, 60, 90 and 120 mg·Ł$^{-1}$ N, respectively. However, the nitrogen concentration obtained was generally low compared to what was reported by Soundy *et al*. (2005) and Semuli (2005) in lettuce and cabbage transplants, respectively.

2.3.1.2 Root development and pulling success

Fresh and dry root mass

As nitrogen increased, fresh root mass increased in a quadratic fashion regardless of sampling date (Table 2.2). At 28 days after sowing, fresh root mass was 8, 47, 73, 94 and 130 mg for transplants that were propagated with 0, 30, 60, 90 and 120 mg·Ł$^{-1}$ N, respectively. At 28, 35 and 42 days after sowing, fresh root mass increased from 13 to 218 mg, 21 to 331 mg and 39.0 to 491.4 mg for transplants that were propagated with 0 to 120 mg·Ł$^{-1}$ N, respectively. At 35 days after sowing, dry root mass of transplants that received 90 and 120 mg·Ł$^{-1}$ N had increased by about 30 % and it had almost doubled for transplants that received 60 mg·L^{-1} N.

At 42 days after sowing, the greatest dry root mass was recorded from transplants that were propagated with 90 mg·L^{-1} N and then decreased as nitrogen increased to 120 mg·L^{-1}. Aloni *et al*. (1991) reported that increasing nitrogen reduced pepper root growth. Tremblay & Senécal (1988) obtained similar results for broccoli, celery and lettuce but reported that dry root mass of pepper was not reduced by application of high levels of nitrogen.

Root: shoot ratio

Regardless of sampling date, nitrogen significantly decreased root: shoot ratio of cabbage transplants(Table 2.2). Transplants that did not receive nitrogen had the highest root: shoot ratio across the sampling dates compared to transplants that received nitrogen. At 21, 28 and 35 days after sowing, root: shoot ratio decreased from 0.488 to 0.185, 0.697 to 0.202 and 0.747 to 0.140, respectively as nitrogen increased from 0 to 120 mg·‰$^{-1}$. The lowest root: shoot ratio was obtained from transplants that were propagated with 120 mg·È$^{-1}$. Aloni *et al*. (1991) reported similar results in a study in which the effect of nitrogen nutrition on growth and carbohydrate partitioning of pepper (*Capsicum annum* L., cv. Maor) was tested. The authors found that root: shoot ratio of pepper transplants was decreased by application of nitrogen. The results obtained also concur with the work of Vavrina *et al*. (1998) who reported a linear decrease in root: shoot ratio of tomato transplants propagated in spring. In fall, the root: shoot ratio decreased in a quadratic fashion when nitrogen increased from 15 to 75 mg·Ł$^{-1}$. Soundy *et al*. (2005) reported a decrease in root: shoot ratio when lettuce transplants were propagated at 0, 30, 60, 90, and 120 mg·ħ$^{-1}$ N.

Root mass ratio

Nitrogen application decreased root mass ratio of cabbage transplants in a quadratic fashion over the three sampling dates. As nitrogen increased from 0 to 120 mg·L^{-1}, root mass ratio decreased from 0.33 to 0.16, 0.41 to 0.17 and 0.43 to 0.12 at 21, 28 and 35 days after sowing (Table 2.2), respectively. Transplants that did not receive nitrogen had the greatest root mass ratio across the sampling dates.

Table 2. 2 Root characteristics of cabbage transplants in response to nitrogen nutrition, March/May 2005

Nitrogen applied ($mg \cdot L^{-1}$)	Fresh root mass (mg)	Dry root mass (mg)	Root: shoot ratio	Leaf mass ratio	Root mass ratio	Pulling success (%)
21 days after sowing (1st sampling)						
0	7.5	4.2	0.488	0.67	0.33	
30	46.5	12.8	0.392	0.72	0.28	
60	72.5	11.1	0.223	0.82	0.18	
90	94.0	13.0	0.199	0.83	0.17	
120	129.5	13.1	0.185	0.84	0.16	
Response	Q**	Q**	L**	Q**	Q**	
28 days after sowing (2nd sampling)						
0	13.2	7.8	0.697	0.59	0.41	
30	67.5	22.7	0.386	0.72	0.28	
60	128.5	25.6	0.288	0.78	0.22	
90	176.5	23.8	0.212	0.83	0.17	
120	217.9	28.2	0.202	0.83	0.17	
Response	Q**	Q**	Q**	Q**	Q**	
35 days after sowing (3rd sampling)						
0	21.0	10.5	0.747	0.57	0.43	
30	221.5	29.8	0.334	0.75	0.25	
60	253.6	33.0	0.243	0.80	0.20	
90	312.5	30.2	0.158	0.86	0.14	
120	331.4	27.7	0.140	0.88	0.12	
Response	Q**	Q**	Q**	Q**	Q**	Q**
42 days after sowing (4th sampling)						
0	39.0	12.5	0.820	0.55	0.45	10
30	361.0	52.2	0.419	0.70	0.30	30
60	396.9	54.0	0.267	0.79	0.21	70
90	457.6	57.5	0.203	0.83	0.17	90
120	491.4	54.0	0.152	0.87	0.13	95
Response	Q**	Q**	Q**	Q**	Q**	Q*

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

Leaf mass ratio

There was a quadratic increase in leaf mass ratio as applied nitrogen increased regardless of sampling date. At 21, 28 and 35 days after sowing, leaf mass ratio increased from 0.67 to 0.84, 0.59 to 0.83, and 0.57 to 0.88 (Table 2.2), respectively as nitrogen increased from 0 to 120 $mg \cdot L^{-1}$. The greatest leaf mass ratio was obtained from transplants that were propagated

at 120 mg·Â$^{-1}$ N across sampling dates. This showed that as nitrogen increased, there was an increased partitioning of dry matter to the shoots than to the roots.

Pulling success

Pulling success increased as the level of nitrogen increased (Table 2.2). Transplants that did not receive nitrogen could not easily pull out of cavity trays showing that if transplants are not given nitrogen they have poor root development. If transplants cannot pull out of cavity trays, the roots will be injured during transplanting and therefore transplants could take longer to establish in the field. This also indicates that transplants that do not receive N during transplant propagation will take longer before they are ready for transplanting.

2.3.1.3 Growth parameters

Specific leaf area

There was a linear increase in specific leaf area in response to N application at 28, 35 and 42 days after sowing (Table 2.3). Regardless of sampling date, the highest specific leaf area was recorded from transplants that received 120 mg·Ð$^{-1}$ N with the lowest specific leaf area recorded from transplants that were propagated at 0 mg·¥$^{-1}$ N. At 21, 28, 35 and 42 days after sowing, specific leaf area increased from 0.187 to 0.296 cm^{-2}·ámg^{-1}, 0.155 to 0.261 cm^{-2}·ámg^{-1}, 0.127 to 0.300 cm^{-2}·ámg^{-1} and 0.120 to 0.243 cm^{-2}·ámg^{-1} as nitrogen increased from 0 to 120 mg·Ã$^{-1}$, respectively. Vavrina *et al*. (1998) reported a linear increase in specific leaf area of tomato transplants propagated during spring season.

Leaf area ratio

Leaf area ratio is the ratio of leaf area to dry mass i.e. the measure of the proportion of the plant that is engaged in photosynthesis. It is also an expression of the ratio between the area of leaf lamina or photosynthesising tissue and total respiring plant tissue (Noggle & Fritz, 1983; Gardner *et. al*., 1990). Application of nitrogen to cabbage transplants lead to an increase in leaf area ratio. At 21, 28, 35 and 42 days after sowing, increasing nitrogen from to 0 to 120 mg·Û$^{-1}$ increased leaf area ratio from 0.125 to 0.250 cm^{2}·ámg^{-1}, 0.091 to 0.218 cm^{2}·ámg^{-1}, 0.073 to 0.263 cm^{2}·ámg^{-1} and 0.066 to 0.211 cm^{2}·ámg^{-1} (Table 2.3), respectively.

Net assimilation rate

Net assimilation rate is the rate of increase in dry mass per unit time per unit of leaf surface. It is also a measure of the amount of photosynthetic product going into plant material or net gain of assimilates per unit of leaf area and time (Noggle & Fritz, 1983; Gardner *et. al*., 1990; Mengel & Kirkby, 2001). Increases in nitrogen lead to a linear increase in net assimilation rate at 28 days after sowing. However, the response changed to quadratic at 35 and 42 days after sowing (Table 2.3). As nitrogen increased from 0 to 120 mg·L^{-1}, net assimilation rate increased from 0.383 to 0.702 mg·cm^{-2}·wk^{-1} respectively at 28 days after sowing. At 35 days after sowing, net assimilation rate was 0.250, 0.379, 0.386, 0.481 and 0.290 mg·cm^{-2}·wk^{-1} for transplants that were propagated at 0, 30, 60, 90 and 120 mg·L^{-1} N, respectively. At the same sampling date, the greatest net assimilation rate was obtained from transplants that received 90 mg·L^{-1} N. Net assimilation rate increased in a quadratic fashion over time indicating that as the plant grew older, the rate of leaf expansion was not directly proportional to dry matter accumulated.

Table 2. 3 Growth parameters of cabbage transplants in response to nitrogen nutrition, March/May 2005

Nitrogen applied (mg·L^{-1})	Specific leaf area (cm^2·mg^{-1})	Leaf area ratio (cm^2·mg^{-1})	Net assimilation rate (mg·cm^{-2}·wk^{-1})	Relative growth rate (mg·mg^{-1}·wk^{-1})
	21 days after sowing (1st sampling)			
0	0.187	0.125		
30	0.183	0.131		
60	0.205	0.167		
90	0.259	0.216		
120	0.296	0.250		
Response	Q**	Q**		
	28 days after sowing (2nd sampling)			
0	0.155	0.091	0.383	3.60
30	0.164	0.118	0.585	4.73
60	0.184	0.143	0.614	4.00
90	0.244	0.201	0.556	2.69
120	0.261	0.218	0.702	3.03
Response	L**	L**	L*	Q* *
	35 days after sowing (3rd sampling)			
0	0.127	0.073	0.250	3.07
30	0.180	0.135	0.379	3.01
60	0.220	0.177	0.386	2.41
90	0.245	0.211	0.481	2.33
120	0.300	0.263	0.290	1.21
Response	L**	L**	Q*	Q**
	42 days after sowing (4th sampling)			
0	0.120	0.066	0.127	1.83
30	0.151	0.106	0.393	3.29
60	0.192	0.152	0.417	2.56
90	0.209	0.174	0.433	2.28
120	0.243	0.211	0.594	2.55
Response	L**	L**	Q**	Q**

Linear (L) or quadratic (Q) effects significant at P=À.05 (*), 0.01 (**) or nonsignificant (NS)

Relative growth rate

Relative growth rate is the size increase of plant per unit interval of time (Noggle & Fritz, 1983). It can also be expressed as dry mass increase over time in relation to the initial mass (Gardner *et. al.*, 1990). Relative growth rate increased in a quadratic fashion at 28, 35 and 42 days after sowing. At 28 days after sowing, relative growth rate was 3.60, 4.73, 4.00, 2.69 and 3.03 mg·mg^{-1}·wk^{-1} for transplants that were propagated at 0, 30, 60, 90 and 120 mg·L^{-1} N,

respectively. The greatest relative growth rate at 28 and 42 days after sowing was achieved at 30 mg·L^{-1} N (Table 2.3).

2.3.1.4 Cabbage head yield and quality

Untrimmed cabbage head yield and head mass

Untrimmed cabbage heads were heads with wrapper leaves (Figure 2.7). Pretransplant nitrogen increased untrimmed head yield and head mass in a quadratic fashion (Table 2.4) even though the plants were given the same amount of fertilizer and subjected to the same agronomic practices in the field. The highest untrimmed head yield and head mass was obtained with pretransplant nitrogen of 60 to 90 mg·L^{-1}.

Figure 2. 7 Cabbage head with wrapper leaves

Trimmed cabbage head yield and head mass

Trimmed head yield increased as nitrogen applied during transplant production increased and reached a maximum at 90 mg·L^{-1} N. Transplants that did not receive nitrogen during transplant production gave the lowest yield compared to transplants that received nitrogen during transplant production (Table 2.4). This showed that nitrogen applied during transplant production contributed to performance of cabbage in the field. Soundy *et al*. (2005) reported that nitrogen applied during transplant production affected yield and head quality of lettuce. Optimum lettuce head yield and quality were achieved with nitrogen level of 60 to 90 mg·L^{-1}.

Nitrogen applied during transplant production affected head diameter and head height (Table 2.4). Head diameter increased as nitrogen applied during transplant production increased and reached maximum at nitrogen level of 90 mg·L^{-1}. Head diameter was 98, 200, 216, 223 and 218 mm for plants that received pretransplant N of 0, 30, 60, 90 and 120 mg·N^{-1}, respectively. Head diameter and head height gives an idea of the head shape. If the head diameter is greater than the head height, the head tend to be flat while a smaller head diameter relative to head height results in a spherical shape. Therefore, the cabbages in this experiment were relatively flat.

Table 2. 4 Cabbage head yield and leaf nitrogen as influenced by pretransplant nitrogen, September 2005

Nitrogen applied (mg·L^{-1})	Untrimmed head		Trimmed head			
	mass (kg)	yield (t·ha^{-1})	mass (kg)	yield (t·ha^{-1})	diameter (mm)	height (mm)
0	1.69	67.6	0.74	29.6	98	130
30	2.42	96.8	1.17	46.7	200	128
60	2.59	103.6	1.42	56.8	216	129
90	2.58	103.2	1.62	64.6	223	149
120	2.50	100.0	1.54	61.6	218	130
Response	Q**	Q**	Q**	Q**	Q**	Q**

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

Relationship between dry root mass and trimmed head yield

Dry root mass had a positive linear relationship with yield (Figure 2.8). Roots are important for anchoring the plant and absorbing nutrients from the soil. A transplant with lower root mass could take long to establish because the roots will have to spread into the soil in order to increase surface area for nutrient absorption and therefore cause low yields. However, for a transplant with greater root mass, the roots will immediately start taking up nutrients for transplant growth resulting in higher yields.

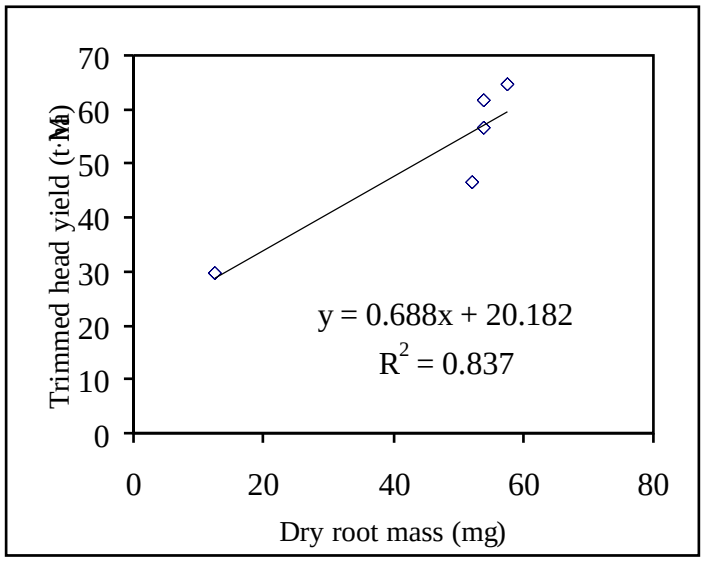


Figure 2. 8 Relationship between dry root mass and trimmed cabbage head yield

Relationship between pulling success and trimmed head yield

There was a positive linear relationship between pulling success and yield (Figure 2.9). This means that when less number of transplants could pull out of cavity trays without breaking, the transplants would give low yield. The reason for this could be that if transplants cannot easily pull out of cavity trays, the roots could be damaged during transplanting and therefore would take long to establish in the field. Moreover, if more transplants could pull out of cavity trays without breaking, this could lead to faster establishment and therefore absorption of nutrients from the soil, leading to higher a yield.

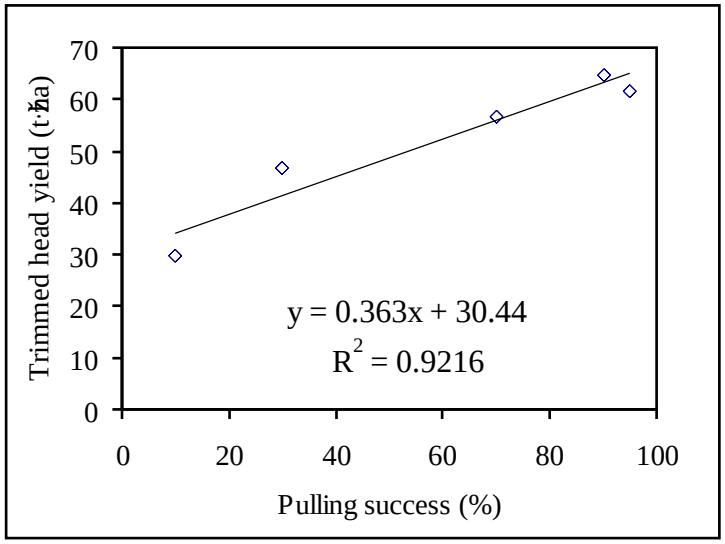


Figure 2. 9 Relationship between pulling success and trimmed cabbage head yield

Cabbage head quality

Core diameter and core height were not affected by nitrogen applied during transplant production. This could suggests that pretransplant nitrogen did not enhance head flowering. In cabbage flowering occurs when the head core extends out of the head resulting in the head cracking. Pretransplant nitrogen improved leaf nitrogen of cabbage heads. Leaf nitrogen content responded quadratically as pretransplant nitrogen increased. The highest leaf nitrogen was 32 g·kg^{-1} for cabbage heads propagated at 60 mg·L^{-1} pretransplant nitrogen. According to Askew (1999b), adequate ranges for nitrogen in the cabbage head is 3.3 to 4.8 % (33 to 48 g·kg^{-1}).

Table 2. 5 Cabbage head quality as influenced by pretransplant nitrogen nutrition, Sept 2005

Nitrogen applied (mg·L^{-1})	Core diameter (cm)	Core height (cm)	Leaf Nitrogen (g·kg^{-1})
0	44.0	7.28	23.2
30	46.9	7.72	22.3
60	46.0	7.73	32.0
90	45.4	7.64	23.3
120	45.4	8.04	25.3
Response	NS	NS	Q**

Linear (L) or quadratic (Q) effects significant at P='0.05 (*), 0.01 (**) or nonsignificant (NS)

2.3.1.5 CONCLUSIONS

Nitrogen increased plant height, leaf number, leaf area, fresh and dry shoot mass, leaf nitrogen, fresh and dry root mass, pulling success, specific leaf area, leaf area ratio, net assimilation rate and leaf mass ratio quadratically. However, as nitrogen increased root: shoot ratio, relative growth rate and root mass ratio decreased in a quadratic fashion. Nitrogen applied during transplant production at 90 mg·L^{-1} gave optimum transplant shoot and root growth. A quality transplant had plant height, leaf area, dry root mass, dry shoot mass, root: shoot ratio, leaf mass ratio, root mass ratio and pulling success of 152 mm, 59 cm^2, 58 mg, 284 mg, 0.20, 0.83, 0.17 and 90 %, respectively.

Pretransplant nitrogen improved untrimmed and trimmed cabbage head yield, head diameter and head height. Transplants propagated with 90 mg·L^{-1} N gave the highest trimmed cabbage yield. Therefore, pretransplant nitrogen is important for subsequent crop performance in the field. In South Africa, transplant growers need to use at least 90 mg·L^{-1} N during autumn/winter in order to achieve quality transplants for improved cabbage head yield.

2.3.1.6 SUMMARY

A greenhouse experiment was conducted to determine the amount of nitrogen that could optimise transplant shoot and root development. Transplants were subsequently planted in the field to assess the impact of nitrogen applied during transplant production on cabbage head yield. Cabbage transplants were propagated with 0, 30, 60, 90 and 120 mg·Ð$^{-1}$ N. Irrigation during the greenhouse experiment was done by floating cavity trays in a nutrient solution until the growth medium reached field capacity. Cavity trays were then removed from the solution and put back on benches. Sampling was initiated at 21 days after sowing and continued weekly until 42 days after sowing. The transplants were planted into the field when at least one treatment could pull out of cavity trays without breaking. In the field, transplants were given the same amount of fertilizer and agronomic practices. Harvesting was done when at least one treatment had reached maturity.

Application of nitrogen increased in a quadratic fashion plant height, leaf number, leaf area and dry shoot mass regardless of sampling dates. Transplants that did not receive nitrogen had

the least plant height, leaf number, relative growth rate and dry root mass but the highest root: shoot ratio and root mass ratio. Nitrogen applied at 120 mg·L^{-1} reduced dry root mass but enhanced dry shoot mass. There was a positive linear relationship between pulling success, dry root mass and yield. Nitrogen level of 90 mg·Ñ$^{-1}$ gave a quality transplant. A quality transplant had plant height of 150 mm, leaf area of 59 cm^2, dry root mass of 58 mg, dry shoot mass of 284 mg, root: shoot ratio of 0.20, leaf mass ratio of 0.83, root mass ratio of 0.17 and pulling success of 90 %. Transplants propagated at 90 mg·Ł$^{-1}$ N gave the highest yield in the field experiment.

2.3.2 Spring/summer experiment

2.3.2.1 Shoot development and leaf N

Plant height

Nitrogen application increased plant height in a linear fashion at 21 days after sowing. However, the pattern changed to quadratic at 28 and 35 days after sowing (Table 2.6). At 28 and 35 days after sowing, plant height increased from 25 to 75 mm, 32 to 133 mm as nitrogen increased from 0 to 120 mg·Å^{-1}, respectively. Regardless of sampling date, transplants that were propagated with 0 mg·Ł$^{-1}$ N had the least plant height. The transplants were stunted, small, and had pale green leaves with thin stems.

Table 2. 6 Shoot characteristics of cabbage transplants as affected by nitrogen nutrition, Aug/September 2005

Nitrogen applied (mg·L^{-1})	Fresh shoot mass (mg)	Dry shoot mass (mg)	Plant height (mm)	Leaf number	Leaf area (cm^2)	Tissue nitrogen (g·kg^{-1})
			21 days after sowing (1st sampling)			
0	8.3	9.5	25.2	1.5	1.43	
30	135.5	38.5	33.4	2.1	8.04	
60	352.0	56.0	47.8	2.5	15.55	
90	454.2	67.5	61.3	2.5	17.80	
120	609.5	67.5	75.4	2.6	16.82	
Response	Q**	Q**	L**	Q**	Q**	
			28 days after sowing (2nd sampling)			
0	133.5	17.0	31.6	1.7	2.66	
30	360.0	67.5	67.5	3.0	14.38	
60	676.5	123.0	103.8	3.7	31.96	
90	936.5	161.5	117.6	3.9	45.98	
120	1309.5	149.0	133.0	4.0	43.48	
Response	Q**	Q**	Q**	Q**	Q**	
			35 days after sowing (3rd sampling)			
0	154.75	20.0	33.5	1.9	3.35	13.0
30	808.50	129.0	82.6	4.2	22.92	26.6
60	1338.00	208.0	119.2	4.3	47.66	32.6
90	1936.00	207.0	146.4	4.7	56.37	41.1
120	2565.50	280.0	165.7	5.1	73.24	43.7
Response	L**	Q**	Q**	Q**	Q**	Q**

Linear (L) or quadratic (Q) effects significant at P=l0.05 (*), 0.01 (**) or nonsignificant (NS)

Leaf number

Regardless of sampling date, application of nitrogen to cabbage transplants increased leaf number in a quadratic fashion (Table 2.6). At 21 days after sowing, leaf number increased from 1.5 to 2.6 for transplants propagated with 0 to 120 mg·L^{-1} N, respectively. As nitrogen increased from 0 to 120 mg·L^{-1}, leaf number increased from 1.7 to 4.0 and 1.9 to 5.1 for transplants sampled at 28 and 35 days after sowing, respectively. Transplants that did not receive nitrogen had the least leaf number regardless of sampling date.

Leaf area

Leaf size in terms of leaf area increased in a quadratic fashion as the level of nitrogen applied to transplants increased (Table 2.6). At 21 and 28 days after sowing, leaf area increased from 1.4 to 16.8 and 2.7 to 43.5 cm^2 as nitrogen increased from 0 to 120 $mg \cdot L^{-1}$. The greatest leaf area was obtained with 90 $mg \cdot L^{-1}$ N in transplants that were sampled at 21 and 28 days after sowing. However at 35 days after sowing, the greatest leaf area was obtained at 120 $mg \cdot L^{-1}$ N

Fresh and dry shoot mass

Fresh shoot mass increased in a quadratic fashion as nitrogen increased at 21 and 28 days after sowing while at 35 days after sowing, the increase was linear. At 21 and 28 days after sowing, fresh shoot mass increased from 8 to 610 mg and 134 to 1310 mg as nitrogen increased from 0 to 120 $mg \cdot L^{-1}$, respectively.

Dry shoot mass increased in a quadratic fashion as the level of nitrogen increased irrespective of sampling date. Increasing nitrogen from 0 to 120 $mg \cdot L^{-1}$, increased dry shoot mass from 10 to 68 mg and 17 to 149 mg for transplants sampled at 21 and 28 days after sowing, respectively. At 35 days after sowing, dry shoot mass increased from 20 to 280 mg for transplants propagated with 0 to 120 $mg \cdot L^{-1}$ N.

Leaf N content

Leaf N was analysed at termination of the greenhouse experiment. There was an increase in the amount of nitrogen in transplant tissues indicating that as the concentration of nitrogen increased in the growing medium, the amount of nitrogen uptake by transplants also increased (Table 2.6). As nitrogen increased from 0 to 120 $mg \cdot L^{-1}$, leaf nitrogen content increased from 13 to 44 $g \cdot kg^{-1}$, respectively. This confirms what was reported by Semuli (2005) that tissue N in cabbage transplants increased as the level of nitrogen increased. Transplants with leaf nitrogen content of =, 26.6 $g \cdot kg^{-1}$ were stunted and grew poorly.

2.3.2.2 Root development and pulling success

Fresh and dry root mass

Nitrogen application increased the fresh root mass regardless of sampling date (Table 2.7). At 21 days after sowing, fresh root mass increased in a linear fashion from 11 to 131 mg as nitrogen increased from 0 to 120 mg·L^{-1}, respectively. Transplants that did not receive nitrogen had the least fresh root mass irrespective of sampling dates. At 28 and 35 days after sowing, fresh root mass increased in a quadratic fashion from 34 to 232 mg and 78 to 485 mg when nitrogen was increased from 0 to 120 mg·L^{-1}, respectively.

Irrespective of sampling date, application of nitrogen during transplant production increased dry root mass in a quadratic fashion. At 21 days after sowing, dry root mass was 4.0, 8.5. 7.5, 8.0, and 7.5 mg for transplants propagated with 0, 30, 60, 90, and 120 mg·L^{-1} N. At 28 days after sowing, dry root mass was 5.7, 18.5, 21.0, 20.5 and 15.5 mg for transplants propagated with 0, 30, 60, 90 and 120 mg·L^{-1} N, respectively. At the same sampling date, the greatest dry root mass was achieved with 60 to 90 mg·L^{-1} N. At the same sampling date, dry root mass was least in transplants propagated with 0 mg·L^{-1} while the greatest dry root mass was recorded from transplants propagated with 60 mg·L^{-1} N.

Root: shoot ratio

Application of nitrogen decreased the root: shoot ratio regardless of sampling date (Table 2.7). At 21 days after sowing, root: shoot ratio decreased linearly as the level of nitrogen increased. At 28 and 35 days after sowing, root: shoot ratio decreased in a quadratic fashion as nitrogen increased. Increasing nitrogen from 0 to 120 mg·L^{-1}, decreased root: shoot ratio from 0.425 to 0.112, 0.340 to 0.104, and 0.366 to 0.127 for transplants sampled at 21, 28, and 35 days after sowing, respectively.

Table 2. 7 Root characteristics of cabbage transplants responding to nitrogen nutrition, Aug/Sept 2005

Nitrogen applied (mg·L^{-1})	Root: shoot ratio	Root mass ratio	Leaf mass ratio	Fresh root mass (mg)	Dry root mass (mg)	Pulling success (%)
	21 days after sowing (1st sampling)					
0	0.425	0.30	0.70	10.5	4.0	
30	0.221	0.18	0.82	48.5	8.5	
60	0.133	0.12	0.88	70.5	7.5	
90	0.118	0.11	0.89	100.5	8.0	
120	0.112	0.10	0.90	131.2	7.5	
Response	L**	Q**	Q**	L**	Q**	
	28 days after sowing (2nd sampling)					
0	0.340	0.25	0.75	34.0	5.7	
30	0.278	0.22	0.78	163.2	18.5	
60	0.171	0.15	0.85	191.7	21.0	
90	0.127	0.11	0.89	221.2	20.5	
120	0.104	0.09	0.91	232.0	15.5	
Response	Q**	Q**	Q**	Q**	Q**	
	35 days after sowing (3rd sampling)					
0	0.366	0.27	0.73	78.2	7.2	10
30	0.237	0.19	0.81	333.5	30.5	40
60	0.171	0.15	0.85	387.5	35.5	95
90	0.152	0.13	0.87	442.5	31.5	90
120	0.127	0.11	0.89	485.0	35.5	95
Response	Q**	Q**	Q**	Q**	Q**	Q**

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

Root mass ratio

Root mass ratio decreased from 0.30 to 0.10, 0.25 to 0.09 and 0.27 to 0.11 as nitrogen increased from 0 to 120 mg·L^{-1} at 21, 28 and 35 days after sowing (Table 2.7). At 35 days after sowing, 85 % of the dry matter was partitioned into shoots and 15 % to roots in transplants that were propagated with ≥60 mg·L^{-1} N. The greatest root mass ratio was obtained from transplants that did not receive nitrogen while the least root mass ratio was recorded from transplants that were propagated at 120 mg·L^{-1} N.

Leaf mass ratio

Leaf mass ratio increased in a quadratic fashion in response to application of nitrogen (Table 2.7). At 21, 28 and 35 days after sowing, increasing nitrogen from 0 to 120 mg·L^{-1} increased leaf mass ratio from 0.70 to 0.90, 0.75 to 0.91 and 0.73 to 0.89, respectively.

Pulling success

Nitrogen application increased pulling success in a quadratic fashion. As nitrogen increased from 0 to 120 mg·L^{-1}, pulling success increased from 10 to 95 %, respectively (Table 2.7). Transplants that did not receive nitrogen had the least fresh and dry root mass and this could have contributed to low number of transplants pulling out of cavity trays. Transplants that were propagated with 60 mg·L^{-1} N and 120 mg·L^{-1} N had the highest pulling success.

2.3.2.3 Growth parameters

Specific leaf area

Nitrogen increased specific leaf area of cabbage transplants and this could have been due to the effect nitrogen had on leaf area. In transplants that were sampled 21 days after sowing, specific leaf area increased in a quadratic fashion from 0.152 to 0.249 cm^2·mg^{-1} as the level of nitrogen increased from 0 to 120 mg·L^{-1} (Table 2.8). At 28 and 35 days after sowing, specific leaf area increased in a quadratic fashion from 0.157 to 0.292 and 0.168 to 0.261 cm^2·mg^{-1} as nitrogen increased from 0 to 120 mg·L^{-1}, respectively. At 35 days after sowing, specific leaf area was greatest with 90 mg·L^{-1} N. Similar results were reported by Vavrina *et al.* (1998). The authors found that specific leaf area increased in a quadratic fashion as nitrogen increased from 15 to 75 mg·L^{-1}.

Leaf area ratio

Nitrogen increased leaf area ratio in a quadratic fashion irrespective of sampling date (Table 2.8). At 21 days after sowing, leaf area ratio increased from 0.106 to 0.224 cm^2·mg^{-1} for transplants that were propagated with 0 and 120 mg·L^{-1} N, respectively. Leaf area ratio increased from 0.157 to 0.292 cm^2·mg^{-1} when nitrogen increased from 0 to 120 mg·L^{-1} at 28 days after sowing. Increasing nitrogen from 0 to 120 mg·L^{-1}, increased leaf area ratio from 0.123 to 0.232.cm^2·mg^{-1} at 35 days after sowing.

Net assimilation rate

At 28 days after sowing, net assimilation rate decreased in a linear fashion as nitrogen increased (Table 2.8). At the same sampling date, net assimilation rate decreased from 4.68 to 3.63 mg·cm^{-2}·wk^{-1}. At 35 days after sowing, nitrogen did not influence net assimilation rate.

Table 2. 8 Growth parameters of cabbage transplants responding to nitrogen nutrition, Aug/September 2005

Nitrogen applied (mg·L^{-1})	Specific leaf area (cm^2·mg^{-1})	Leaf area ratio (cm^2·mg^{-1})	Net assimilation rate (mg·cm^{-2}·wk^{-1})	Relative growth rate (mg·mg^{-1}·wk^{-1})
	21 days after sowing (1st sampling)			
0	0.152	0.106		
30	0.209	0.170		
60	0.277	0.245		
90	0.263	0.235		
120	0.249	0.224		
Response	Q**	Q**		
	28 days after sowing (2nd sampling)			
0	0.157	0.117	4.68	0.523
30	0.213	0.167	3.58	0.603
60	0.261	0.223	3.57	0.820
90	0.284	0.252	3.63	0.885
120	0.292	0.264	3.20	0.789
Response	Q**	Q*	L**	Q*
	35 days after sowing (3rd sampling)			
0	0.168	0.123	1.50	0.180
30	0.178	0.144	4.06	0.620
60	0.230	0.196	2.53	0.525
90	0.273	0.237	1.11	0.269
120	0.261	0.232	2.65	0.651
Response	Q**	Q**	NS	L**

Linear (L) or quadratic (Q) effects significant at P=<0.05 (*), 0.01 (**) or nonsignificant (NS)

Relative growth rate

Relative growth rate increased as nitrogen increased. At 28 days after sowing, the response was quadratic but it later changed to linear at 35 days after sowing (Table 2.8). At 28 days after sowing, relative growth rate increased from 0.523 to 0.885 mg·mg^{-1}·wk^{-1} for transplants

that were propagated with 0 and 90 mg·Â$^{-1}$ N, respectively. Relative growth rate increased from 0.180 to.651 mg·mg^{-1}·á·wk^{-1} at 35 days after sowing when nitrogen increased from 0 to 120 mg·L^{-1}.

2.3.2.4 Cabbage head yield, and quality

Untrimmed cabbage head yield and head mass

Pretransplant nitrogen increased untrimmed head mass and untrimmed head yield (Table 2.9). Head mass increased from 3.28 to 4.07 kg for cabbage transplants that were propagated with 0 and 120 mg·L^{-1} N, respectively. Untrimmed head yield increased linearly as the levels of nitrogen applied during transplants production increased.

Table 2. 9 Untrimmed and trimmed cabbage head yield and leaf nitrogen as influenced by pretransplant nitrogen, Jan 2006

Nitrogen applied (mg·E^{-1})	Untrimmed head		Trimmed head			
	mass (kg)	yield (t·ha^{-1})	mass (kg)	yield (t·ha^{-1})	diameter (mm)	height (mm)
0	3.28	73.41	2.49	57.82	73.8	135.0
30	3.15	79.04	2.61	63.26	201.3	148.5
60	3.23	99.41	2.66	82.01	223.8	135.0
90	3.55	92.91	2.88	75.51	218.8	152.5
120	4.07	103.31	3.25	82.62	225.0	146.3
Response	Q**	L**	Q**	Q**	Q**	NS

Linear (L) or quadratic (Q) effects significant at P=.05 (*), 0.01 (**) or nonsignificant (NS)

Trimmed cabbage head yield and head mass

Trimmed cabbage head mass increased as the level of pretransplant nitrogen increased. Head mass increased from 2.49 to kg for transplants that were propagated with 0 mg·L^{-1} N to 3.25 kg for transplants that received 120 mg·L^{-1} N during transplant production (Table 2.9). Trimmed head yield increased as the level of nitrogen applied during transplant production increased, reaching a plateau at 60 mg·L^{-1} N. In tomato, Liptay *et al*. (1992) reported no change in total yield due to transplant nutrition but said 50 to 100 mg·L^{-1} N (low N) decreased

early yield. Bar-Tal *et al*. (1990) found out that bell pepper transplants with >160 mg top dry mass had the greatest growth rate which lead giving higher early pod yield but not total yield.

Cabbage head quality

Pretransplant nitrogen influenced leaf nitrogen and core diameter but not core height. Leaf nitrogen content increased in a quadratic fashion as pretransplant nitrogen increased even though the plants received the same amount of fertilizer in the field. It increased from 19.1 to 24.9 $g \cdot kg^{-1}$ when pretransplant nitrogen increased from 0 to 120 $mg \cdot L^{-1}$. However, the leaf nitrogen obtained was lower than leaf nitrogen obtained during the autumn/winter experiment. The reason for the lower leaf nitrogen in spring/summer could have been due to the higher soil temperatures and leaching of nitrogen by higher rainfall in summer.

Table 2. 10 Cabbage head quality as influenced by pretransplant nitrogen nutrition, Jan 2006

Nitrogen ($mg \cdot L^{-1}$)	Core diameter (mm)	Core height (mm)	Leaf nitrogen $g \cdot kg^{-1}$
0	21.0	77.5	19.1
30	23.8	75.8	18.2
60	23.8	65.0	18.9
90	38.3	90.0	21.3
120	31.3	70.0	24.9
Response	Q**	NS	Q**

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

2.3.3.5 CONCLUSIONS

Application of nitrogen during the spring season increased in a quadratic fashion plant height, leaf number, leaf area, fresh and dry shoot mass, leaf nitrogen, fresh and dry root mass, pulling success, specific leaf area, leaf area ratio, net assimilation rate and leaf mass ratio in a quadratic fashion. However, as nitrogen increased root: shoot ratio, relative growth rate and root mass ratio decreased in a quadratic fashion. Nitrogen applied during transplants production at 60 $mg \cdot L^{-1}$ gave optimum shoot and root growth. A quality transplant had plant height of 119.2 mm, leaf area of 47.66 cm^{-2}, dry root mass of 35.5 mg, dry shoot mass of 208 mg, root: shoot ratio of 0.117, leaf mass ratio of 0.85, root mass ratio of 0.15 and pulling success of 95 %.

Pretransplant nitrogen improved untrimmed and trimmed cabbage head yield, head diameter and head height. Therefore, pretransplant nitrogen is important for subsequent crop performance in the field. In South Africa, transplant growers need to use about 60 mg·L^{-1} N in spring in order to achieve quality transplants for improved cabbage head yield.

2.3.3.6 SUMMARY

A greenhouse experiment was conducted during spring to determine the amount of nitrogen that could optimise transplant shoot and root development. The transplants were subsequently planted in the field to assess the impact of nitrogen applied during transplant production on cabbage head yield. Cabbage transplants were propagated with 0, 30, 60, 90 and 120 mg·L^{-1} N. Irrigation during greenhouse experiment was done by floating cavity trays in nutrient solution until the medium reached field capacity. Cavity trays were then removed from the solution and put on benches. Sampling was initiated at 21 days after sowing and continued weekly until 35 days after sowing. The transplants were planted into the field when at least one treatment could pull out of cavity trays without breaking. In the field, transplants were given the same amount of fertilizer and subjected to the same agronomic practices. Harvesting was done when at least one treatment had reached maturity.

Application of nitrogen increased plant height, leaf number, leaf area and dry shoot mass in a quadratic fashion regardless of sampling dates. Transplants that did not received nitrogen had the least plant height, leaf number, relative growth rate and dry root mass but greatest root: shoot ratio and root mass ratio. Nitrogen applied at 120 mg·L^{-1} reduced dry root mass but enhanced dry shoot mass. Nitrogen level of 60 mg·L^{-1} gave a quality transplant. A quality transplant had plant height of 119 mm, leaf area of 47.7 cm^2, dry root mass of 35.5 mg, dry shoot mass of 208 mg, root: shoot ratio of 0.17, leaf mass ratio of 0.85, root mass ratio of 0.15 and pulling success of 95 %. Transplants propagated at 60 mg·L^{-1} N also gave the highest yield.

CHAPTER 3

GROWTH OF CABBAGE TRANSPLANTS AS AFFECTED BY PHOSPHORUS NUTRITION

3.1 INTRODUCTION

Phosphorus is the second most important nutrient after nitrogen in plant nutrition. The role of phosphorus in plants is mainly in energy storage and transfer through adenosine diphosphate (ADP) and adenosine triphosphate (ATP). Energy obtained during photosynthesis is stored in phosphate compounds for use in vegetative and reproductive growth (Tisdale *et al*., 1993). Phosphorus plays a role in cell division, stimulates root growth and enhances plant maturity (Acquaah, 2005). Phosphorus has been reported to increase stem diameter and height, shoot and root mass and leaf area of celery transplants (Dufault, 1985). In lettuce transplants, Soundy *et al.* (2001b) reported a decrease in root: shoot ratio in response to increasing phosphorus. In addition, fresh and dry root mass, root length and area increased linearly with increasing phosphorus levels. Phosphorus also improved pulling success from 30 % to 90 %. However, data is lacking on the response of cabbage transplants to phosphorus applied frequently through floatation irrigation. Therefore, a study was conducted to determine the impact of phosphorus in cabbage transplant shoot and root growth.

3.2 MATERIALS AND METHODS

The experiment was conducted during the winter season at the Hatfield Experimental Farm of the University of Pretoria (26° 12'S, 28° 10'E). The experiment was conducted in a greenhouse. Seeds of cabbage cultivar 'Drumhead' were sown on 24 June 2005 and the experiment was terminated on 31 July 2005. The layout of the experiment was a randomized complete block design with four replications with each replication having 50 plants. The trays used were 200 inverted pyramid cavity trays that are commonly used in South Africa for vegetable transplant production. Cavity trays were filled with 'Cultera' growing medium and three seeds were sown per cavity. Thereafter, the trays were covered with a thin layer of vermiculite. The growing medium had no added fertilizer. Irrigation was done with a

watering can until treatment application was initiated. Transplants were thinned to leave one plant per cavity.

Phosphorus levels were 0, 15, 30, 45 and 60 $mg \cdot L^{-1}$ supplied as NaH_2PO_4. Potassium and nitrogen were applied at 30 and 90 $mg \cdot L^{-1}$ supplied from KCl and NH_4NO_3, respectively. Other nutrients like Ca, Mg, S, B, Mn, Mo Cu and Zn were applied at half strength Hoagland's solution. Application of treatments started 5 - 6 days after emergence. The nutrient solutions were prepared in 150 L containers and were replaced only when depleted. Irrigation was done by floating cavity trays in nutrient solution until the medium reached field capacity. Cavity trays were then removed from nutrient solutions and put on benches. After every irrigation, the nutrient solutions were put back into the containers. The greenhouse air temperature was monitored using a Johnson controls, Penn F010 wall mounted thermometer. During the experiment, the average minimum and maximum temperatures were 20 ^{o}C and 30 ^{o}C, respectively.

3.2.1 Sampling

Sampling was initiated on 16 July 2005 and continued weekly until 31 July 2005. Measurements of plant height, number of expanded true leaves (leaves with a clearly visible petiole), leaf area (using leaf area meter, model Ll-3100, Ll-COR, Lincoln, Nebraska), root and shoot (fresh and dry) mass were recorded from five transplants sampled every week from each replication. Shoot and root dry mass were obtained by drying samples at 65 °C for 48 hours. After being removed from cavity trays, transplants were washed under running tap water until all the soil had been removed and then divided into shoots and roots before measurements were taken. The experiment were terminated when transplants from at least one treatment across all replications could easily pull out of tray cells without breaking. At termination of the experiment, five plants were pulled from each replicate and their pulling success recorded. Pulling success (%) was the number of plants that could be removed from the cells without breakage. The remaining plants were harvested and shoots dried in an oven for 48 hours at 65 ^{o}C, before being submitted to the University of Pretoria Soil Science Laboratory for tissue analysis of total N.

Growth parameters calculated were (Hunt, 1982; Gardner, Pearce & Mitchell, 1990; Nicola & Cantliffe, 1996):

- Root to shoot ratio (RSR = dry root mass ÷ dry shoot mass)
- Relative growth rate (RGR = [ln(final total dry mass – ln(initial total dry mass) ÷ (final time – initial time)])
- Net assimilation rate (NAR = (final total dry mass – initial total dry mass) ÷ (final time – initial time) × [(ln(final leaf area) – ln(initial leaf area)])
- Specific leaf area (SLA = leaf area ÷ dry shoot mass)
- Leaf area ratio (LAR = leaf area ÷ total dry mass)
- Root mass ratio (RMR = dry root mass ÷ total dry mass)
- Pulling Success (PLS = Percentage of transplants that could easily pull out of trays without breaking)

Data was then subjected to analysis of variance using the Statistical Analysis System (SAS Institute Inc., 2003) software. Treatment sums of squares were partitioned into linear and quadratic polynomial contrasts.

3.3 RESULTS AND DISCUSSION

3.3.1 Shoot development

Leaf area

Leaf area increased as phosphorus increased (Table 3.1). At 21 days after sowing, the leaf area increased in a linear fashion from 6.90 to 15.79 cm^2 for transplants that were propagated at 0 and 60 $mg \cdot L^{-1}$ P, respectively (Figure 3.3).Leaf area increased in a quadratic fashion from 13.0 to 36.7 mg at 28 days after sowing as phosphorus increased from 0 to 45 $mg \cdot L^{-1}$. Similar results were reported on pepper (Dufault & Schultheis, 1994), tomato (Melton & Dufault, 1991) and celery (Dufault, 1985). Soundy *et al*. (2001a) also reported a quadratic decrease in leaf area as applied phosphorus increased.

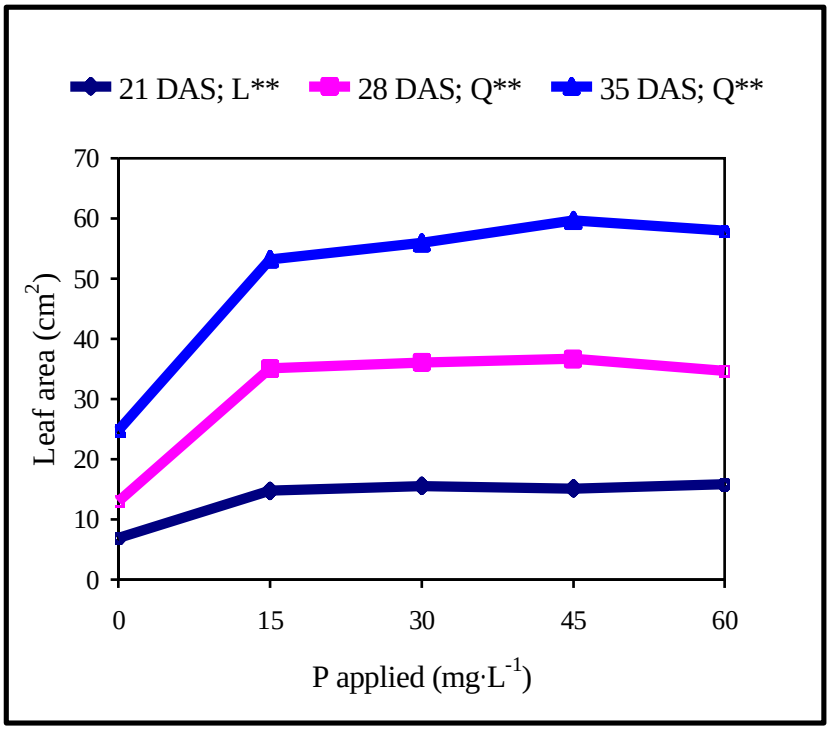


Figure 3.1 Leaf area of cabbage transplants as affected by phosphorus nutrition at 21, 28 and 35 days after sowing (linear (L) or quadratic (Q) effects significant at P= 0.05 (*), 0.01 (**) or nonsignificant (NS)

Fresh and dry shoot mass

Fresh shoot mass increased as phosphorus increased regardless of sampling dates (Table 3.1). At 21 days after sowing, fresh shoot mass increased from 40 to 758 mg as phosphorus increased from 0 to 30 mg·L^{-1}. At 28 and 35 days after sowing, fresh shoot mass increased from 224 to 1523 mg and 264 to 2485 mg, respectively, as nitrogen increased from 0 to 45 mg·L^{-1}.

Application of phosphorus affected dry shoot mass of cabbage transplants. At 21 days after sowing, greatest dry shoot mass was recorded from transplants that received 30 mg·L^{-1} P (Table 3.1). At 28 days after sowing, as phosphorus increased from 0 to 45 mg·L^{-1}, dry shoot mass increased from 36.2 to 146.0 mg, respectively. At 35 days after sowing, dry shoot mass increased from 52.8 to 219.5 mg when phosphorus was increased from 0 to 45 mg·L^{-1}. However, at 35 days after sowing, the highest dry shoot mass was obtained at 15 mg·L^{-1} P as the response was quadratic indicating that an increase in phosphorus resulted in an increase at a decreasing rate. Phosphorus at 5 to 45 mg·L^{-1} combined with nitrogen at 75 or 225 mg·L^{-1} increased fresh and dry shoot mass of pepper (*Capsicum annuum* L.) transplants but not when combined with 25 mg·L^{-1} N (Dufault & Schultheis, 1994). Melton & Dufault (1991) reported

that phosphorus at 5 to 45 mg·Â$^{-1}$ increased fresh shoot mass of tomato transplants. Soundy *et al*. (2001a) propagated lettuce transplants at 0, 15, 30, 45 and 60 mg L^{-1} P and reported that application of at least 15 mg·Ł$^{-1}$ P through floatation irrigation to a peat + vermiculite mix was required to produce a transplant with enough roots for easy pulling.

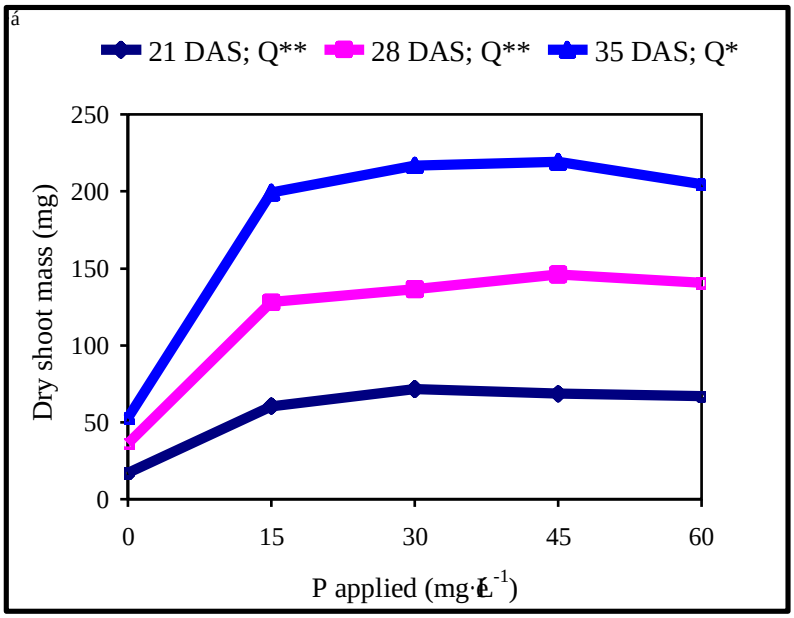


Figure 3.2 Dry shoot mass of cabbage transplants as affected by phosphorus at 21, 28 and 35 days after sowing [Linear (L) or quadratic (Q) effects significant at P=ŵ0.05 (*), 0.01 (**) or nonsignificant (NS)]

Plant height

At the 21 and 28 days after sowing, application of phosphorus did not affect plant height (Table 3.1). However, at 35 days after sowing, increasing phosphorus resulted in a quadratic increase in plant height. During the same sampling date, plant height increased from 133 to 150 mm for transplants that were propagated with 0 and 45 mg·Ł$^{-1}$ N, respectively. Melton & Dufault (1991a) reported that increasing phosphorus from 5 to 45 mg·Ł$^{-1}$ increased tomato transplant height.

Table 3.1 Shoots characteristics of cabbage transplants responding to phosphorus nutrition, June/July 2005

Phosphorus applied (mg·B^{-1})	Fresh shoot mass (mg)	Plant height (mm)	Leaf number	Leaf Phosphorus (g·Rg^{-1})
21 days after sowing (1st sampling)				
0	40	90.9	3.45	
15	627	84.3	3.15	
30	758	87.6	3.30	
45	713	85.3	3.36	
60	736	86.7	3.20	
Response	Q**	NS	NS	
28 days after sowing (2nd sampling)				
0	224	117.0	4.25	
15	1375	119.4	4.30	
30	1493	122.0	4.50	
45	1523	122.5	4.32	
60	1492	120.0	4.20	
Response	L**	NS	NS	
35 days after sowing (3rd sampling)				
0	264	132.9	4.80	3.1
15	2263	146.5	5.00	5.5
30	2413	143.1	4.85	6.2
45	2485	150.2	4.80	6.0
60	2343	147.4	4.87	6.1
Response	Q**	Q*	NS	Q**

Linear (L) or quadratic (Q) effects significant at P=9.05 (*), 0.01 (**) or nonsignificant (NS)

Leaf number

Number of leaves was not affected by application of phosphorus regardless of date of sampling (Table 3.1). At 21 days after sowing transplants had 3 leaves, it increased to 4 and 5 at 28 and 35 days after sowing, respectively. Increasing phosphorus from 5 to 45 mg·L^{-1} increased leaf number of pepper (Dufault & Schultheis, 1994) and tomato transplants (Melton & Dufault, 1991a).

Leaf phosphorus content

Leaf phosphorus increased as the concentration of phosphorus increased in the nutrient solution (Table 3.1). Leaf phosphorus increased from 3.1 to 6.1 g·kg^{-1} on a dry mass basis as phosphorus increased from 0 to 60 mg·Õ$^{-1}$ in the nutrient solution. However, the greatest leaf phosphorus was obtained from transplants that were propagated with 30 mg·L^{-1} P. Soundy *et*

al. (2001a) reported that maintaining tissue phosphorus concentration in the range of 3.0 to 4.0 g·kg^{-1} was adequate for production of high quality lettuce transplants.

3.3.2 Root development

Fresh and dry root mass

Phosphorus significantly affected transplant fresh root mass irrespective of date of sampling (Table 3.2). At 21 days after sowing (DAS), fresh root mass increased in a linear fashion as phosphorus increased. At 28 and 35 days after sowing, fresh root mass increased in a quadratic fashion with increasing phosphorus and reached a maximum at 45 mg·L^{-1} P.

Irrespective of sampling date, dry root mass increased in a quadratic fashion as phosphorus increased. At 21 days after sowing (DAS), dry root mass increased from 8 to 21 mg for transplants that were propagated at 0 and 60 mg·Ó$^{-1}$ P respectively (Table 3.2). At the same sampling date, dry root mass of transplants that were propagated with 30 and 60 mg·‰$^{-1}$ P was 21 mg. Dry root mass increased from 14 to 28 mg at second sampling (28 days after sowing) when phosphorus increased from 0 to 60 mg·ñ$^{-1}$ P. At 35 days after sowing, dry root mass increased from 22 to 43 mg when phosphorus increased from 0 to 60 mg·§$^{-1}$. Applying 5 to 125 mg·L^{-1} P increased celery transplant root mass (Dufault, 1985). Karchi, Dagan & Cantliffe (1992) found that propagating lettuce transplants with high N and low P, lead to enhanced leaf growth over root growth. However, Soundy *et al*. (2001a) propagated lettuce transplants at 0, 15, 30, 45 and 60 mg·Ł$^{-1}$ P combined with 60 or 100 mg·Ł$^{-1}$ N. The authors found that phosphorus combined with 100 mg·Ø$^{-1}$ N improved shoot growth but adversely affected root growth compared to 60 mg·å$^{-1}$ N.

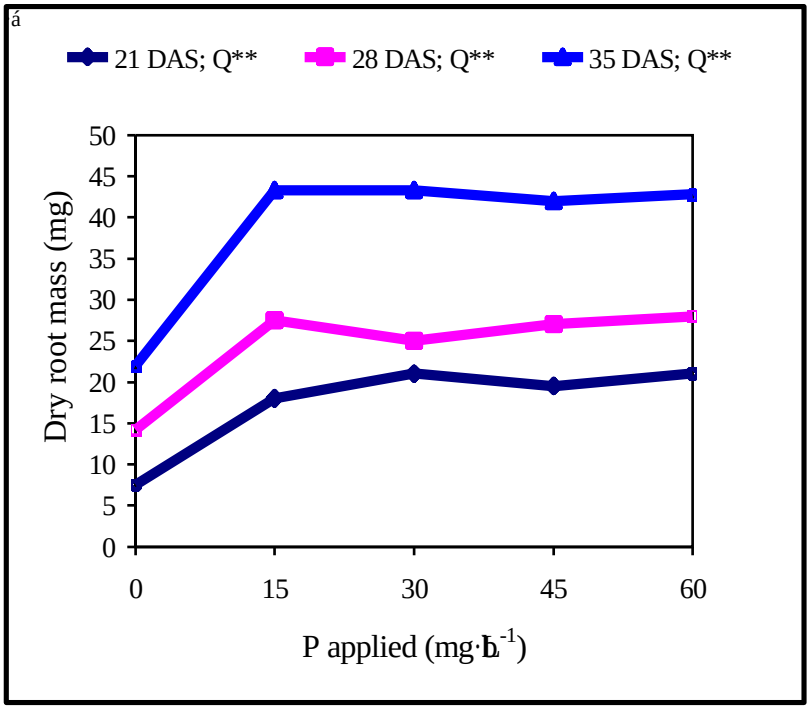


Figure 3.3 Dry root mass of cabbage transplants as affected by phosphorus nutrition at 21, 28 and 35 days after sowing [Linear (L) or quadratic (Q) effects significant at P=— 0.05 (*), 0.01 (**) or nonsignificant (NS)]

Root: shoot ratio

Root: shoot ratio decreased in response to application of phosphorus (Table 3.2). At 28 DAS, the root: shoot ratio was 0.39, 0.22, 0.18, 0.19 and 0.20 when phosphorus was applied at 0, 15, 30, 45 and 60 mg·Ð$^{-1}$, respectively. Transplants that did not receive phosphorus had the greatest root: shoot ratio regardless of sampling dates because they had poor shoot growth.

Table 3.2 Root characteristics of cabbage transplants as affected by phosphorus nutrition, June/July 2005

Phosphorus applied (mg·L^{-1})	Root: shoot ratio	Root mass ratio	Leaf mass Ratio	Fresh root mass (mg)	Pulling success (%)
21 days after sowing (1st sampling)					
0	0.45	0.31	0.69	23.5	
15	0.30	0.23	0.77	131.5	
30	0.30	0.22	0.78	166.5	
45	0.29	0.22	0.78	168.5	
60	0.31	0.24	0.76	181.5	
Response	Q**	Q**	Q**	L**	
28 days after sowing (2nd sampling)					
0	0.39	0.28	0.72	47.5	
15	0.22	0.18	0.82	297.5	
30	0.18	0.16	0.84	344.5	
45	0.18	0.16	0.84	439.0	
60	0.20	0.16	0.84	415.0	
Response	Q**	Q**	Q**	Q**	
35 days after sowing (3rd sampling)					
0	0.43	0.30	0.70	51.5	40
15	0.22	0.18	0.82	340.0	90
30	0.20	0.16	0.84	395.5	90
45	0.19	0.16	0.84	480.5	80
60	0.21	0.17	0.83	460.3	90
Response	Q**	Q**	Q**	Q**	Q**

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

Root mass ratio

Phosphorus application significantly affected root mass ratio (Table 3.2). Root mass ratio decreased quadratically as phosphorus increased. At 21 days after sowing, root mass ratio decreased from 0.31 to 0.22 for transplants that were propagated at 0 to 45 mg·L^{-1} P. At 28 days after sowing, root mass ratio decreased from 0.28 to 0.16 for transplants that received 0 to 60 mg·L^{-1} P, however the root mass of transplants that received 30, 45 and 60 mg·L^{-1} P was similar. Root mass ratio decreased from 0.30 to 0.16 for transplants that received 0 to 45 mg·L^{-1} P during 3rd sampling (35 days after sowing). Phosphorus resulted in about 80% of dry matter being partitioned to the shoots while about 20% went to roots.

Leaf mass ratio

Leaf mass ratio increased in a quadratic fashion as phosphorus increased. At 21 days after sowing, leaf mass ratio increased from 0.69 to 0.78 for transplants that were propagated at 0 to 45 mg·ł$^{-1}$ P (Table 3.2). Leaf mass ratio increased from 0.72 to 0.84 at 28 days after sowing when phosphorus was increased from 0 to 30 mg·Ë$^{-1}$. Transplants that did not receive phosphorus had the lowest leaf mass ratio while the highest leaf mass ratio was recorded from transplants that received 30 mg·Ł$^{-1}$ P.

Pulling success

Phosphorus application increased the success of removing transplants from cavity trays without breaking (Table 3.2). Transplants that did not receive phosphorus were of poor quality, as only 40 % of them could be pulled out of cavity trays without breaking.

3.3.4 Growth parameters

Specific leaf area

Specific leaf area decreased in a quadratic fashion as phosphorus application increased irrespective of sampling date (Table 3.3). At 21 days after sowing, specific leaf area decreased from 0.410 to 0.218 cm^2·ámg^{-1} in transplants that were propagated with 0 and 30 mg·Ú$^{-1}$ P, respectively. Specific leaf area decreased from 0.361 to 0.247 cm^2·ámg^{-1} as phosphorus increased from 0 to 60 mg·E^{-1} at 28 days after sowing. At 25 days after sowing, specific leaf area decreased from 0.490 to 0.283 cm^2·ámg^{-1} as phosphorus increased from 0 to 60 mg·û$^{-1}$. Transplants that did not receive phosphorus had a higher specific leaf area compared to transplants that received phosphorus.

Table 3.3 Growth parameters of cabbage transplants in response to phosphorus nutrition, June/July 2005

Phosphorus applied ($mg \cdot L^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Net assimilation rate ($mg \cdot g m^{-2} \cdot wk^{-1}$)	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)
	21 days after sowing (1st sampling)			
0	0.410	0.284		
15	0.244	0.188		
30	0.218	0.169		
45	0.221	0.172		
60	0.236	0.180		
Response	Q**	Q**		
	28 days after sowing (2nd sampling)			
0	0.361	0.260	2.67	0.72
15	0.274	0.225	3.28	0.68
30	0.265	0.224	2.81	0.56
45	0.251	0.212	3.50	0.68
60	0.247	0.206	3.36	0.65
Response	Q**	Q**	Q**	Q**
	35 days after sowing (3rd sampling)			
0	0.490	0.342	1.24	0.37
15	0.267	0.219	2.01	0.45
30	0.258	0.215	2.24	0.48
45	0.272	0.228	1.93	0.41
60	0.283	0.234	1.72	0.39
Response	Q**	Q**	Q**	Q**

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

Leaf area ratio

Regardless of sampling date, leaf area ratio decreased in a quadratic fashion when applied phosphorus increased (Table 3.3). At 21 days after sowing, leaf area ratio decreased from 0.284 to 0.169 $cm^2 \cdot mg^{-1}$ when phosphorus increased 0 and 30 $mg \cdot L^{-1}$, respectively with the lowest leaf area ratio obtained at 30 $mg \cdot L^{-1}$ P. Leaf area ratio decreased from 0.260 to 0.206 $cm^2 \cdot mg^{-1}$ at 28 days after sowing when potassium increased from 0 to 60 $mg \cdot L^{-1}$. At 35 days after sowing, leaf area ratio decreased from 0.342 to 0.215 $cm^2 \cdot mg^{-1}$ as potassium increased from 0 to 30 $mg \cdot L^{-1}$. At the same sampling time, the lowest leaf area ratio obtained from transplants that were propagated at 30 $mg \cdot L^{-1}$ P.

Net assimilation rate

Application of phosphorus increased the net assimilation rate irrespective of sampling date (Table 3.3). Increasing phosphorus from 0 to 45 mg·L^{-1}, increased net assimilation rate from 2.67 to 3.50 mg·qm^{-2}·ávk^{-1} in transplants that were sampled 28 days after sowing. At 35 days after sowing, the greatest net assimilation rate was achieved with 30 mg·Ë$^{-1}$ P.

Relative growth rate

Phosphorus application enhanced relative growth rate at 35 days after sowing (Table 3.3). However, there was a quadratic decrease in relative growth rate at 28 days after sowing. At the same time relative growth rate decreased from 0.72 to 0.68 mg·ímg^{-1}·ávk^{-1} in transplants that were propagated with 0 and 30 mg·L^{-1} P. At 35 days after sowing, the relative growth rate increased from 0.37 to 0.48 mg·hmg^{-1}·ávk^{-1} in transplants that received 0 and 30 mg·Ł$^{-1}$ P, respectively. Soundy *et al*. (2001b) found that phosphorus applied to lettuce transplants improved relative growth rate.

3.4 CONCLUSIONS

Phosphorus applied at about 15 mg·Ľ$^{-1}$ through floatation irrigation was enough to give transplants with optimum shoot and root growth. Quality transplants had plant height of 146.5 mm, root: shoot ratio of 0.22, dry root mass of 43.3 mg, dry shoot mass of 219.5 mg, leaf phosphorus of 5.48 g·kg^{-1} and pulling success of 90 %. Phosphorus application improved the quality of cabbage transplants by increasing pulling success from 40 % to 90 %.

3.5 SUMMARY

A greenhouse experiment was conducted to determine the effect of phosphorus on shoot and root growth. Cabbage transplants were propagated at 0, 15, 30, 45 and 60 mg·L^{-1} P supplied from NaH_2PO_4. Nitrogen and potassium were applied at 90 and 30 mg·Ł$^{-1}$ supplied from NH_4NO_3 and KCl, respectively. Irrigation was done by floating cavity trays in nutrient solution until the growing medium reached field capacity. Transplant trays were then removed from the growing medium and put back on the benches. At 21 days after sowing, sampling was started and continued weekly until 35 days after sowing. At each sampling date, the following parameters were recorded; plant height, leaf number, leaf area, fresh shoot mass and fresh root mass. Dry shoot and root mass were obtained by drying the samples at 65 ^{o}C

for 48 hours. At 35 days after sowing, five transplants were removed from each replication and the number of transplants that pulled out without breaking was recorded.

Application of phosphorus increased plant height, leaf area, fresh shoot mass, leaf phosphorus concentration and dry root mass. Phosphorus applied at 15 $mg \cdot L^{-1}$ through floatation irrigation was enough to improve cabbage transplant shoot and root growth. A quality transplant had plant height of 146.5 mm, root: shoot ratio of 0.22, dry root mass of 43.3 mg, dry shoot mass of 219 .5 mg, leaf phosphorus of 5.48 $g \cdot kg^{-1}$ and pulling success of 90%.

CHAPTER 4

RESPONSE OF CABBAGE TRANSPLANTS TO POTASSIUM NUTRITION

4.1 INTRODUCTION

Potassium is used as an activator in many enzymatic reactions in the plant. Also, potassium plays a role in the guard cells found around the stomata, therefore, controls the opening and closing of the stomata (Salisbury & Ross, 1992; Tisdale *et. al*., 1993; Hochmuth, 2001). Potassium is important in carbohydrate formation and translocation of sugars (Acquaah, 2005). Potassium has been reported to play an important role in growth and elongation which could be because of its osmoticum and a synergetic effect with indole acetic acid (IAA). Dela Guardia & Benlloch (1980) reported stem elongation in sunflower plants after being propagated at varying levels of K^+ combined with different concentrations of gibberillic acid (GA_3). Potassium is taken up as K^+ ion.

Leaf area of celery and broccoli was increased by potassium applied daily at 50 to 350 mg·L^{-1} while lettuce leaf area was only increased when potassium was increased in combination with 350 mg·L^{-1} N but not with 150 mg·L^{-1} N. In addition, increasing potassium combined with 150 mg·L^{-1} N decreased pepper leaf area but increased it when nitrogen increased to 350 mg·L^{-1}. However, neither root growth nor root: shoot ratio of broccoli, celery and lettuce were affected by potassium (Tremblay & Senécal 1988).

In another study, Soundy *et al*.. (2001a) reported that increasing potassium in nutrient solution from 0 to 60 mg·L^{-1}, increased fresh and dry root mass of lettuce transplants. However, fresh and dry shoot mass, leaf area, root: shoot ratio, relative growth rate, leaf mass ratio and root mass ratio were not affected by applied K irrespective of initial K in the growing medium. When 60 mg·L^{-1} N was compared with 100 mg·L^{-1} N at various levels of K, dry root mass was reduced at 100 mg·L^{-1} Ncompared to 60 mg·L^{-1} N irrespective of level of K.

Data is still lacking on the response of cabbage transplants to applied potassium. Therefore, the objective of this study was to determine the effect of potassium nutrition on shoot and root development of cabbage transplants.

4.2 MATERIALS AND METHODS

The experiment was conducted during the winter season at the Hatfield Experimental Farm of the University of Pretoria (26° 12'S, 28° 10'E). The experiment was conducted in a greenhouse. Seeds of cabbage cultivar 'Drumhead' were sown on 24 June 2005 and the experiment was terminated on 31 July 2005. The layout of the experiment was a randomized complete block design with four replications with each replication having 50 plants. The transplant trays used were 200 inverted pyramid cavity trays that are commonly used in South Africa for vegetable transplant production. Cavity trays were filled with 'Cultera' growing medium and three seeds were sown per cavity. Thereafter, the trays were covered with a thin layer of vermiculite. The growing medium had no added fertilizer. Irrigation was done with a watering can until treatment application was initiated. Transplants were thinned to leave one plant per cavity.

Potassium levels were 0, 15, 30, 45 and 60 mg·Ł$^{-1}$ supplied as KCl. Phosphorus and nitrogen were applied at 30 and 90 mg·Ł$^{-1}$ supplied from NaH_2PO_4 and NH_4NO_3, respectively. Other nutrients like Ca, Mg, S, B, Mn, Mo Cu and Zn were applied at half strength Hoagland's solution. Application of treatments started 5 - 6 days after emergence. The nutrient solutions were prepared in 150 L containers and were replaced only when depleted. Irrigation was done by floating cavity trays in nutrient solution until the growing medium reached field capacity. Transplant trays were then removed from nutrient solution and put back on benches. After every irrigation, the nutrient solution was put back into the containers. The greenhouse air temperature was monitored using Johnson controls, Penn F010 wall mounted thermometer. During the experiment, the minimum and maximum temperature was 20 and 30 ^{o}C, respectively.

4.2.2 Sampling

Sampling was initiated on 16 July 2005 and continued weekly until 31 July 2005. Measurements of plant height, number of expanded true leaves (leaves with a clearly visible petiole), leaf area (using leaf area meter, model Ll-3100, Ll-COR, Lincoln, Nebraska), root and shoot (fresh and dry) mass were recorded from five transplants sampled every week from each replication. After being removed from cavity trays, transplants were washed under running tap water until all the growing medium had been removed and then divided into shoots and roots before measurements were taken. Shoot and root dry mass were obtained by

drying transplants at 65 °C for 48 hours before weighing them. The experiment was terminated when transplants from at least one treatment across all replications could easily pull out of tray cells without breaking. At termination of the experiment, five plants were pulled from each replicate and their pulling success recorded. Pulling success (%) was the number of plants that could be removed from the cells without breakage. The remaining plants were harvested and oven dried before being ground to pass through a 2 mm sieve. After that, the samples were submitted to the University of Pretoria Soil Science Laboratory for tissue analysis of total K.

Growth parameters calculated were (Hunt, 1982; Gardner, Pearce & Mitchell, 1990; Nicola & Cantliffe, 1996):

- Root to shoot ratio (RSR = dry root mass ÷ dry shoot mass)
- Relative growth rate (RGR = [ln(final total dry mass – ln(initial total dry mass) ÷ (final time – initial time)])
- Net assimilation rate (NAR = (final total dry mass – initial total dry mass) ÷ (final time – initial time) × [(ln(final leaf area) – ln(initial leaf area)])
- Specific leaf area (SLA = leaf area ÷ dry shoot mass)
- Leaf area ratio (LAR = leaf area ÷ total dry mass)
- Root mass ratio (RMR = dry root mass ÷ total dry mass)
- Pulling success (PLS = Percentage of transplants that could easily pull out of trays without breaking)

Data was then subjected to analysis of variance using the Statistical Analysis System (SAS Institute Inc., 2003) software. Treatment sums of squares were partitioned into linear and quadratic polynomial contrasts.

4.3 RESULTS AND DISCUSSION

4.3.1 Shoot development

Plant height

At the first and second sampling dates, plant height was not affected by application of potassium (Table 4.1). However, at 35 days after sowing, plant height had increased in a

linear fashion in response to potassium application. At 35 days after sowing, the plant height had increased to 140, 144, 144, 162 and 152 mm for transplants that received 0, 15, 30, 45 and 60 mg·L^{-1} K, respectively. According to Acquaah (2005), potassium plays a role in cell division and this could be the reason for the linear increase in plant height attained at 35 days after sowing. However, this contradicts what has been reported on lettuce (Soundy *et al*., 2001a), tomato (Melton & Dufault, 1991) and celery (Dufault, 1985) that potassium did not affect plant height. Moreover, the difference could have been because the authors used growing medium that contained some extractable potassium and, therefore, the potassium in the medium alone could have been enough for transplant growth.

Leaf number

Leaf number was not affected by application of potassium during transplant production irrespective of date of sampling (Table 4.1). At 2 1 days after sowing, transplants had 3 leaves and this increased to 4 and 5 at 28 and 35 days after sowing, respectively. Most authors have reported that potassium had no effect on leaf number of different vegetables that they tested, such as lettuce (Soundy *et al*., 2001a) and tomato (Melton & Dufault, 1991).

Leaf area

Leaf area was affected by application of potassium to cabbage transplants (Table 4.1). At 21 days after sowing, leaf area decreased in a quadratic fashion with the largest leaf area recorded from transplants that were propagated with 0 mg·L^{-1} K. At 28 days after sowing, leaf area increased in a quadratic fashion as potassium increased reaching a maximum at potassium level of 30 mg·L^{-1} and then decreased. At 35 days after sowing, leaf area was not affected by applied potassium. The reason for the increase in leaf area at second sampling (28 days after sowing) could have been due to the role potassium play in cell division and carbohydrate formation. The results obtained confirmed what Tremblay & Senécal (1988) reported that application of potassium with high levels of nitrogen increased leaf area of lettuce and pepper. However, the results contradicts the findings of Dufault (1985), Melton & Dufault (1991a) and Soundy *et al.* (2001a) who reported that application of potassium had no effect on leaf area of celery, tomato and lettuce, respectively.

Table 4.1 Shoot characteristics of cabbage transplants in response to potassium nutrition, June/July 2005

Potassium applied ($mg \cdot L^{-1}$)	Plant height (mm)	Leaf number	Leaf area (cm^2)	Fresh shoot mass (mg)	Dry shoot mass (mg)	Leaf potassium ($g \cdot kg^{-1}$)
			21 days after sowing (1st sampling)			
0	70.0	2.9	14.69	640	64.5	
15	69.3	3.1	13.30	544	65.0	
30	71.9	2.7	14.52	557	64.5	
45	71.2	3.2	13.91	598	64.0	
60	71.6	2.9	14.63	599	63.7	
Response	NS	NS	Q**	Q**	NS	
			28 days after sowing (2nd sampling)			
0	107.2	4.4	33.13	1474	144.0	
15	115.6	4.6	34.08	1488	143.7	
30	118.3	4.4	35.10	1572	143.2	
45	109.9	4.3	32.94	1374	144.0	
60	112.0	4.1	32.70	1311	142.7	
Response	NS	NS	Q**	Q**	NS	
			35 days after sowing (3rd sampling)			
0	140.2	5.2	58.68	2542	284.0	17.23
15	144.1	5.2	60.12	2836	282.7	16.25
30	143.6	5.1	59.01	2911	283.5	21.88
45	162.0	5.3	61.33	3238	284.0	26.88
60	152.4	5.3	58.83	2830	283.7	29.88
Response	L**	NS	NS	Q**	NS	Q**

Linear (L) or quadratic (Q) effects significant at P=<0.05 (*), 0.01 (**) or nonsignificant (NS)

Fresh and dry shoot mass

Fresh shoot mass increased in a quadratic fashion as potassium increased at 28 and 35 days after sowing. At first sampling, fresh shoot mass decreased in a quadratic fashion from 640 to 544 mg as potassium increased. At the same time, the lowest fresh shoot mass was obtained from transplants that propagated at 15 $mg \cdot L^{-1}$ K.

Potassium did not affect dry shoot mass regardless of sampling time (Table 4.1). Elimination of potassium in the nutrient solution during transplant production did not have any detrimental effect on shoot growth of celery (Dufault, 1985), tomato (Melton & Dufault, 1991a) and lettuce (Soundy *et al.*, 2001a).

Leaf potassium content

The leaf potassium content in the transplant tissues increased quadratically as K applied increased (Table 4.1). The potassium content in the tissues was 17.23, 16.25, 21.88, 26.88 and 29.88 $g \cdot kg^{-1}$ for transplants that received 0, 15, 30, 45 and 60 $mg \cdot L^{-1}$ K, respectively. However, despite the significant increase in the concentration of potassium in the plant tissue, potassium did not affect dry shoot mass.

4.3.2 Root development

Fresh and dry root mass

Application of potassium increased fresh root mass irrespective of sampling time (Table 4.2). At 21 days after sowing, fresh root mass was 124, 127, 113, 94 and 89 mg for transplants that were propagated with 0, 15, 30, 45 and 60 $mg \cdot L^{-1}$ K, respectively. Dry root mass was not affected by application of potassium irrespective of sampling dates. Irrespective of potassium level, dry root mass increased as the transplants grew older (21, 28 and 35 DAS). Liptay *et al*. (1992) reported that in tomato, increasing potassium decreased root growth.

Root: shoot ratio

Root: shoot ratio was not affected by potassium regardless of sampling dates (Table 4.2). Similar results were reported on celery (Dufault, 1985), broccoli, celery and lettuce (Tremblay & Senécal, 1988), tomato (Melton & Dufault, 1991) and lettuce (Soundy *et al*., 2001a).

Table 4.2 Root characteristics of cabbage transplants in response to potassium nutrition, June/July 2005

Potassium applied ($mg \cdot L^{-1}$)	Fresh root mass (mg)	Dry root mass (mg)	Root: shoot ratio	Root mass ratio	Leaf mass ratio	Pulling success (%)
21 days after sowing (1st sampling)						
0	124.0	15.2	0.236	0.19	0.81	
15	126.5	15.2	0.234	0.19	0.81	
30	112.6	15.0	0.233	0.19	0.81	
45	93.8	15.0	0.234	0.19	0.81	
60	89.0	14.0	0.220	0.18	0.82	
Response	L**	NS	NS	NS	NS	
28 days after sowing (2nd sampling)						
0	141.5	22.5	0.157	0.13	0.87	
15	149.5	22.7	0.158	0.14	0.86	
30	196.5	22.2	0.155	0.16	0.84	
45	209.0	21.5	0.149	0.14	0.86	
60	265.5	21.5	0.149	0.14	0.86	
Response	Q**	NS	NS	NS	NS	
35 days after sowing (3rd sampling)						
0	541.2	51.0	0.213	0.16	0.84	85
15	305.5	51.7	0.182	0.15	0.85	90
30	588.0	51.0	0.185	0.16	0.84	90
45	592.5	52.5	0.187	0.16	0.84	95
60	593.5	51.5	0.176	0.15	0.85	90
Response	Q**	NS	NS	NS	NS	Q**

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

Root mass ratio

Root mass ratio was not affected by application of potassium (Table 4.2). About 84% of dry matter was partitioned to shoots and while 16% to roots. This could suggest that potassium does not play a major role in dry matter partitioning.

Leaf mass ratio

Leaf mass ratio was not affected by application of potassium (Table 4.2).

Pulling success

Potassium application improved the pulling success of cabbage transplants. The pulling success increased from 85 to 95 % when applied potassium was increased from 0 to 45 mg·L^{-1} (Table 4.2).

4.3.3 Growth parameters

Specific leaf area

Potassium application affected specific leaf area only at 21 and 28 days after sowing (Table 4.3). Specific leaf area was 0.232, 0.237, 0.245, 0.229, 0.229 cm^2·mg^{-1} at second sampling (28 days after sowing) for transplants that were propagated with 0, 15, 30, 45 and 60 mg·L^{-1} K, respectively. Specific leaf area of transplants increased in a quadratic fashion as potassium increased at 28 days after sowing, this could be due to the quadratic increase potassium had on leaf area. At 28 days after sowing, specific leaf area was greatest with potassium level of 30 mg·L^{-1}. Soundy *et al*. (2001a) reported that at 28 DAS, the specific leaf area of lettuce transplants was not affected by potassium combined with 60 mg·L^{-1} N but increased linearly when potassium was combined with 100 mg·L^{-1} N. At 35 days after sowing, potassium did not affect specific leaf area and this could mean that potassium had reached luxury consumption and this according to Acquaah (2005) is when an increase in potassium does not have an effect plant growth.

Leaf area ratio

Leaf area ratio was 0.184, 0.166, 0.183, 0.176 and 0.188 cm^2 mg^{-1} (Table 4.3) at 21 days after sowing in transplants that were propagated with 0, 15, 30, 45 and 60 mg·L^{-1} K. Leaf area ratio was affected by potassium during first and second sampling, but was not affected by potassium at 35 days after sowing. Soundy *et al*. (2001a) reported that at 28 DAS, leaf area ratio of lettuce was not affected by potassium combined with 60 mg·L^{-1} N, but increased linearly when potassium was combined with 100 mg·L^{-1} N.

Table 4.3 Growth parameters of cabbage transplants in response to potassium nutrition, June/July 2005

Potassium applied ($mg \cdot L^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)
	21 days after sowing (1st sampling)			
0	0.228	0.184		
15	0.205	0.166		
30	0.225	0.183		
45	0.217	0.176		
60	0.227	0.188		
Response	Q**	Q**		
	28 days after sowing (2nd sampling)			
0	0.232	0.200	3.78	0.730
15	0.237	0.205	3.91	0.730
30	0.245	0.212	3.69	0.733
45	0.229	0.199	3.92	0.747
60	0.229	0.199	3.84	0.737
Response	Q**	Q**	NS	NS
	35 days after sowing (3rd sampling)			
0	0.206	0.175	3.80	0.705
15	0.212	0.179	3.68	0.701
30	0.208	0.176	3.67	0.704
45	0.216	0.183	3.74	0.708
60	0.208	0.176	3.83	0.714
Response	NS	NS	Q**	NS

Linear (L) or quadratic (Q) effects significant at P=Ÿ.05 (*), 0.01 (**) or nonsignificant (NS)

Net assimilation rate

At 28 days after sowing, potassium application did not affect net assimilation rate of cabbage transplants (Table 4.3). However, during the third sampling the net assimilation rate decreased in a quadratic fashion to applied K. At 35 days after sowing, the net assimilation rate was 3.80, 3.68, 3.67, 3.74 and 3.83 $mg \cdot cm^{-2} \cdot wk^{-1}$ for transplants propagated with 0, 15, 30, 45 and 60 $mg \cdot L^{-1}$ K, respectively.

Relative growth rate

Relative growth rate was not affected by potassium application irrespective of date of sampling (Table 4.3). This showed that potassium did not contribute to accumulation of dry matter in cabbage transplants.

4.4 CONCLUSIONS

Application of potassium to cabbage transplants did not affect shoot and root growth therefore potassium applied as low as 15 mg·Ï$^{-1}$ is enough for cabbage transplant growth.

4.5 SUMMARY

A study was conducted to determine the effect of potassium nutrition on shoot and root development of cabbage transplants.

'Drumhead' seeds were sown in cavity trays on 22 June 2005. Potassium was applied at 0, 15, 30, 45, and 60 mg·ħ$^{-1}$ supplied from KCl. Nitrogen and phosphorus were applied at 90 mg·ħ$^{-1}$ and 30 mg·L^{-1} supplied from NH_4NO_3 and NaH_2PO_4 respectively. Sampling was initiated on 15 July 2005 and continued weekly until 31 July 2005. During each sampling, the number of leaves, plant height, leaf area, shoot and root (fresh and dry) mass were recorded from five transplants sampled from each replication. Dry shoot and root mass was obtained by drying shoots and roots in an oven at 65 ^{o}C for 48 hours.

The leaf area, specific leaf area and leaf area ratio were affected at the first and second sampling but not at third sampling. The plant height was affected by potassium at third sampling. Potassium affected the net assimilation rate between 28 DAS and 35 DAS and this is due to the effect potassium had on leaf area at second sampling (28 DAS). However, application of potassium to cabbage transplants did not affect shoot and root growth therefore potassium applied as low as 15 mg·Ł$^{-1}$ is enough for cabbage transplant growth.

GENERAL DISCUSSION AND CONCLUSIONS

Poor root development is a problem in transplants that are produced in cavity trays as transplants tend to break when being pulled out of cavity trays during transplanting. Cabbage transplants were propagated at different levels of N, P and K using floatation irrigation system. During the autumn and spring seasons, nitrogen applied to cabbage transplants improved shoot and root growth. Higher levels of nitrogen compared to lower levels increased dry matter partitioning to the shoots than to the roots, resulting in decreased root: shoot ratios and root mass ratios. This showed that higher levels of nitrogen encourage more shoot growth at the expense of root growth. Moreover, applied nitrogen increased net assimilation rate, specific leaf area, leaf area ratio and relative growth rate indicating an increase in shoot growth.

In transplants that were sampled 42 and 35 days after sowing, increasing applied nitrogen from 0 to 120 mg·L^{-1}, increased plant height from 35.0 to 157.0 mm and 33.5 to 165.7 mm during autumn and spring, respectively. . Transplants that were propagated during spring were generally taller than those propagated during autumn. The difference in plant height could be attributed to the difference in greenhouse air temperature and light during autumn and spring.

Leaf nitrogen and pulling success also improved as nitrogen increased during the two seasons. Leaf nitrogen content of transplants that were propagated during autumn increased from 10.3 to 28.3 g·kg^{-1} while that in transplants that were propagated during spring increased from 13.0 to 43.7 g·kg^{-1} as applied nitrogen increased from 0 to 120 mg·L^{-1}. The high temperatures in autumn could have contributed to the lower leaf nitrogen content because as air temperature increases, the stomata will close to reduce moisture loss leading to reduced nutrient uptake. During autumn, quality transplants were obtained from transplants that were propagated at 90 mg·L^{-1} N while in spring quality transplants were obtained from transplants that received 60 mg·L^{-1} N. The results obtained indicate that during transplant production nitrogen fertilisation need to be varied according to prevailing air temperature and amount of light available.

Pretransplant nitrogen, improved yield of cabbage despite the fact that transplants were given the same amount of fertilizer and same agronomic practices. During autumn, transplants that

were propagated at 90 mg·Â$^{-1}$ N gave higher cabbage yield while in spring, the highest yield was recorded from transplants that received 60 mg·L^{-1} N. Trimmed yield increased from 29.6 to 64.6 t·ha^{-1} during winter and summer, the increased was from 57.8 to 82.01 t·ha^{-1}. Yield in summer was higher than that in winter because in summer cabbage heads were heavier than those harvested in winter. The other reason could be the slow growth of plants in winter which resulted in most plants having unmarketable heads because they were too small. Pretransplant nitrogen improved head quality in all the seasons. The head diameter increased from 98 to 223 mm during winter as pretransplant nitrogen increased from 0 to 90 mg·L^{-1} while in spring the increase was from 173.8 to 225 mm as pretransplant nitrogen increased from 0 to 120 mg·Ì$^{-1}$. This indicates that pretransplant nitrogen should be considered as it affects the yield potential of cabbage even if the transplant were given the same amount of fertilizers and agronomic practices in the field.

Phosphorus application improved leaf area, fresh and dry shoot mass, fresh and dry root mass, pulling success and leaf phosphorus content indicating that applied phosphorus enhanced transplant growth. As nitrogen increased from 0 to 45 mg·Ç$^{-1}$, plant height increased from 132.9 to 150.2 mm in transplants that were sampled 35 days after sowing. Leaf area also increased from 24.22 to 55.96 cm^2 in transplants that were propagated with 0 to 30 mg·Ñ$^{-1}$ P. Phosphorus contributed more to dry shoot mass and therefore lead to a decrease in specific leaf area and leaf area ratio. Application of phosphorus improved the pulling success from 40 % to 90 %. However, most of the increases in growth were achieved with 15 mg·þ$^{-1}$ P. Therefore, application of at least 15 mg·L^{-1} P during cabbage transplant production was enough to give quality transplants.

Potassium nutrition did not affect most of the shoot and root parameters. However, plant height increased from 140.2 to 162.0 mm as nitrogen increased from 0 to 45 mg·Ì$^{-1}$, above that plant height decreased during the third sampling. Increasing the level of potassium in the nutrient solution increased leaf potassium quadratically despite the fact that potassium had no effect on leaf number, leaf area or dry shoot mass. Pulling success was improved by application of potassium even though potassium did not affect dry root mass but increased fresh root mass. Therefore, applying at least 15 mg·Û$^{-1}$ K during cabbage transplant production was enough to give quality transplants.

In conclusion, a quality transplant can be produced with 15 mg·Ł$^{-1}$ K. Phosphorus applied at 15 mg·L^{-1} was enough to give quality transplants. Nitrogen applied at 90 mg·L^{-1} in autumn

and 60 mg·Â$^{-1}$ in spring could be considered to adequate for cabbage transplant production. Pretransplant nitrogen at 90 mg·L^{-1} during winter and 60 mg·L^{-1} in summer resulted in higher yields. The results obtained indicates that preatransplant nitrogen in important in cabbage production. Transplant producers should always take into account the difference in air temperature and amount of light between the seasons and adjust amount of nitrogen applied accordingly.

Issues relating to relationship between amount of N, P and K applied during plant growth and the effect on the nutritive value of the produce and cost of producing transplants using floatation irrigation system were not addressed in the current study. Therefore, these issues need to be considered in future studies that will be done on cabbage production.

GENERAL SUMMARY

Cabbage transplants were propagated with different levels of nitrogen, phosphorus and potassium in separate experiments to determine the amount of nitrogen, phosphorus and potassium that could optimise shoot and root development.

To determine the effect of phosphorus nutrition in shoot and root growth, cabbage transplant were propagated by floating them in nutrient solutions containing, 0, 15, 30, 45 and 60 mg·L^{-1} P. When phosphorus levels were increased from 0 to 45 mg·L^{-1}, plant height, leaf area and fresh and dry shoot mass increased but decreased as phosphorus increased to 60 mg·L^{-1}. Dry root mass was highest in transplants that received 15 mg·L^{-1} P. Applied phosphorus increased leaf phosphorus and pulling success but reduced root: shoot ratio, root mass ratio, specific leaf area and leaf area ratio. Only about 40 % of transplants grown with 0 P could pull out of cavity trays compared to about 90 % pulling success achieved with any level of P. Quality transplants had plant height of not more than 146 mm, root: shoot ratio of 0.22, dry root mass of not less than 43 mg, dry shoot mass of 219 .5 mg, leaf phosphorus of 5.48 g·kg^{-1} and pulling success of 90%. These results indicate that phosphorus applied at15 mg·L^{-1} via floatation irrigation was enough to give quality cabbage transplants.

In order to determine the amount of nitrogen that could optimise shoot and root growth, cabbage transplants were propagated at 0, 30, 60, 90 and 120 mg·D^{-1} N during autumn and in spring. Increasing nitrogen, increased plant height, leaf number, leaf area, fresh and dry shoot mass, leaf nitrogen, fresh and dry root mass, leaf mass ratio and pulling success, specific leaf area, leaf area ratio, net assimilation rate and relative growth rate. However, the root: shoot ratio and root mass ratio were decreased as nitrogen increased regardless of season. Transplants grown with 90 mg·L^{-1} N had plant height of not more than 152 mm, dry shoot mass of less than 283 mg and dry root mass of 57.5 mg. About 10 % of transplants that were propagated with 0 N could pull out of cavity trays while 90 % of transplants that received N could pull out of cavity trays during autumn. During spring, a quality transplant had plant height of not more than 119 mm, leaf area of 47.7 cm^{-2}, dry root mass of 35.5 mg, dry shoot mass of 208 mg, root: shoot ratio of 0.17, leaf mass ratio of 0.85, root mass ratio of 0.15 and pulling success of 95 %.

In the field during winter, cabbage head yield and head mass at harvest were improved by pretransplant nitrogen. The highest trimmed head mass was recorded from plants grown at pretransplant nitrogen of 90 mg·L^{-1}. About 90 mg·L^{-1} pretransplant nitrogen was enough to transplants that had the highest dry root mass and gave the highest trimmed head yield and mass. Pretransplant nitrogen improved cabbage head quality in terms of core diameter and core height. Pretransplant N did not affect the core diameter and core height indicating that the heads were not going to produce flower stalk.

In spring, pretransplant nitrogen of 60 mg·L^{-1} gave the highest head yield and mass. Core height was not affected by pretransplant nitrogen showing pretransplant nitrogen does not enhance flowering. The cabbage flower is the extension of the head core out of the cabbage head. The higher the head core extend through the head, the marketability of the head reduces it tends to crack.

Floating cavity trays in nutrient solution containing, 0, 15, 30, 45 and 60 mg·L^{-1} K increased plant height, fresh shoot mass, leaf potassium, specific leaf area, pulling success, leaf area ratio and net assimilation rate. Moreover, applied potassium did not affect leaf number, leaf area, dry shoot mass, root: shoot ratio, root mass ratio, leaf mass ratio and relative growth rate. Plant height increased from 140.2 to 162.0 mm when potassium increased from 0 to 90 mg·L^{-1} above which the plant height decreased. The highest fresh shoot mass was achieved with 45 mg·L^{-1} K. 85 % of transplants that received 0 K could pull out cavity trays while about 90 % of transplants that received K could pull out of the trays. Therefore, applying at least 15 mg·L^{-1} K during cabbage transplant production was enough to give quality transplants.

LITERATURE CITED

ACQUAAH, G. 2005. Principles of crop production: Theory, techniques and technology. 2nd Ed. Pearson Prentice Hall, New Jersey.

ADAMS, P., 1991. Effects of increasing the salinity of the nutrient solution with major nutrients or sodium chloride on the yield, quality and composition of tomatoes grown in rockwool. *J. Hort. Sci.* 66, 201 207.

ADAMS, P. & HO, L.C., 1989. Effects of constant and fluctuating salinity on the yield, quality and calcium status of tomatoes. *J. Hort. Sci*. 64, 725-732.

ADLER P.R., DUFAULT, R.J. & WATERS Jr., L., 1984. Influence of nitrogen, phosphorus and potassium on asparagus transplant quality. *HortScience* 19, 565 566.

ALONI, B., PASHKAR, T. & KARNI, L., 1991. Nitrogen supply influence carbohydrate partitioning of pepper seedlings and transplant development. *Amer. Soc. Hort. Sci*. 116, 995 999.

ASIAN VEGETABLE RESEARCH AND DEVELOPMENT CENTER, 1990. Vegetable production training manual. Tainan, Taiwan.

ASKEW, D., 1999a. Cabbage series: Part IV: Fertilizer application and liming. Hygrotech Forum. Newsletter of Hygrotech Seed (Pty) Ltd, Pretoria.

ASKEW, D., 1999b. Cabbage series: Part VI: Nutritional disorders, harvesting and marketing. Hygrotech Forum. Newsletter of Hygrotech Seed (Pty) Ltd, Pretoria.

BABB, M.F., 1940. Residual effects of hardening of tomato, cabbage, and cauliflower plants. USDA Tech. Bul. 760 (Cited by Dufault, 1998).

BAR-TAL, A., BAR-YOSEF, B. & KAFKAFI, U., 1990. Pepper transplant response to root volume and nutrition in the nursery. *Agron. J*. 82, 989-995.

BASSOCU, L. & NICOLA, S., 1992. Effect of nutrition and substrate water content on growth under protection of pepper seedlings and fruit production in the field. *Acta Hortic*. 323, 121-126.

BASSOCU, L. & NICOLA, S., 1995. Supplementary light and pretransplant nitrogen effects on tomato seedling growth and yield. *Acta Hortic*. 396, 313-320.

BIERNBAUM, J.A. & VERSLUYS, B.N., 1998. Water management. *HortTechnology* 8. Online, http://google.com/innopac.up.ac.za. Accessed: 23.06.2005.

BROWWER, R., 1962. Nutritive influences on the distribution of dry matter in the plant. *Neth. J. Agr.Sci*. 10, 399-408 (Cited by Aloni *et al*., 1991).

CANTLIFFE, D.J. & KARCHI, Z., 1992. Performance of crisphead lettuce cultivars on plyethylene-mulched, drip-irrigated sandy soils in Florida. Proc. Fla. State Hort. Soc. 105, 340-342.

DELA GUARDIA, M.D. & BENLLOCH, M., 1980. Effects of potassium and gibberellic acid on stem growth of whole sunflower plants. *Physiol. Plant* 49, 443-448 (Cited by Mengel & Kirkby, 1987).

DUFAULT, R.J., 1985. Relationship among nitrogen, phosphorus and potassium fertility regimes on celery transplant growth. *HortScience* 20, 1104-1106.

DUFAULT, R.J., 1986. Influence of nutritional condition on muskmelon transplant quality and early yield. *J. Amer. Soc. Hort. Sci*. 111, 698 703.

DUFAULT, R.J., 1987. Use of slow-release nitrogen and phosphorus fertilizers in celery transplant production. *HortScience* 22, 1268-1270.

DUFAULT, R.J., 1998. Vegetable transplant nutrition. *HortTechnology* 8. Online, http://goggle.com/innopac.up.ac.za. Accessed: 9.02.2005.

DUFAULT, R.J. & SCHULTHEIS, J.R., 1994. Bell pepper seedling growth and yield following pretransplant nutritional conditioning. *HortScience* 29, 999-1001.

FISHER, K.J. & BENSON, B.L., 1983. Effects of nitrogen and phosphorus nutrition on the growth of asparagus seedlings. *Sci. Hortic*. 21, 105-112.

FISHER, K.J. & BENSON, B.L., 1984. Effects of nitrogen, volume of media, plant density and module shape on the growth of asparagus seedlings. *Sci. Hortic*. 24, 45-51.

GARDNER, F.P., PEARCE, R.B. & MITCHELL, R.L., 1990. Physiology of crop plants. 2nd Ed. Ames: The Iowa State University Press, Iowa, USA.

GARTON, R.W & WIDDERS, I.E., 1990. Nitrogen and phosphorus preconditioning of small-plug seedling influence processing tomato productivity. *HortScience* 25, 655-657.

GILBERT, Z. & HADFIELD, J., 1992. Down-to earth fruit and vegetable gardening in South Africa. Struik Publishers. Singapore.

HAVLIN, J.L., BEATON, J.D., TISDALE, L.S. & NELSON, W.L., 2005. Soil fertility and fertilizers: An introduction to nutrient management. 7 th Ed. Pearson Prentice Hall.

HEMY, C., 1984. Growing vegetables in South Africa. Macmillan Publishers. South Africa.

HOCHMUTH, G.J., 2001. Fertilizer management for greenhouse vegetables – Florida greenhouse vegetable production handbook. Vol.3.Online: http://o-edis.ifas.ufl.edu. Accessed: 20/06/2005.

HUANG, J., NELSON, P.V., BAILEY, D.A., FONTENO, W.C. & MINGIS, N.C., 2002. Assessment of the need for nitrogen, phosphorus, potassium and sulphur preplant nutrients for plug seedling growth. *HortScience* 37, 529-533.

HUNT, R., 1982. Plant growth curves: The functional approach to plant growth analysis. Edward Arnold, London.

INGESTAD, T., 1979. Nitrogen stresses in birch seedlings. *Physiol. Plant* 45, 149-157 (Cited by Aloni *et al*., 1991).

KARCHI, Z., DAGAN, A. & CANTLIFFE, D.J., 1992. Growth of containerized lettuce transplants supplemented with varying concentrations of nitrogen and phosphorus. *Acta Hortic*. 319, 365-370.

LESKOVAR, D.I. & CANTLIFFE, D.J., 1993. Comparison of plant establishment method, transplant or direct-seeded, on growth and yield of bell pepper. *J. Amer. Soc. Hort. Sci*. 118, 17 22.

LESKOVAR, D.I. & HEINEMAN, R.R., 1994. Growth of 'TAM –Mild Jalapeno-1' pepper seedlings affected by greenhouse irrigation systems. *HortScience* 29, 1470 1474.

LIPTAY, A. & NICHOLLS, S., 1993. Nitrogen supply during greenhouse transplant production affects subsequent tomato growth in the field. *J. Amer. Soc. Hort. Sci*. 118, 339-342.

LIPTAY, A., NICHOLLS, S. & SKKEMMA, P., 1992. Optimal mineral nutrition of tomato transplants in the greenhouse for maximum performance in the field. *Acta Hortic*. 319, 489-492.

MASSON, J., TREMBLAY, N. & GOSSELIN, A., 1991a. Nitrogen fertilization and HPS supplementary lighting influence vegetable transplant production. I. Transplant growth. *J. Amer. Soc. Hort. Sci*. 116, 594 598.

MASSON, J., TREMBLAY, N. & GOSSELIN, A., 1991b. Effects of nitrogen fertilisation and HPS supplementary light on vegetable transplant production. II. Yield. *J. Amer. Soc. Hort. Sci*. 116, 599 602.

MELTON, R.R. & DUFAULT, R.J., 1991a. Nitrogen, phosphorus and potassium fertility regimes affect tomato transplant growth. *HortScience* 26, 141 142.

MELTON, R.R. & DUFAULT, R.J., 1991b. Tomato seedling growth, earliness, yield, and quality following pretransplant nutritional conditioning and low temperatures. *J. Amer. Soc. Hort. Sci.* 116, 421-425.

MENGEL, K. & KIRKBY, E.A., 2001. Principles of plant nutrition. 5th Ed.: International Potash Institute, Bern, Switzerland.

NATIONAL DEPARTMENT OF AGRICULTURE, 2004. Abstracts of agricultural statistics. South Africa.

NATIONAL SCIENCE AND DEVELOPMENT BOARD, 1980. Food composition tables. 5th revision. Manila, Philipinnes (Cited by Asian Vegetable Research and Development Center, 1990).

NICOLA, S. & BASOCCU, L., 2000. Timing of nitrogen application influence tomato (*Lycopersicon esculentum* MILL.) seedling nitrogen content, growth rates and biomass partitioning, and field fruit earliness. *Acta Hortic*. 533, 127-134.

NICOLA, S. & CANTLIFFE, D.J., 1996. Increasing cell size and reducing medium compression enhances lettuce transplant quality and field production. *HortScience* 31, 184-189.

NOGGLE, G. R. & FRITZ, G. J., 1983. Introductory Plant Physiology. 2nd Ed. Prentice-Hall Inc. Englewood Cliffs, New Jersey.

PIERCE, L.C., 1987. Vegetables: Characteristics, production and marketing. John Wiley and sons. Toronto, Canada.

PREECE, J.E. & READ, P.E., 2005. The biology of horticulture: An introductory textbook. 2nd Ed. John Wiley & Sons, Inc. Hoboken, New Jersey.

RIDEOUT, J.W., 2004. Field growth and yield of tomato transplant grown in the float system using low phosphorus fertilizer and height restricting cultural practices. *HortScience* 39, 23 27.

RIDEOUT, J.W. & OVERSTREET, L.F., 2003. Phosphorus rate in combination with cultural practices reduces excessive growth of tomato seedlings in the float system. *HortScience* 38, 524 528.

RYDER, E.J., 1979. Leafy salad vegetables. AVI Publishing Company. Inc., Westport, Connecticut.

SALISBURY, F.W. & ROSS, C.W., 1992. Plant Physiology. 4th Ed. Wadsworth Publishing Company, Belmont, California

SALUNKHE, D.K, DESAI, B.B. & BHAT N.R., 1987. Vegetable and flower seed production. Agricole Publishing Academy. New Delhi.

SEMULI, K.L.H., 2005. Nitrogen requirements for cabbage (*Brassica olerecea capitata*) transplants and crop response to spacing and nitrogen top-dressing. M. Inst. Agrar. Dissertation. University of Pretoria, Pretoria, South Africa.

SHOEMAKER, J.S., 1949. Vegetable growing. John Wiley & Sons. New York.

SINGH, R.V. & NAIK, L.B., 1988. Response of cabbage to plant spacing, nitrogen and phosphorus levels. *Indian J. Hort.* 45, 325-328 (Cited by Semuli, 2005).

SMITH, K., 1995. Keith Smith's classic vegetable catalogue. Thomas C. Lothian (Pty) Ltd. Port Melbourne, Australia.

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 a floatation irrigation system. II. Potassium. *HortScience* 36, 1071 1074.

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

SOUNDY, P., CANTLIFFE, D.J., HOCHMUTH, G.J. & STOFFELLA, P.J., 2005. Management of nitrogen and irrigation in lettuce transplants production affects transplant root and shoot development and subsequent crop yields. *HortScience* 40, 607-610.

STATISTICAL ANALYSIS SYSTEM, 2003. SAS User's guide: Statistics Release 8.2. SAS institute Inc., Cary NC, USA.

TINDALL, H.D., 1979. Commercial vegetable growing. Oxford University Press. Great Britain.

TISDALE, L.S., NELSON, W.L., BEATON, J.D. & HAVLIN**,** J.L., 1993. Soil fertility and fertilizers. Macmillian Publishing 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. & GOSSELIN, A., 1989. Growth and nutrient status of celery seedlings in response to nitrogen fertilization and NO_3:NH_4 ratio. *HortScience* 24, 284-288.

TREMBLAY, N. & SENÉCAL, M., 1988. Nitrogen and potassium in nutrient solution influence seedling growth of four vegetable species. *HortScience* 23, 1018-1020.

TREMBLAY, N., YELLE, S. & GOSSELIN, A., 1987. Effects of CO_2 enrichment, nitrogen and phosphorus fertilization on growth and yield of celery transplants. *HortScience* 24, 875-876.

VAVRINA, C.S., HOCHMUTH, G.J., CORNELL, J.A. & OLSON, S.M., 1998. Nitrogen fertilization of Florida-grown tomato transplants: Seasonal variation in greenhouse and field performance. *HortScience* 33, 251 254.

WARING, R.H., McDONALD, A.J.S., LARSSON, S., ERICSSON, T., WIRÉN, A., ARWIDSON, E. & LOHAMMAR, T., 1985. Differences in chemical composition of plants grown at constant relative growth rates with stable mineral nutrition. *Oecologia* 66, 57-160.

WEERAKOON, M.W., OLSZYK, D.M. & MOSS, D.N., 1999. Effects of nitrogen nutrition on responses of rice seedlings to carbon dioxide. *Agric. Ecosys. & Environ*. 72, 1-8.

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*. 111, 498 501.

WIDDERS, I.E., 1989. Pretransplant treatments of N and P influence growth and elemental accumulation in tomato seedlings. *J. Amer. Soc. Hort. Sci*. 114, 416 420.

WURR, D.C.E., COX, E.F. & FELLOWS, J.R., 1986. The influence of transplant age and nutrient feeding regime on cauliflower growth and maturity. *J. Hort. Sci*. 61, 503-508.

APPENDICES

Table A1 Analysis of variance for shoot and root characteristics of cabbage transplants as affected nitrogen applied during autumn, March/May 2005

Source of variation	Degrees of freedom	F-probability levels of						
		Dry shoot mass (mg)	Dry root mass (mg)	Plant Height (mm)	Leaf area (cm^2)	Root: shoot ratio	Pulling success (%)	Leaf nitrogen content ($g \cdot kg^{-1}$)
21 days after sowing								
N level	4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0006		
Error	12	-	-	-	-	-		
N level L	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001		
N level Q	1	0.0030	< 0.0001	< 0.0001	0.1942	0.0794		
28 days after sowing								
N level	4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	<0.0001		
Error	12	-	-	-	-	-		
Nlevel L	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001		
Nlevel Q	1	0.0238	0.0021	0.0080	0.0481	< 0.0001		
35 days after sowing								
Nlevel	4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	<0.0001		
Error	12	-	-	-	-	-		
Nlevel L	1	< 0.0001	< 0.0001	<0.0001	< 0.0001	< 0.0001		
Nlevel Q	1	< 0.0001	< 0.0001	0.0062	0.9430	< 0.0001		
42 days after sowing								
Nlevel	4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Error	12	-	-	-	-	-	-	-
Nlevel L	1	< 0.0001	< 0.0001	<0.0001	< 0.0001	< 0.0001	< 0.0001	0.0035
Nlevel Q	1	0.0200	< 0.0001	< 0.0001	0.0018	< 0.0001	< 0.0001	< 0.0001

[1]*,**Not significant, significant at p =≥0.05 or p =≥0.01

Table A2 Analysis of variance for growth characteristics of cabbage transplants as affected nitrogen applied during autumn, March/May 2005

Source of variation	Degrees of freedom	F-probability levels of					
		Root mass ratio	Leaf mass ratio	Specific leaf area ($cm^2 \cdot g^{-1}$)	Leaf area ratio ($cm^2 \cdot g^{-1}$)	Net assimilation rate ($cm^2 \cdot g^{-1} \cdot wk^{-1}$)	Relative growth rate ($cm^2 \cdot g^{-1} \cdot wk^{-1}$)
21 days after sowing							
N level	4	< 0.0001	< 0.0001	0.0058	< 0.0001		
Error	12	-	-	-	-		
N level L	1	< 0.0001	< 0.0001	0.0005	< 0.0001		
N level Q	1	< 0.0001	< 0.0001	0.1343	0.1303		
28 days after sowing							
N level	4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0236	< 0.0001
Error	12	-	-	-	-	-	-
N level L	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0421	0.0002
N level Q	1	0.0005	0.0005	0.2097	0.72.02	0.0648	< 0.0001
35 days after sowing							
N level	4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0356	< 0.0001
Error	12	-	-	-	-	-	-
N level L	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0495	0.0002
N level Q	1	< 0.0001	< 0.0001	0.6395	0.3070	0.0158	<0.0001
42 days after sowing							
N level	4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Error	12	-	-	-	-	-	-
N level L	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0265	0.00328
N level Q	1	< 0.0001	< 0.0001	0.4871	0.1007	0.0002	0.0003

[1]*,**Not significant, significant at p =Ì0.05 or p =Ì0.01

Table A3 Analysis of variance of head yield and head quality as affected by pretransplant nitrogen during autumn/summer, Sept 2005

Source of variation	Degrees of freedom	F-probability levels of					
		Untrimmed head		Trimmed head		Head diameter (mm)	Head height (mm)
		yield ($t \cdot ha^{-1}$)	mass (kg)	yield ($t \cdot ha^{-1}$)	mass (kg)		
N level	4	<0.0001	< 0.0001	< 0.0001	< 0.0001	0.0514	0.0002
Error	12	-	-	-	-	-	-
N level L	1	< 0.0001	< 0.0001	0.0001	0.0002	0.0082	0.0213
N level Q	1	< 0.0001	0.0002	< 0.0001	< 0.0001	0.0216	0.0135

[1]*,**Not significant, significant at $p = \overline{0}.05$ or $p = \overline{0}.01$

Table A4 Analysis of variance for shoot and root characteristics of cabbage transplants as affected nitrogen applied during spring, Aug/September 2005

Source of variation	Degrees of Freedom	[1]F-probability levels of						
		Dry shoot mass (mg)	Dry root mass (mg)	Plant Height (mm)	Leaf area (cm^2)	Root: shoot ratio	Pulling success (%)	Leaf nitrogen content ($g \cdot kg^{-1}$)
21 days after sowing								
N level	4	< 0.0001	0.0017	< 0.0001	< 0.0001	< 0.0001		
Error	12	-	-	-	-	-		
N level L	1	< 0.0001	0.0057	< 0.0001	< 0.0001	< 0.0001		
N level Q	1	< 0.0001	0.0003	0.2186	< 0.0001	< 0.0001		
28 days after sowing								
N level	4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001		
Error	12	-	-	-	-	-		
N level L	1	< 0.001	< 0.0001	< 0.0001	< 0.0001	0.0002		
N level Q	1	< 0.0001	< 0.0001	0.0004	0.0397	< 0.0001		
35 days after sowing								
N level	4	< 0.0001	< 0.0001	< 0.001	< 0.0001	< 0.0001	< 0.0001	0.0098
Error	12	-	-	-	-	-	-	-
N level L	1	< 0.0001	< 0.0001	0.7298	< 0.0001	0.0364	0.0056	0.0003
N level Q	1	0.0001	< 0.0001	< 0.0001	0.0003	< 0.0001	0.0002	< 0.0001

[1]*,**Not significant, significant at p =,0.05 or p =,0.01

Table A5 Analysis of variance for growth characteristics of cabbage transplants as affected nitrogen applied during spring, Aug/September 2005

Source of variation	Degrees of freedom	[1]F-probability levels of					
		Root mass ratio	Leaf mass ratio	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Net assimilation rate ($cm^2 \cdot mg^{-1} \cdot wk^{-1}$)	Relative growth rate ($cm^2 \cdot mg^{-1} \cdot wk^{-1}$)
				21 days after sowing			
N level	4	< 0.0001	< 0.0001	< 0.0001	< 0.0001		
Error	12	-	-	-	-		
N level L	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001		
N level Q	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001		
				28 days after sowing			
N level	4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0171	0.0041
Error	12	-	-	-	-	-	-
N level L	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0039	0.0009
N level Q	1	0.0854	0.0854	0.0088	0.0107	0.1735	0.0404
				35 days after sowing			
N level	4	< 0.001	< 0.001	< 0.0001	< 0.0001	0.0001	< 0.0001
Error	12	-	-	-	-	-	-
N level L	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.4968	0.0024
N level Q	1	0.0003	0.0003	0.0252	0.0005	0.00997	0.1563

[1]*,**Not significant, significant at p =í0.05 or p =í0.01

Table A6 Analysis of variance for head yield and head quality of cabbage as affected by pretransplant nitrogen during spring, Sept. 2005/Jan. 2005

Source of variation	Degrees of freedom	[1]F-probability levels of					
		Untrimmed head		Trimmed head			
		yield (t·ha^{-1})	mass (kg)	mass (t·ha^{-1})	mass (kg)	Head diameter (mm)	Head height (mm)
Nlevel	4	0.0074	0.0023	0.0061	0.0009	< 0.0001	0.0518
Error	12	-	-	-	-	-	-
Nlevel L	1	0.0017	0.0235	0.0019	0.0065	< 0.0001	0.0859
Nlevel Q	1	0.9827	0.0004	0.0002	0.0024	0.0021	0.6211

[1]*,**Not significant, significant at p =₮0.05 or p =₮0.01

Table B1 Analysis of variance of shoots and roots characteristics of cabbage transplants as affected by potassium nutrition, June/July 2005

Source of variation	Degrees of freedom	[1]F-probability levels of						
		Dry shoot mass (mg)	Dry root mass (mg)	Plant Height (mm)	Leaf area (cm^2)	Root: shoot ratio	Pulling success (%)	Leaf nitrogen content ($g \cdot kg^{-1}$)
21 days after sowing								
K level	4	0.5060	0.2776	0.2578	< 0.0001	0.3010		
Error	12	-	-	-	-	-		
K level L	1	0.1546	0.0663	0.659	0.1655	0.0898		
K level Q	1	0.4560	0.2987	0.7390	< 0.0001	0.3336		
28 days after sowing								
K level	4	0.4717	0.2846	0.0902	< 0.0001	0.3055		
Error	12	-	-	-	-	-		
K level L	1	0.8848	0.0492	0.6639	0.0008	0.0532		
K level Q	1	0.1940	0.5492	0.0402	< 0.0001	0.6931		
35 days after sowing								
K level	4	0.4449	0.1756	0.0008	0.4674	0.1356	0.0026	0.0002
Error	12	-	-	-	-	-	-	-
K level L	1	0.0877	0.2442	0.0004	0.6553	0.1285	0.0349	0.0019
K level Q	1	0.6558	0.4739	0.4483	0.3088	0.5099	0.0067	0.0003

[1]*,**Not significant, significant at p =á0.05 or p =á0.01

Table B2 Analysis of variance of growth characteristics of cabbage transplants as affected by potassium nutrition June/July 2005

Source of variation	Degrees of freedom	[1]F-probability levels of					
		Root mass ratio	Leaf mass ratio	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Net assimilation rate ($cm^2 \cdot mg^{-1} \cdot wk^{-1}$)	Relative growth rate ($cm^2 \cdot mg^{-1} \cdot wk^{-1}$)
21 days after sowing							
K level	4	0.7435	0.7435	< 0.0001	0.0005		
Error	12	-	-	-	-		
K level L	1	0.1937	0.1937	0.0640	0.0465		
K level Q	1	0.7370	0.7370	0.0008	0.0024		
28 days after sowing							
K level	4	0.1354	0.1354	< 0.0001	< 0.0001	0.0402	0.5042
Error	12	-	-	-	-	-	-
K level L	1	0.0170	0.0170	0.0039	0.0650	0.4462	0.7217
K level Q	1	0.2146	0.2146	< 0.0001	< 0.0001	0.8227	0.5042
35 days after sowing							
K level	4	0.1018	0.1018	0.4588	0.5699	0.0207	0.8398
Error	12	-	-	-	-	-	-
K level L	1	0.2447	0.2447	0.5465	0.6276	0.2846	0.4624
K level Q	1	0.3672	0.3672	0.3183	0.3507	0.0019	0.8755

[1]*,**Not significant, significant at p =j0.05 or p =j0.01

Table C1 Analysis of variance of shoots and roots characteristics of cabbage transplants as affected by phosphorus nutrition, June/July 2005

Source of variation	Degrees of freedom	[1]F-probability levels of						
		Dry shoot mass (mg)	Dry root mass (mg)	Plant Height (mm)	Leaf area (cm^2)	Root: shoot ratio	Pulling success (%)	Leaf phosphorus content ($g \cdot kg^{-1}$)
			21 days after sowing					
P level	4	< 0.0001	< 0.0001	0.2356	< 0.0001	< 0.0001		
Error	12	-	-	-	-	-		
P level L	1	< 0.0001	< 0.0001	0.1265	< 0.0001	< 0.0001		
P level Q	1	< 0.0001	< 0.0001	0.2345	< 0.0001	< 0.0001		
			28 days after sowing					
P level	4	< 0.0001	< 0.0001	0.1356	< 0.0001	< 0.0001		
Error	12	-	-	-	-	-		
P level L	1	< 0.0001	< 0.0001	0.3298	< 0.0001	< 0.0001		
P level Q	1	< 0.0001	< 0.0001	0.2125	< 0.0001	< 0.0001		
			35 days after sowing					
P level	4	< 0.0001	< 0.0001	0.2300	< 0.0001	< 0.0001	0.0069	0.0036
Error	12	-	-	-	-	-	-	-
P level L	1	< 0.0001	< 0.0001	0.3246	< 0.0001	< 0.0001	0.0362	0.0194
P level Q	1	< 0.0001	< 0.0001	0.4125	< 0.0001	< 0.0001	0.00152	0.0002

[1]*,**Not significant, significant at p = 0.05 or p = 0.01

Table C2 Analysis of variance of growth characteristics of cabbage transplants as affected by applied phosphorus, June/July 2005

Source of variation	Degrees of freedom	[1]F-probability levels of					
		Root mass ratio	Leaf mass ratio	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Net assimilation rate ($cm^2 \cdot mg^{-1} \cdot wk^{-1}$)	Relative growth rate ($cm^2 \cdot mg^{-1} \cdot wk^{-1}$)
21 days after sowing							
P level	4	< 0.0001	< 0.0001	< 0.0001	< 0.0001		
Error	12	-	-	-	-		
P level L	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001		
P level Q	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001		
28 days after sowing							
P level	4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Error	12	-	-	-	-	-	-
P level L	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0003	0.0119
P level Q	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.5736	0.0002
35 days after sowing							
P level	4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Error	12	-	-	-	-	-	-
P level L	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
P level Q	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

*,**Not significant, significant at p =f0.05 or p =f0.01