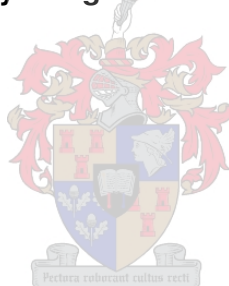


**THE INFLUENCE OF NUTRIENT SOLUTIONS ON GROWTH,
SEED PRODUCTION AND SEED QUALITY OF BROCCOLI
(*Brassica oleracea* L. var. *italica* Plenck).**

By

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**Thesis presented in partial fulfillment of the requirements for the degree
Master of Science in the Faculty of AgriSciences at Stellenbosch University**



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Declaration

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Date: 25 February 2011

ABSTRACT

THE INFLUENCE OF NUTRIENT SOLUTIONS ON GROWTH, SEED PRODUCTION AND SEED QUALITY OF BROCCOLI (*Brassica oleracea* L. var. *italica* Plenck).

Little is known about the nutrient requirements of broccoli grown for seed production. During 2006 and 2007 broccoli were grown for seed production in sand bags in a net structure, using a drain to waste hydroponic system. The experimental design was a randomized complete block with seven treatments replicated in four blocks. In 2006 seven nutrient solution treatments were tested. The Standard solution based on Steiner's universal solution was compared with different levels of N, S, K and Ca with regard to the effect on total biomass, nutrient concentration, nutrient assimilation, seed yield and quality. No significant differences in total biomass produced were found. Total dry mass increased by 225% from the mature head stage until harvest of seed. Nutrient concentration in plant samples were not influenced by treatments except where low levels of K and S in nutrient solutions led to significantly lower levels of K and S concentrations. The total assimilation of elements were calculated to determine the effect of the much longer growth period needed for seed production in comparison to normal head production on nutrient requirements. Major elements assimilated ha⁻¹ was: N 173.0 kg, P 35.5 kg, K 348.4 kg, Ca 114.7 kg, Mg 30.5 kg, S 42.2 kg.

The seven treatments used during 2007 included three of the treatments which were used in 2006 as well as treatments with foliar sprays containing Ammonium Nitrate and Calcium Metalosate. The standard solution treatment was also used in 2007 to compare results with 2006. Plant analysis done on plants from the standard solution (2006 & 2007) showed similar trends. As the plants developed towards maturity there was a relative increase in concentration in the top plant parts (pods, flowers and stems) for Ca, Mg and S. Contrary, N and P concentration declined. The minor elements, Fe, Mn and B also increased in concentration in the top plant parts at harvest indicating a strong relative flow of these elements to the top plant parts towards maturation. Concentration values of major elements in plant samples were generally different when the two years were compared. Element concentrations in the seed pods were in general higher than in the rest of the plant indicating the pods as a strong sink on the plants.

During both years the two best nutrient solutions for yield were the same, namely the Standard solution and Standard - K which contain low levels of K. During 2006 no significant differences in seed quality were found. During 2007 no significant differences were found for seed quality measurements, except for size (of the cotyledons). The results indicate that no special adjustments need to be made to the Standard solution in order to produce good broccoli seed yield of good quality. As substantial differences in nutrient solution composition did not significantly affect the quality of broccoli seed produced. Seed yield was however significantly affected by nutrient solution composition.

Key words: Brassica seed, broccoli seed, seed production, broccoli nutrition, hydroponic production, broccoli production, nutrient assimilation.

UITTREKSEL

DIE INVLOED VAN VOEDINGSMENGSELS OP DIE GROEI, SAAD PRODUKSIE EN SAAD KWALITEIT VAN BROKKOLI (*Brassica oleracea L. var. italica* Plenck).

Min inligting is bekend rakende die voedingsbehoefte van brokkoli wat gekweek word vir saadproduksie. Gedurende 2006 en 2007 is brokkoli gekweek vir saadproduksie in sakke sand in 'n net struktuur met 'n oop hidroponiese besproeiingstelsel. Die proefontwerp was 'n ewekansige geheel blok met sewe behandelings wat ewekansig binne bloke toegeken is en herhaal is in vier blokke. Sewe voedingsmengsel behandelings is gedurende 2006 toegepas. Die Standaard mengsel is geskoei op Steiner se universele mengsel en dit is vergelyk met verskillende vlakke van N, S, K en Ca t.o.v. die invloed daarvan op biomassa produksie, voedingselement konsentrasie, voedingselement assimilasië, saad opbrengs en saad kwaliteit. Biomassa geproduseer het nie wesenlik verskil nie. Totale droë massa het met 225% toegeneem vanaf die volwasse kop tot die oes stadium. Die konsentrasie van voedings elemente in plant monsters is nie beïnvloed deur behandelings nie behalwe in gevalle waar lae konsentrasies van K en S in die voedingsmengsels gelei het tot lae konsentrasies van K en S in plantontledings. Die totale opname van voedingselemente is bereken om die effek van die veel langer groeiperiode wat benodig word vir saadproduksie in vergelyking met normale kop produksie te bepaal t.o.v. voedingselement behoefte. Makro element opname per hektaar was as volg: N 173.0 kg, P 35.5 kg, K 348.4 kg, Ca 114.7 kg, Mg 30.5 kg, S 42.2 kg.

Die sewe behandelings van 2007 het drie behandelings van 2006 ingesluit asook behandelings van blaarbespuitings met Ammonium Nitraat en Kalsium Metalosaat. Die Standaard voedingsmengsel is weer gebruik ten einde die resultate van 2006 en 2007 te vergelyk. Voedingselement ontledings op plante van die Standaard mengsel (2006 & 2007) is vergelyk en het soortgelyke tendense aangedui. Soos wat plante ontwikkel het na volwassenheid was daar 'n relatiewe toename in konsentrasie in die boonste plant dele (peule, blomme en stele) van Ca, Mg en S. In teenstelling hiermee het die konsentrasies van N en P afgeneem. Die mikro elemente Fe, Mn en B het ook in konsentrasie toegeneem in die boonste plant dele teen oes wat daarop dui dat daar 'n sterk relatiewe vloe van hiedie elemente na die boonste plant dele plaasvind met volwasse wording. Die konsentrasie vlakke van makro elemente in plantontledings het in die algemeen wesenlik verskil tussen die twee jare. Die voedingselement konsentrasies was in die algemeen hoër in die saad peule as in die res van die plant wat daarop dui dat die peule as 'n sterk sink op die plant funksioneer.

In beide jare was die hoogste opbrengs afkomstig van die Standaard voedingsmengsel en die Standaard – K mengsel wat lae vlakke van K bevat het. Gedurende 2006 is geen wesenlike verskille in saadkwaliteitsnorme gevind nie. Soortgelyke resultate is gevind in 2007 behalwe vir grootte van die kiemblare. Die resultate dui daarop dat dit nie nodig is om die Standaard voedingsmengsel samestelling te verander ten einde goeie opbrengs saad van goeie gehalte te produseer nie. Wesenlike verskille in voedingsmengsels het geen invloed op die kwaliteit van brokkoli saad gehad nie. Saad opbrengs is egter wesenlik beïnvloed deur die samestelling van die voedingsmengsels.

Sleutel woorde: brassica saad, brokkoli saad, saad produksie, brokkoli voeding, hidroponiese produksie, brokkoli produksie, voedingstof assimilasië.

DEDICATED TO MY WIFE AND CHILDREN

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CHAPTER 1

INTRODUCTION

The production of *Brassica* vegetables is a worldwide phenomenon. Brassica vegetables of economic importance being produced in South Africa include cauliflower (*Brassica oleracea L. var. botrytis L.*), broccoli (*Brassica oleracea L. var. italica Plenck*) and cabbage (*Brassica oleracea L. var. capitata L.*). Taking into account only cauliflower and cabbage the value and volume of products sold during 2004 on the national fresh markets were 158 500 tons to the value of R99.6 million (Abstract of Agricultural Statistics, 2006 NDA). The word broccoli is derived from the Latin word *Brachium* meaning arm or branch. Being indigenous in Italy it was introduced to the United States of America around 1925. Broccoli is the most nutritious of the Cole crops, especially in vitamin content, iron and calcium. It contains 3.3 percent protein and has a high content of vitamin A & C. It also contains thiamine, niacin and riboflavin. Broccoli also contains high concentrations of carotenoids, which are believed to have preventative qualities with regards to human cancer. It may also play a role in reducing levels of serum cholesterol. It is rich in sulphoraphane, a compound associated with reducing the risk of cancer. The US is the largest producer of broccoli but it is produced world wide, especially in cooler areas (Ray & Yadav, 1954).

Brassica vegetables are also produced for seed production. Over the past ten years the production of broccoli and cauliflower seed in the lower Olifants river valley irrigation scheme had steadily increased. The seed is produced under contract for an international seed company. The F1 hybrid seed is exported. The

seed is a high value crop and of considerable economic importance in the region. Problems that are being experienced by local growers are that, in contrast to requirements for normal production where the heads are harvested, fertilizer requirements for the production of seed from broccoli plants are not known. This is partly due to the fact that the production period from transplanting of seedlings to harvest of the seed is typically 32 weeks (Pers. Comm., 2006: G.J. Kersop, PO Box 463, Lutzville), while the production period from transplanting to harvest for normal vegetable production is typically between 6 and 22 weeks (Coertze *et al*, 1994). Because of this longer growth period, the total amount of major- and minor elements that is removed by a single broccoli crop produced for seed is not known. The assimilation of nutrient elements at different growth stages is also not known.

The growers are of the opinion that certain nutritional elements are important to produce high quality and quantity of seed. Unfortunately very little information exists in the literature with regard to the quantity and relation of nutritional elements and their effect on the quality and quantity of broccoli seed produced. In the literature information of the effect of different elements on the production of canola seed (rape seed) (*Brassica napus*), does exist but whether the same principles apply to seed produced from broccoli is not known.

Due to this, research trials were conducted with the following objectives:

1. Investigate the effect of different nutrient solutions and treatments on the quality characteristics and yield of broccoli seed produced.

2. Investigate the concentration and total quantity of major and minor elements in broccoli plants at different growth stages.
3. Investigate dry matter production in response to different nutrient solutions at different growth stages.
4. Determine the total weight of major and minor elements per hectare incorporated into above ground plant parts during broccoli seed production.
5. Investigate the concentration of major and minor elements in top and bottom parts of broccoli in order to gain understanding of the allocation of the elements through growth stages.

CHAPTER 2

LITERATURE REVIEW

2.1 Growth and development of *Brassica* crops

Broccoli belongs to the family *Brassicaceae*, more commonly known as the mustard family and it consists of more than 300 genera and 3000 species (Rubatzky & Yamaguchi, 1997). Furthermore Broccoli belongs to the genus *Brassica* which is comprised of many economically important species which yield edible roots, stems, leaves, buds, flowers and seeds. The taxonomy of *Brassica* is complicated. This genus is comprised of six species, three being considered basic species and the rest are amphidiploid forms. The three elementary species, their chromosome numbers and genetic nomenclatures are: *B. nigra* Koch (black mustard, n=8, genome B), *B. oleracea* L. (**cole crops**, n=9, genome C) and *B. campestris* L. (turnip and Chinese cabbage group, n=10, genome A). The amphidiploids are: *B. carinata* Braun (Ethiopian mustard, n=17, genome BC), *B. napus* L. (Swedes, rape, rutabagas, n=19, genome AC) and *B. juncea* (L.) Czern. (brown mustard, n=18, genome AB). Evidently they originated in nature from crosses between the elementary species. There exists a wide differentiation of varieties (Opeña *et al.*, 1988).

Mendham & Salisbury, (1995) refer to the fact that a distinction between growth and development of the plant is made. Development is seen as the progress of a crop through its life cycle and growth is the increase in size of organs, and the accumulation of dry matter, firstly as sugars, then as storage and structural materials in leaves, stems and fruits. In the case of **rapeseed** the growth stages

identified are given below. The growth processes coupled with each development stage are given in brackets:

2.1.1 Rapeseed development stages

(A) Sowing; (B) Emergence (Expansion of cotyledons, growth of taproot); **(C) Leaf production** (Establishment of root system and expansion of leaves, interception of solar radiation, photosynthesis, increased leaf dry weight.); **(D) Inflorescence initiation** – vernalization and photoperiod responses; **(E) Stem elongation** – photoperiod responses (Stem dry weight increases, stem photosynthesis commences, reserves laid down); **(F) Flower bud development** – ovule numbers determined; **(G) Flowering** – pollination, seed set (Leaf area and root extension close to maximum. Flowers shade leaves, young pods); **(H) Pod development** – pod and seed abortion, final numbers determined (Pod and stem photosynthesis replaces declining leaf area as leaves senesce. Pod walls reach maximum size and seed growth commences); **(I) Seed development** – formation of embryo, storage cells (Seed growth with assimilate from leaves, stems, pods. Oil and protein synthesis and storage in seeds). The interaction between development and growth at each stage builds up the potential and then the actual yield of the crop. All stages are to a greater or lesser degree under genetic control and are affected by environmental influences such as temperature, solar radiation etc (Mendham & Salisbury, 1995).

2.1.2 Chinese cabbage development stages

The growth stages of **Chinese cabbage** (Opeña *et al.* 1988), including seed stage is relevant to seed production of *Brassica*, particularly broccoli as it is a heading plant as well.

(A) Emergence stage: Germination of (Chinese cabbage) seeds requires water, oxygen and suitable temperatures. Rapid germination follows water absorption to 40% to 50% moisture content. The radicle first emerges out of the seed, usually about 24 hours after the seed has taken in water under optimum temperatures. The seedling will begin to grow upward once the root has grown 2-3 cm into the soil. The hypocotyl emerges first above the soil and the two cotyledons unfold at the top of the hypocotyl, and then part and extend. In optimum conditions seedlings take about three to four days to emerge above the soil.

(B) Seedling stage: During this stage the plant starts to photosynthesize after the two first true leaves develop between the fully extended cotyledons. Later, many leaves are formed at the growing point without much increment in height.

(C) Rosette stage: The rosette is formed by the first two or three whorls of leaves that are fully expanded, nonheading leaves in an approximate horizontal position close to the soil surface. New leaves continually form at the growing point. Inner leaves tend to grow more vertically, usually under shaded conditions after new whorls of leaves have grown.

(D) Heading stage: During this stage the marketable head is formed. Heads starts to form at about the 12th to 13th leaf stage for early maturing varieties or the 24th to 25th leaf for late maturing varieties when the youngest innermost leaves start to incurve and touch at their tips. As more leaves are formed along the vertical axis of the plant the head is eventually formed. During this stage the plant's increase in height is limited and the typical heading shape is assumed. The young head grows fast until the maximum firmness and size is reached at which time it is ready for harvest.

(E) Flowering stage: Depending on the photoperiod and / or temperature during the growth period, flower initiation will take place either before or after heading. The stem normally bolts (elongates) as the flower buds initiate and develop.

(F) Silique (pod) and seed stage: After fertilization and within a period of three to four weeks, the endosperm and the siliques containing 10-25 seeds develop quickly and reach their full length and diameter. The fully developed pods require about two weeks to mature.

2.1.3 Morphological features

The following morphological features of **Chinese cabbage** (Opeña *et al.* 1988) which are of importance in a study of seed production of Brassica crops will be discussed here:

(A) Inflorescence: A simple, elongated, indeterminate inflorescence bears stalked or pedicelled flowers in terminal racemes on the main stem and its

branches. Individual flowers are supported by pedicels attached to the main axis of the inflorescence. The pedicels are only about 1-1.5 cm long but the inflorescence may be as long as 1m.

(B) Flower: The flowers are bisexual and perfect. During differentiation four sepals, six stamens, two carpels and four petals develop successively. The carpels form a superior ovary with false septum and two rows of campylotropous ovules. The androecium is tetradynamous because there are four long and two short stamens. The bright yellow petals are arranged in the form of a cross, thus the family name Cruciferae. The four sepals are more or less erect. The buds open under the pressure of the rapidly growing petals. The opening process begins in the afternoon and usually the flowers are fully expanded by the following morning. The anthers open a few hours later than the flowers, the latter being slightly protogynous. The nectar which attracts pollinators is secreted by the two nectaries situated between the bases of the short stamens of the ovary. Two other inactive nectaries are situated outside the bases of the pairs of long stamens. This description above is much the same as described by Halevy (1985) in his description of the floral morphology of *Brassicaceae*.

(C) Siliques: The fruit of the Chinese cabbage is often called a pod and consists of a glabrous silique. It is about 3-5 mm wide and can be over 7 cm long with two rows of seeds lying along the edges of the thin replum (an outgrowth of the placenta – false septum). A pod may contain 10 to 25 seeds, depending on the variety. In the case of Chinese cabbage the pod reaches maximum length about three to four weeks after opening of the flower. When the silique is fully ripe and

dry, dehiscence takes place through the two valves breaking away from below upwards, the seeds staying attached to the placenta.

(D) Seed: The shape of the seeds are globular to slightly oval, about 1-2 mm in diameter, light brown at first, but becoming grayish black to red-brown later. The seed is a mature fertilized ovule. After fertilization the endosperm develops immediately although the embryo does not start to grow for some days. The embryo generally stays small for about two weeks, but then fills most of the seed as the endosperm becomes almost completely absorbed. The cotyledons are folded together with the radicle lying between them (conduplicate). Reserve food is stored in the cotyledons. The seed coat consists of the derivatives of two integuments. From outside to the interior, the following parts can be distinguished: a thin walled and compressed epidermis, a layer of collapsed sub epidermal tissue, a supporting layer of radially elongated cells with thickened, brown colored sidewalls, and an irregular layer of pigmented cells. The seed coat is usually featureless but sometimes the radicle position is indicated by a low ridge.

2.1.4 Physiology of flowering

Flowering marks the transition from vegetative to reproductive stages in seed plants (Opeña *et al.* 1988). From the standpoint of seed production it is thus a crucial event. Flowers are modified shoots produced by the modified shoot meristems, the flower primordia. Once a meristem has been determined to be a flower primordium, it usually can not to revert to vegetative growth. The main problem in the physiology of flowering is to understand which factors cause a

shoot meristem to become a flower primordium and how they consummate their action. The flowering of all *Brassica* vegetables is associated with bolting or the rapid elongation of the axis. Bolting is an easy indicator of flowering, but it can occur without flowering. The physiological control of flowering may be exerted at any of several fairly definitive development stages of the plant. Environmental cues may provoke the induction of the reproductive state – the initiation of floral meristems, the morphological development of flowers, and anthesis itself.

The reproductive development of *Brassica* plants are usually triggered by such environmental variables as temperature and photoperiod. Low temperature and long day conditions promote development of bolting with or without flower formation in most species of *Brassica* (Opeña *et al.* 1988). In the case of **broccoli**, development is mainly determined by temperature rather than photoperiod and the development from emergence to floral initiation can be predicted with the use of thermal time models (Tan *et al.*, 1999). For the development period from flowering to harvest of rapeseed, temperature is the main factor controlling development (Mendham & Salisbury, 1995). Many *Brassica* species are induced to flower by low temperatures. In the case of *B. oleracea* (cole crops) the effect of vernalization can only be obtained when growing plants are chilled, not seeds. This is called green plant vernalization versus seed vernalization. In the case of *B. oleracea*, the effective vernalization temperatures are confined to the 0° to 5 °C range. Flower induction in some subspecies of *B. oleracea* is extremely difficult and long vernalization periods are required. At least six weeks of vernalization at 3 °C of plants with at least 15 green leaves are necessary to bring about normal flowering of different

subspecies of *B. oleracea*. Some tropical species may produce flowers without exposure to low temperatures. After vernalization, warm temperatures can have a depressing effect on the earliness of flowering. In the case of Chinese cabbage to achieve the same result, increasing the period of vernalization is more effective than lowering the vernalization temperature (Opeña *et al.* 1988).

2.1.5 Photoperiod

Most *Brassica* species are considered to be quantitatively long-day plants. The longer the daylength during growth, the more extensive and earlier the flowering becomes. The older the plant before photoinduction, the greater the flowering percentage at a given daylength. Many *Brassica* species which react to vernalization also respond to long-day stimulation of flowering. The interaction of these two factors can be either complimentary or supplementary. It seems that there is no critical daylength for *Brassica* species (or it is shorter than eight hours if it exists) but a combination of vernalization and long day is required for maximum flowering of specifically Chinese cabbage. (Opeña *et al.* 1988).

In a summary with regards to the above, Halevy (1985) notes that *Brassica* varieties show a large variation in flowering response to the environment, including obligate and preferential needs for vernalization and long photoperiods. In some cases there is a well-defined juvenile phase before vernalization is effective. The nature of the photoperiodic reaction is complex and possibly involves the action of phytochrome and photosynthesis. Centuries of domestication have produced a myriad of forms with different uses and

corresponding variation in photoperiod responses which match different growing conditions (Halevy, 1985).

2.1.6 Regulation by growth substances

Growth substances (hormones) play important roles in the control of flowering. Of all plant hormones, gibberellins (GA) are the most effective. GA replaces the need for long day or low temperature in some *Brassica* species and speeds up flowering in Chinese cabbage when it is applied during seed vernalization or vegetative growth. Not all cold requiring or long day requiring *Brassica* species can be induced to flower with GA. A combination of vernalization with GA application was proposed as an alternative to long day treatment of incomplete vernalization in order to bring about flowering in some difficult to flower *B. oleracea* and *B. napus*. The effectiveness of this method however, depends on the crop variety (Opeña *et al.* 1988).

2.1.7 Flowering

It appears that the optimum temperature for flowering range from 18° to 25°C. When temperatures rise above 32°C it usually results in abnormal floral development with enlarged sepal but defective anthers, and poor pollen production and viability resulting in poor or no pod setting. The optimum relative humidity (RH) for anthesis is 60-70%. RH above 90% is not good for the flowering and pollination process (Opeña *et al.* 1988). Thus, high temperatures are a major limiting factor in the production of seed of Chinese cabbage.

2.1.8 Seed dormancy

Seed of *Brassica* vegetables exhibit dormancy for a certain period after harvest. This period varies with species and cultivars, normally ranging from 0 to 140 days. For *B. oleracea*, dormancy ranges from short to long and for *B. napus* and *B. juncea*, dormancy is usually long. The removal of dormancy is usually delayed when Brassica seeds are stored under extremely dry or humid conditions. The optimal RH range for the removal of seed dormancy in *Brassica* species is from 10% to 70%, depending upon species and varieties. The mean germination period is shortest and the percentage of germination highest from 25° – 35°C for *Brassica* vegetables. The response is different for dormant seeds versus non dormant seeds. The optimum temperatures for dormant seeds range from 15° – 25°C. Varieties also differ in their response to germination temperatures (Opeña *et al.* 1988).

2.1.9 Silique and seed development

As investigations into the silique and seed development of Brassica vegetables have been scarce (Opeña *et al.* 1988), this aspect will be looked at in detail by studying *B. napus*, specifically rapeseed.

The model of Leterme (Mendham & Salisbury, 1995) summarizes the factors affecting a pod from flowering to harvest. Three main phases of development are:

Phase 1: Increase in pod length: Duration 200 to 300°C d. Pods are heterotrophic as they rely on imported assimilates. During this period it attain maximum length and the number of seeds is largely determined. The main

variables responsible are leaf area index at the beginning of the period, number of flowers per unit area, duration of flowering, radiation, and temperature. These factors interact to determine the number of pods and seeds.

Phase 2: Maximum growth rate of pod walls: Duration is about 300°C d. Pod walls attain maximum size and area, but seed growth is limited. Pods are autotrophic, fixing most of the carbon required for pod and seed growth.

Phase 3: Maximum growth rate of seeds: Duration is about 300°C d. This is largely governed by the surface area of pods and stems and the amount of radiation received. Most carbon goes into seed growth.

During the second and third phases, growth rates are limited by either the amount of radiation intercepted or the potential maximum growth rate of pods and seeds. These stages should be borne in mind when a plant nutrition program for broccoli for seed production is compiled. It also has implications for agronomic production techniques.

The number of pods that develop in the *Brassica* genus usually remains constant regardless of environmental conditions, indicating that losses due to abscission are minimal. However the number of seeds per silique usually decreases during silique development even under favorable conditions. The decrease is due to fast failure of embryo development, followed by a gradual decline in seed development and finally the exclusion of poorly developed seed at maturity. The reasons for this is not clear but competition for assimilates may be responsible

and have a close relationship to environmental conditions. Mendham & Salisbury (1995) indicated that a critical period of 3-4 weeks after full flowering of rape seed exist during which seed abortion and pod survival took place. This period of 3-4 weeks corresponds to the time of maximum growth rate of pod hulls, which is also the period of maximum demand for assimilates and nutrients. Limiting assimilates during this stage appear to be the major influence affecting number of pods and final seeds. In the case where fewer pods are formed, rape seed plants are able to respond by increasing the number of seeds per pod (Mendham & Salisbury, 1995). In the case of rapeseed during full flower, the flowers (mainly in the top part of the canopy) have a definite reducing influence on the interception of radiation and thus an influence on the production of assimilates by leaves and young pods (Mendham & Salisbury,1995).

Both pre- and post flowering growth has a significant influence on seed yield of *Brassica* species. Seed yields decrease with a reduced period of vegetative development. They increase with an increase in dry matter accumulation in the period between anthesis and final harvest (Opeña *et al.* 1988). This is confirmed by Mendham & Salisbury (1995) who indicated that a longer stem elongation phase was associated with higher yield. Accumulation of sufficient leaf area and thus yield potential is important for yield.

The growth and final size of seed is important. The duration of seed growth is largely determined by temperature. The rate of growth is determined by the supply of assimilate, nutrients and water. Assimilate supply is determined by a range of factors, some of which were mentioned above. Pre-flowering growth

sets up the photosynthetic potential of leaves and stems, with reserves making a significant contribution to final growth in some circumstances. The number of seeds and pods which survive the stress conditions, assimilate shortages and changing nature of the photosynthetic surfaces during flowering determines the size of the sink for photosynthates. The green surface areas of the pod walls which determines the quantity of sun light intercepted is also an important factor determining the supply of assimilate to the seeds in the pods (Mendham & Salisbury, 1995).

It was estimated that the contribution to the dry matter accumulation in the seeds was 37% from leaves, 32% from the pod walls and 31% from the stem. Nearly 75% of the assimilates from the topmost leaf were translocated to the growing pods. As noted above the pods have an important photosynthetic function and provide a considerable amount of photosynthates to the developing seed (Opeña *et al.* 1988). Mendham & Salisbury (1995) indicated that in the case of rape seed the reserves built up pre-anthesis were only estimated to contribute about 10% to the final harvested yield. This has obvious implications for plant growth post-anthesis, particularly solar radiation interception, assimilate production, water availability and mineral nutrition.

2.2 Climatic requirements of *Brassica* crops

The climatic requirements of cauliflower and broccoli are quite similar (Olivier & Coertze, 1998). Cabbage is more tolerant with regards to conditions that are not optimal. These crops prefer a cool, humid climate. For this reason the most common production seasons include autumn, winter and spring. The optimum

temperature for growth and development is about 18°C with an average maximum of 24°C and an average minimum of 4.5°C. Cabbage can tolerate minimum temperatures as low as -3°C without damage provided that quick changes between day and night temperatures do not occur (Van Niekerk & Coertze, 1998). Cauliflower is more sensitive towards high and extremely low temperatures. The hot and dry summer months of the Western Cape is not optimal for the production of cauliflower and broccoli but cabbage is less affected by these conditions. If a crop is produced during the summer months, lower yield and quality can be expected. For this reason optimal planting times for the Western Cape are: Cauliflower – December to March; Broccoli – December to March and Cabbage – November to April (Coertze, 1997).

2.3 Soil and nutrient requirements of *Brassica* crops

2.3.1 Cole as vegetable crops

Major elements

Cole crops are known to have high requirements for fertilizer especially nitrogen and potassium. Thirty tons of cabbage heads will remove from the soil approximately 120 kg nitrogen, 20 kg phosphorus, 100 kg potassium and 85 kg calcium (Jackson & Coertze, 1998). In the case of broccoli the plants with their heads will remove approximately 185 kg nitrogen, 11.2 kg phosphorus and 235 kg potassium hectare⁻¹ (Maynard & Hochmuth, 1997).

Guidelines for the fertilization of Cole crops are given in **Table 2.1**, but should be used in conjunction with a soil analysis. These guidelines are for average yields. In the case of high yields the levels should be increased progressively.

Table 2.1 Nutrition guidelines for cole crops (FSSA)

Cole crops	N application kg/ha		
N	160-260		
	P-application in soil-P (mg kg⁻¹, Bray 1)		
P soil content	0-20	21-50	>50
	kg ha ⁻¹		
P application	100	70	40
	K-application at in soil-K (mg kg⁻¹, NH₄OAc)		
K soil content	<80	81-150	>150
	kg ha ⁻¹		
K application	160	120	60

Source: Bemestingshandleiding, MVSA, 2003

A further guideline for Cole crop production for the fresh market was given by the Mayford Technical Centre in **Table 2.2**.

Table 2.2 Mayford fertilizer guidelines for cole crops

Crop	Low application Kg/Ha			High application Kg/Ha			Time of application
	N	P	K	N	P	K	
Cabbage							
Basic	60	90	60	80	120	80	At planting
Side dressing	20	0	0	20	0	0	3 weeks after plant
Side dressing	20	0	0	20	0	0	8 weeks after plant
Broccoli							
Basic	100	150	100	100	150	100	With planting
Side dressing	20	0	0	20	0	0	4 weeks after plant
Cauliflower and Brussel Sprouts							
Basic	80	120	80	100	150	100	With planting
Side dressing	20	0	0	20	0	0	4 weeks after plant

Source: Mayford Technical Centre, Farmer's Weekly 31 May 2002

Comparing **Table 2.1** and **2.2** it is interesting to note that the amount of N recommended by the FSSA (160-260 kg) is higher compared to the Mayford (100-120 kg) guide. The FSSA guideline (40-100 kg) for P fertilization is lower than

that of Mayford (90-150 kg). K Fertilization recommendation by the FSSA (60-160 kg) is higher at the high levels compared to the guide by Mayford (60-100 kg). In general the guidelines differ a lot but recommendations will be influenced by soil content of major elements.

It must however be kept in mind that different cultivars may respond differently to fertilization. Hong (1991) found that the fertilizer needs of Chinese cabbage may also vary with cropping season, variety and soil condition. Schulte auf'm Early *et al* (2010) found that different white cabbage cultivars (different genotypes) differed in N efficiency and in yield at high N supply.

Research done by Dufault (1988) on the nitrogen and phosphorus requirements of broccoli produced in a soilless medium in greenhouses showed that the amount of macro elements needed per 15 liter pot for quality broccoli was:

5.6 gram Nitrogen per pot

0.21 gram Phosphorus per pot

1.6 gram Potassium per pot

If one assumes production takes place in a greenhouse clad with net and the aim is seed production then typically thirty three thousand (33 000) plants per hectare will be planted. This is the spacing used in the Olifants river valley irrigation area. (Pers. Comm., 2006, Mr. G.J. Kersop, P O Box 463, Lutzville). This would translate to:

184 kg Nitrogen per hectare

6.9 kg Phosphorus per hectare

52.8 kg Potassium per hectare

The amount of P and K is low compared to the fertilizer recommendations of **Table 2.1** and **2.2**.

An important issue that needs to be kept in mind is that the level of nitrogen fertilizer applied can influence the ability of plants to withstand pathogens (Sandu, 1992). Research regarding the appearance of *Sclerotinia sclerotiorum* in cauliflower produced for seed indicated that the level of infestation increased with an increased level of nitrogen fertilization. By lowering nitrogen fertilization in the form of urea and calcium ammonium nitrate and increasing the use of kraal manure (10 to 40 tons per acre) effective control was achieved (Sandu, 1992). This is an important issue as *Sclerotinia* is a major problem in the Olifants river valley seed production area. In addition to this excess nitrogen may result in lower yields in cole (Nkoa *et al.*, 2000). This may be due to several factors. Raven and Smith (1976) for example reported that osmotic problems were due to the disruption of the cation-anion balance and intracellular pH when nitrate reduction follows the termination of leaf cell expansion. Ammonium and its equilibrium partner ammonia are toxic at low concentrations. The main pathway of detoxification of ammonium ions taken up by the roots and ammonia derived from nitrate reduction, photorespiration or N₂ fixation, is incorporation into amino acids, amides and related compounds (Marschner, 1995). When ammonium uptake exceeds ammonium assimilation, deleterious effects follow. Several mechanisms for the removal of excess solutes from shoot tissue exist. All these mechanisms which involves transport or synthesis and require energy and are

costly to the cell and can be viewed as a diversion to its normal growth activities (Nkoa *et al.*, 2000). Regulation of nitrogen supply to conform to plant needs could increase yield.

In **Table 2.3** the critical (deficiency) values, adequate ranges, high values and toxicity values for plant nutrient content of some Cole crops are given (Maynard & Hochmuth, 1997). This table can be used in order to do plant analysis at the prescribed times. This information can then be used as a guide in plant nutrition.

Table 2.3 Critical (deficiency) values, adequate ranges and high values for plant nutrient content for certain cole crops

Crop	Plantpart	Sampling time	status	%						ppm					
				N	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
Broccoli	MRML*	Heading	Deficient	<3.0	0.30	1.1	0.8	0.23	0.20	40	20	25	20	3	0.04
			Adequate	3.0	0.30	1.5	1.2	0.23	-	40	25	45	30	5	0.04
			range	4.5	0.50	4.0	2.5	0.40	-	300	150	95	50	10	0.16
			High	>4.5	0.50	4.0	2.5	0.40	-	300	150	100	100	10	-
Cabbage	MRML	5weeks after transplant	Deficient	<3.2	0.30	2.8	0.5	0.25	-	30	20	30	20	3	0.30
			Adequate	3.2	0.30	2.8	1.1	0.25	0.30	30	20	30	20	3	0.30
			range	6.0	0.60	5.0	2.0	0.60	-	60	40	50	40	7	0.60
			High	>6.0	0.60	5.0	2.0	0.60	-	100	40	50	40	10	-
Cauliflower	MRML	Buttoning	Deficient	<3.0	0.40	2.0	0.8	0.25	0.60	30	30	30	30	5	-
			Adequate	3.0	0.40	2.0	0.8	0.25	0.60	30	30	30	30	5	-
			range	5.0	0.70	4.0	2.0	0.60	1.00	60	80	50	50	10	-
			High	>5.0	0.70	4.0	2.0	0.60	-	100	100	50	50	10	-
Cauliflower	MRML	Heading	Deficient	<2.2	0.30	1.5	1.0	0.25	-	30	50	30	30	5	-
			Adequate	2.2	0.30	1.5	1.0	0.25	-	30	50	30	30	5	-
			range	4.0	0.70	3.0	2.0	0.60	-	60	80	50	50	10	-
			High	>4.0	0.70	3.0	2.0	0.60	-	100	100	50	50	10	-

*MRML- Most recently mature leaf
Adapted from: Maynard & Hochmuth, 1997.

Research done by Karitonas (2002) however showed the following mineral content values for broccoli leave samples at an N level of 240 kg N ha⁻¹:

Element	Concentration g kg ⁻¹
N	26.1 - 31.3
P	3.3 - 4.6
K	23.6 - 31.1
Ca	34.6 - 55.9
Mg	5.0 - 7.9

In general these values correspond with that given in **Table 2.3**. However there are differences for K and Ca. Especially with regards to K it seems that large differences can exist. Very low levels of K were found to be adequate (Dufault, 1988).

In an experiment to determine the response of Chinese cabbage to different levels of N fertilization, Jian (1990) found that significant differences in marketable yield was obtained from different levels of N fertilization. Marketable yield increased as N fertilization was increased from 0 to 150 kg N ha⁻¹. However increasing N to 180 kg ha⁻¹ lead to a decrease in yield. The recommended rate under the growth conditions was between 120 and 150 kg N ha⁻¹. This research showed that N is one of the most important nutrients for obtaining reliable and optimal yields and head quality of Chinese cabbage, but is also the most difficult element to manage so that adequate but not excessive N is available throughout the growing season. Physiological disorders tend to occur when the appropriate fertilizers are not applied (Jian, 1990). These findings are confirmed in a greenhouse experiment with Chinese cabbage variety *Dabadaba* which was cultivated in pots filed with non-fertile soil (Tshikalange, 2006). Optimum application rates for N and K were shown to be 188 kg N ha⁻¹ and 100 kg K ha⁻¹.

Application rates of N and K above the optimum rates reduced biomass production. A critical application rate for P was identified to be 37.5 kg P ha⁻¹.

Transplants

It is not only the nutrition of the established cole crop that is important. Nutrition of seedlings (transplants) is also important as it can influence yield and transplant quality. Semuli (2005) found that a nutrition solution with 90 mg L⁻¹ N produced good quality cabbage transplants with a large dry root mass that pulled easily from the transplant trays. Similar results were obtained in South Africa with autumn cabbage transplants (More, 2006), but in spring plantings best results were obtained from transplants that received 60 mg L⁻¹ N. In these studies, higher N application rates increased relative growth rate, net assimilation rate, leaf area ratio, specific leaf area, pulling (from trays) success, leaf mass ratio, leaf nitrogen, fresh and dry root mass, plant height, leaf number, leaf area and fresh and dry shoot mass. In contrast to this, the root: shoot ratio and root mass ratio were decreased as N increased. About 10% of transplants grown with 0 N could pull out of cavity trays while 90% of transplants that received N could pull out of cavity trays during autumn. Application rates of at least 15 mg L⁻¹ K and 15 mg L⁻¹ P are recommended (More, 2006).

In contrast to this Tremblay & Senécal (1988) found that the root dry mass of broccoli was decreased as N was increased. This reduced root: shoot ratio which is not ideal as transplants with poor root systems tend to suffer more from transplant shock (Weston & Zandstra, 1986). Wurr *et al.* (1986) also recommended a “low” N level of 52 mg L⁻¹ because it increased the number of

cauliflower leaves and transplants had a high percentage dry matter at transplanting.

Fertilizer application

It is generally recommended that split applications of fertilizers be made in the production of cole crops (Welch *et al.*, 1985). Semuli (2005) studied the response of cabbage to top dressings of 50, 100 and 150 kg N Ha⁻¹ and found that under his conditions a top dressing of 100 kg N Ha⁻¹ resulted in the highest yield (per unit area) and head mass. Broccoli that was irrigated with sub-surface drippers in sandy loam soils, however showed no quality or quantity response to the frequency of fertilization (Thomson, *et al.*, 2003). It was for this reason recommended that fertilizer could be given monthly on sandy loam soils with sub-surface dripping. In contrast to this, greenhouse studies with hydroponically grown broccoli showed that changing the N supply from 250 mg L⁻¹ to 150 mg L⁻¹ at inflorescence initiation resulted in a significant increase in shoot dry weight and a 58% increase in yield (Nkoa *et al.*, 2000).

Water soluble and fertilizers high in P are generally used as base or basal fertilizer at planting to stimulate early root and shoot growth. These fertilizers are mixed with the topsoil so that nutrients are immediately available to the newly established plants and the fast developing root systems are able to utilize the broadcasted fertilizer through better contact with the soil (Jones, 1982; Semuli, 2005). The aim of the basal applications is to increase soil fertility, particularly P levels to 25-35 mg·kg⁻¹ (Bray 2). Where the soil has high fertility the maintenance

application may not be banded but broadcasted with a small amount applied as pop-up at planting (Semuli, 2005).

Minor elements

In **Table 2.4** the relative response of Cole crops to micronutrients are given (Maynard & Hochmuth, 1997). From this table it is clear that broccoli and cauliflower are sensitive to low levels of Boron (B), Molybdenum (Mo) and Iron (Fe). Broccoli, cauliflower and cabbage need more than 0.5 ppm B in the soil (Maynard & Hochmuth, 1997). Cauliflower with a relationship of Ca to B of more than 800:1 (plant analysis) has a shortage of B (Bhandari and Thakur, 1985).

B deficiency symptoms of broccoli are very similar to that of cauliflower. Square shaped cavities in the core of broccoli plants are therefore an indication of a lack of B (Jackson & Coertze, 1998).

Less severe shortage of B in the soil can be rectified by adding 5 kg Borax ha⁻¹. In cases of severe shortages 20 kg ha⁻¹ can be added (Jackson and Coertze, 1998). It usually is too late to rectify the problem when symptoms of B shortage are noticed on the crop. If the crop is still young a foliar spray can be applied. One kg Borax in 500L to 1000L water ha⁻¹ can be applied. A foliar application at a concentration 0.1-0.2% B is recommended. However caution should be taken as a 0.4% concentration decreased yield and quality in cauliflower (Zhu, 2005).

Table 2.4 Relative response of Cole crops to micronutrients

Response to micronutrients						
Crop	Mn	B	Cu	Zn	Mo	Fe
Broccoli	Medium	High	Medium	-	High	High
Cabbage	Medium	Medium	Medium	Low	Medium	Medium
Cauliflower	Medium	High	Medium	-	High	High

The crops listed will respond as indicated to applications of micronutrients when that micronutrient concentration in the soil is low
Source: Adapted from Maynard & Hochmuth, 1997.

From **Table 2.4** it is clear that broccoli is sensitive for Molybdenum shortages. In case of shortages an abnormal growth of the leaves called whiptail can develop. This is true for cauliflower but also for broccoli to a lesser degree (Jackson and Coertze, 1998). Molybdenum foliar applications at a concentration of 0.1% $((\text{NH}_2)_4)_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$ delivered good results (Zhu, 2005). Mo shortages tend to develop in soils with a pH of lower than 4.5 because the Mo in the soil becomes unavailable to the plants. This problem can be rectified by liming according to a soil analysis report. In known cases of Mo shortages the seedlings can be sprayed in their seedbeds 7-10 days before transplanting. This can be done with 30 gram sodium- or ammonium molybdenum per 50 liters of water per 10 square meter seedbed. If foliar applications in the transplanted crop are needed it can be done with 60 to 120 gram sodium- or ammonium molybdenum per 1000 liter of water per hectare (Jackson and Coertze, 1998).

Iron (Fe), Manganese (Mn) and Zinc (Zn) very seldom cause problems in Cole crops in South Africa (Jackson and Coertze, 1998). In the Olifants river valley seed production area growers in general add one of the commercial minor element mixtures to their fertilizer program. Although it has not been scientifically

tested it does seem to have a positive effect on seed quality (Pers. Comm., 2006, Mr. P. Brink, PO Box 114, Vanrhynsdorp, 2006).

Soil pH

Soil pH is an important factor affecting the availability of plant nutrients. Extremes in soil pH also affect the functioning of microorganisms. High pH levels decrease the availability of Zn, Mn, Fe and Cu. In the case of very low pH levels Al and Mn may reach toxic levels with reduced availability of N, P, K, S, Ca, Mg, and Mo (Jones, 2003). Soil pH is important for Cole crops. Broccoli, cauliflower and cabbage fall into the category of vegetables that are slightly tolerant to soil acidity (Maynard and Hochmuth, 1997). These crops can be grown successfully on soils that are on the alkaline side of neutrality. They do well up to pH 7.6 if there is no deficiency of essential nutrients. Liming should be done in soils where pH (H₂O) is lower than 5.8. The quantity and type of lime should be informed by a soil analysis. Lime must be applied at least four weeks before planting (Jackson and Coertze, 1998).

Organic fertilizing

Cole crops generally respond positively to organic fertilizing (Jackson and Coertze, 1998). Organic matter can be added in the form of compost, kraal manure, chicken manure, ghwano, green manure and the remains of the previous harvest. The quantity will in many cases be determined by cost factors. As organic matter in general does not contain a lot of nutrients, it is advised that it be used in conjunction with chemical fertilizers (Lecuona, 1996).

The use of rice straw mulching at 2.5 tons per hectare was effective in increasing the yield of Chinese cabbage. This was probably due to better moisture control under mulch as well as cooler soil temperatures. Chinese cabbage is sensitive to high temperatures (Salas, 1992).

In experimentation with nitrogen and humus it was found that the different N and humus rates applied produced significantly different effects on plant growth, total yield and head yield of Chinese cabbage. Yield increased with an increase in N and humus levels. The highest yield was produced by a combination of 12 t-humus ha⁻¹ and 120 kg-N ha⁻¹. There was, however, no interaction between humus and N (Ping, 1989).

2.3.2 Seed production of cole crops

Literature concerning the nutrition of seed producing cole crops is very scarce. The period from transplanting of seedlings to harvest is about 32 weeks (224 days) depending on the cultivar. Although no research has been done previously, the following plant nutrition program which is based on practical experienced is used as a general guideline. (Pers. Comm., 2006: G.J. Kersop, PO Box 463, Lutzville):

165 kg N ha⁻¹

100 kg P ha⁻¹

400 kg K ha⁻¹

160 kg Ca ha⁻¹

Guidelines for the production of seed from Chinese cabbage indicate that faster N dissipation in soils lead to earlier flowering and lower seed yields. If N is supplied too late, the harvest becomes late, the plants fall over and damage by disease and insects increase. Since supplying a sufficient amount of N at the initial stage of flowering is most effective in increasing seed yield, side dressing of N at this stage is recommended. K also has to be supplied at this stage. B supplementation is also necessary where content in the soil is low. For artificially vernalized Chinese cabbage plants, it is suggested that 150 kg N ha⁻¹ be supplied in a split application with half applied before planting and the second half applied two weeks after planting. Further application of 30 kg N, 30 kg P₂O₅ and 20 kg K₂O at bolting time with another side dressing at mid flowering time of 15 kg N and 10 kg K₂O, suggested. Borax at 10 kg per hectare is applied before planting in cases of low B content (Opeña *et al.* 1988).

In research (Mishra, 1992) the effect of N and B fertilization on the yield of cauliflower seed was investigated. P and K were kept constant at 80kg P₂O₅ and 60kg K₂O. Three levels of N were applied, 90kg, 120kg, 150kg and 180kg ha⁻¹. B was applied at levels of 10 and 15 kg ha⁻¹. The results showed that N had a significant effect on plant height, number of branches, number and length of pods, number and weight of seeds and seed yield. It was found that the optimum level of N fertilization in that situation was 150 kg ha⁻¹. This level also brought about maximum seed germination. A further increase in N to 180 kg ha⁻¹ was not effective as lodging was caused by inducing undue lengthening of the stem internodes which delayed the maturation of plants and also affected the seed quality. The time of N application did not have any effect on seed yield or quality.

Sharma and Rastogi, (1992) found that N fertilization at 200 kg/ha delivered the best yield of cauliflower seed ha⁻¹. It is however expected that optimum levels would differ at different times, locations and cultivars.

Different levels of boron application significantly affected number of branches, number of pods, 1000 seed weight and seed yield. The optimum level of B application in this case was at 10 kg ha⁻¹ which gave better results than 15 kg ha⁻¹ (Mishra, 1992).

Lyons *et al.*, (2009) investigated the response of *Brassica rapa* L. to a low dose of Selenium (as sodium selenite) in terms of growth responses and seed production. No change in total biomass was found but the Se treatment was associated with a 43% increase in seed production. It was further found that Se treated plants produced pollen that had 2% unviable grains compared to 14% unviable grains for the control plants. Se-treated plants produced seed with a mean germination rate of 92% compared to a mean of 81% for the control. It has been suggested that if Se was essential to vascular plants, an available Se concentration as low as 1.0 µg kg⁻¹ in growth media would be able to satisfy their Se requirements. Some plant species are considered to be non accumulators while other accumulates Se. The fast growing *Brassica* species, Indian mustard and canola has been identified as new secondary Se-accumulator species. (Terry *et al.* 2000).

2.3.3 Seed production of rapeseed

Rapeseed is the most important *Brassica* crop grown for seed production. Fertilizer requirements and responses of rapeseed may provide some guidelines that can be used to determine the nutrition needs of broccoli grown for seed.

Nitrogen

Approximately 70 kg of N is needed for every 1 ton of rapeseed produced. One ton of rapeseed contains approximately 35 kg N with 42% oil and 38% protein. At a yield of 3 t ha⁻¹, 150-210 kg N ha⁻¹ is needed. The effectiveness of N uptake is relatively weak in the case of rapeseed (Kimber & McGregor, 1995).

Many studies showed the importance of nitrogen nutrition to growth and yield of rapeseed (Kimber & McGregor, 1995). The effect on plant development is in general not that large, but protein synthesis, leaf expansion and leaf growth are largely affected. High rates of N may also reduce oil content in the seed. Most N needed by the crop is taken up before flowering stage, and then redistributed to pods and seeds from leaves and stems. Pod walls can act as temporary reservoirs for nitrogen and may supply as much as 25% of the seed requirement. Pod walls can also act as storage reservoirs for other nutrients, particularly P, Zn and Mg. Higher grain yields in response to N applications are most often found to be the result of additional pods m⁻², with little effect on later developed yield components. N application at the rosette to early stem elongation stages has generally been more beneficial than earlier or later applications (Kimber and McGregor, 1995).

The translocation of N from foliar components to the pods and seed is influenced by the level of N fertilization. With high N application rates, translocation of N to the seed did not happen. Nitrogen translocation to the seeds utilized on average the following proportions of N available in the source: 66% of that available from the leaves, 53% from the pods, 27% from the stem and 17% from roots (Kimber & McGregor, 1995). These translocation values of N may indicate that a relatively large, well developed and healthy broccoli plant may also need to be developed in order to achieve optimum seed yield.

Phosphorus

The need for P in rapeseed is not very high. Approximately 12 kg P is removed per one ton of seed harvested. Oil and protein content of rapeseed is not significantly affected by P fertilization (Kimber and McGregor, 1995).

Potassium

Rapeseed needs large quantities of K as more than 200 kg Ha⁻¹ K₂O is mobilized in the plants although only 25 kg K₂O is removed per ton of seed. Maximum absorption occurs during stem elongation when daily uptake can be as high as 15 kg K₂O ha⁻¹ (Kimber and McGregor, 1995). It was found during trials with K fertilization (Avilla *et al.*, 2004) that application of KCl increased germination and vigor of canola seed. Furthermore it was found that the total fungi found on seed were lower. It appears that K fertilization is important during seed production.

Sulphur

Brassica crops have a relatively high demand for S as the protein content of the seed is high (Haneklaus *et al.*, 1999). Furthermore S is important as it is essential for optimal N utilization by plants. In cases where S shortages are experienced the utilization of N can be as low as 25% (Haneklaus *et al.*, 1999). In rapeseed a lack of S can lead to severe loss of yield. Fertilization of S at 40 kg ha⁻¹ was shown to be sufficient in rapeseed production. It was shown that as S fertilization is increased, the yield of rapeseed increased and the oil content of the seed also progressively increased as S was increased (Malik *et al.*, 2004). These results were confirmed (Grant *et al.*, 2003) and it was further found that increases in S and oil concentration is accompanied by lower chlorophyll and seed N concentration. The oil content of rapeseed stands in an inverse relation to the N concentration in the seed. With increased N fertilization it is found that the oil content of the seed decreases (Smith *et al.*, 1988). Oil in the seed serves as a source of energy and carbon in germinating seed (Kimber and McGregor, 1995). Janzen & Bettany (1984) estimated the optimal ratio of N to S in the soil to be 7:1. Ratios below 7 resulted in inefficient utilization of assimilated S and ratios exceeding 7 resulted in reduced seed yields.

Calcium

Calcium is an important major element for plant growth. Most of the functions of Ca as a structural component of macromolecules are related to its capacity for coordination, by which it provides stable but reversible intermolecular linkages, predominantly in the cell walls and at the plasma membrane. It is important, particularly for this research, to keep in mind that in order to protect the roots

against the adverse effects of various other cations in the soil solution the Ca concentration required for optimal growth has to be much higher in soil solutions than in balanced flowing nutrient solutions (Marschner, 1995). In research into the Ca requirements of canola Brennan *et al.*, (2007) found that the two cultivars investigated displayed large seed yield responses to applied Ca (in the form of calcium sulfate). One of the cultivars produced no seeds when no Ca was applied and showed a 97% increase to applied Ca and required about 462 mg Ca pot⁻¹ to produce 90% of the maximum seed yield.

Magnesium

Mg is required for chlorophyll production and for numerous enzymatic functions. Mg affects oilseed rape nutrition and the amount in the crop can rise to 28 kg ha⁻¹. About 50% of this is removed with the seeds. Ca affects Mg absorption and the Ca : Mg ratio in the soil should be taken into account when deciding application rates (Kimber and McGregor, 1995).

Minor elements

Table 2.5 Optimal content of minor elements in leaves of rapeseed at stem elongation.

Element	Optimum content (ppm)
Copper	4.5
Zinc	37.5
Iron	100-130
Manganese	40
Boron	20-25
Molybdenum	0.5-0.7

Source: Kimber & McGregor

From **Table 2.5** we can see that comparatively high levels of Fe are required. Relatively small content of Mo is needed. Zn, Mn and B optimum content are

fairly similar. Cu content is also fairly low. As in the case of other Brassica plants, rapeseed is sensitive to low levels of B (Kimber and McGregor, 1995)

2.4 Agronomic production techniques of *Brassica* crops

2.4.1 Planting density

The optimum planting density per hectare is determined by the specific cultivar. Densities of 16 000 to 40 000 plants per hectare is generally recommended for cauliflower (Hygrotech Vegetable Table, 1998). Spacing of 600 mm to 700 mm between rows and 450 mm in the row is generally used but may differ between cultivars. Sharma and Rastogi (1992) found that spacing of 60 cm x 30 cm gave the highest seed yield per hectare but the highest yield per plant was at 60cm x 60cm. Typical plant spacing in the Olifants river valley seed production area is 75cm x 40cm (Pers. Comm., 2006, Mr. G.J. Kersop, P O Box 463, Lutzville). Spacing has an influence on the size of the heads and the resultant yield per hectare. Research showed that cabbage forms somewhat smaller more pointed heads when planted at higher densities (Bosch *et al.*, 1998). Experimentation in South Africa also indicated that spacing had a definite influence on cabbage head mass and yield per unit area (Semuli, 2005). As intra-row spacing was decreased, increasing densities, cabbage head mass decreased but yield per unit area increased. For untrimmed cabbage heads the highest yield was produced at 300 x 500 mm spacing. Spacing of 500 x 500 mm produced heavier and larger heads. Spacing did not appear to influence head quality but head diameter was influenced with more flat heads being obtained from the wide spacing (Semuli, 2005). Yamarak (1993) also found that cauliflower cultivar and spacing had interactions to head size and weights, plant height and canopy.

Vigorous vegetative growth and high densities also tend to enhance insect infestations. Good size heads were obtained from spacing of 30 x 60-70 cm but higher total yield was obtained from spacing of 30 x 30-50 cm (Yamarak, 1993).

Crop growth under conditions where nutrients and water are not limiting can mostly be explained by the ability of the crop to intercept and utilize solar radiation which is affected by planting density. An almost linear relationship between yield and intercepted radiation has been discovered for many crops (Olesen & Grevsen, 1997).

2.4.2 Soil preparation

Soil preparation should commence at least 8 weeks prior to planting (Bosch *et al.*, 1998). This would assist with weed control and combat cutworm. In instances where a compaction layer exists, breaking up the layer with a tine implement to at least 600 mm in depth is essential. In order to ensure a thorough planting surface it might be necessary to use a cultivator or disc implement. In cases where nematodes are a problem, they should be controlled with a registered fumigant at least 2 weeks before planting. During winter production the nematode population increases at a slow rate and fumigation would probably not be necessary. Should there, however, be an uncertainty regarding the nematode population pressure, soil samples should be extracted so that a nematode count can be performed by a trustworthy laboratory (Bosch *et al.*, 1998).

2.4.3 Rotational cropping

Rotational cropping is essential in Cole production in order to limit the build up of soil borne diseases. Cole crops should not be cultivated on the same land more than once every four years. In the rotational system, crops should be alternated between the different plant families. Cauliflower should thus not be followed by broccoli or any other *Cruciferae*. Cole crops are not easily influenced by prior plantings of other plant families. It is an advantage when the preceding crop adds organic material to the soil (Bosch *et al.*, 1998).

2.4.4 Establishment

Direct sowing in the field is possible, but it requires intensive and exact management. It would require very thorough soil preparation, prior weed control, quality seed, overhead irrigation and pathogen and insect control. Growers commonly use nurseries to produce the seedlings. Nutrition of the transplants is important as the quality of the transplant and final yield may be influenced by it (More, 2006). The seedlings should at least be one month old before transplanting, which is usually not a problem for Cole crops (Van Niekerk & Coertze, 1998). The protection of young plants against cutworm and diamond black moth is essential (Bosch *et al.*, 1998).

2.4.5 Irrigation

Water requirements for Cole crops are high. Evapo transpiration of 4 mm or higher per day during the summer has been measured for cabbage (Coertze, 1998). Water usage of the crop would depend on the climate of the region as well as the season during which production takes place. The use of tensiometers

or other soil moisture measuring devices are recommended to improve water use efficiency and irrigation scheduling. When the moisture content of the soil in which the majority of the roots appear has dropped to just below field capacity, irrigation can be applied to refill it to field capacity (Coertze, 1998).

According to studies on root depth which were done by the Roodeplaat Institute for Vegetables and Ornamentals, the effective root zone of cabbage is up to 600 mm. It is thus not necessary to irrigate the soil to a level deeper than this. It is however recommended that prior to planting, the soil should be irrigated to a depth of 1000 mm. After this, irrigation is determined by measuring the soil moisture level. A mature crop has the largest water requirement and effective irrigation at this stage is important. Young plants should also be sufficiently irrigated as they do not easily recover from water stress. This is especially true in the case of cultivars that have a short production cycle (Coertze, 1998). Water stress after transplanting of cauliflower induces earlier head formation and this can be very negative.

Irrigation of Cole crops for seed production is especially critical during the time of anthesis and optimal seed production is obtained if plants are optimally irrigated during this time (George, 1999). Rapeseed responds well to irrigation and oil content in the seed increase with irrigation up to pod ripening, the stage when most oil accumulation is taking place. The most critical time for water availability is during flowering and early pod development. During this time number of pods and seeds are determined (Mendham & Salisbury, 1995).

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CHAPTER 3

THE INFLUENCE OF DIFFERENT NUTRIENT SOLUTIONS ON BIOMASS PRODUCTION AND NUTRIENT CONTENT OF BROCCOLI (*Brassica oleracea* L. var. *italica* Plenck) PRODUCED FOR SEED.

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ABSTRACT

During 2006 and 2007 broccoli plants were grown in trials for seed production in a net structure. The plants were grown in sand bags utilizing a drain to waste hydroponic system. The experimental design was a randomized complete block with 7 treatments replicated in four blocks. During 2006 seven nutrient solutions were used. The Standard solution was based on Steiner's universal solution and different levels of N, S, K and Ca were used in the experimental solutions. The influence of different nutrient solutions was investigated with regard to total biomass, nutrient element concentration and nutrient assimilation. No significant differences in total biomass produced in response to the different nutrient solutions were found. Total dry mass per plant increased by 225% from the mature head stage until harvest of seed. Nutrient concentration in plant samples were not influenced by treatments except where low levels of K and S in nutrient solutions led to significantly lower levels of K and S concentrations. Higher levels of N, S, K and Ca in nutrient solutions had no significant effect on concentrations in plant samples. Assimilation of elements in response to treatments was not significant. The total assimilation of elements at four growth stages were investigated noting in particular the much longer period of production in comparison to normal head production. Major elements assimilated ha⁻¹ was: N 173.0 kg, P 35.5 kg, K 348.4 kg, Ca 114.7 kg, Mg 30.5 kg, S 42.2 kg.

All the treatments of 2006 were not repeated during 2007 but the standard solution (treatment) was the same. Plant analysis from the standard treatment of element concentration at different growth stages at different plant parts were done during 2006 and 2007. Plant analysis results of the two years were compared. Similar trends emerged during the two production seasons. As the plants developed towards maturity there was a relative increase in concentration in the top plant parts for Ca, Mg and S. This increase was particularly strong for Ca. In contrast, N and P concentration declined. The minor elements, Fe, Mn and B also increased in concentration in the top plant parts at harvest indicating a strong relative flow of these elements to the top plant parts towards maturation. Element concentrations in the seed pods were in general higher than in the rest of the plant indicating the pods as a strong sink on the plants.

Key words: Brassica seed, Broccoli seed, Broccoli nutrition, Hydroponic production, Broccoli production, Nutrient assimilation.

INTRODUCTION

The production of *Brassica* vegetables is a worldwide phenomenon. One of the important *Brassica* vegetables produced is broccoli, *Brassica oleracea* L. var. *italica* Plenck. The seed required to produce broccoli for fresh markets is supplied by a number of international seed companies. One such company that sells seed in various countries has been contracting producers for seed production of broccoli seed in the West Coast region of South Africa. Production takes place in the lower part of the Olifants river valley in the proximity of the towns of Lutzville and Vredendal. Over the past ten years the production of F1 hybrid broccoli and cauliflower seed has steadily increased in the region. The seed crop is of considerable economic importance in the region.

Knowledge about the nutritional requirements of broccoli plants grown for seed production is not known. Thorough knowledge and experience about production for fresh markets exist. The production period from transplanting to harvest for normal head production varies between 6 and 22 weeks (Coertze, 1998). For broccoli seed production the production period is typically 32 weeks (Pers. Comm., 2006: G.J. Kersop, PO Box 463, Lutzville). This is of course a much longer growing season. Growers suspect that certain nutrients might be especially important for the production of good quality broccoli seed at high yields. The quantities and relation of these elements are not known. The total weight of major and minor plant nutrients assimilated by broccoli plants during the long production season required for seed production is unknown. The relation and concentration of these nutrient elements to each other in the plant at different plant parts at different growth stages is unknown.

The objective of this study was to determine the effect of different nutrient solutions (different nutrient levels) on the assimilation of major and minor nutrient elements into broccoli (cultivated for seed) plant biomass at different growth stages and the concentration of these nutrient elements in the plant at different growth stages. The total mass of these elements assimilated by broccoli plants per hectare was also investigated. The influence of the nutrient solutions on total biomass production was investigated as well. The treatments used during the two production seasons of 2006 and 2007 were not exactly the same, though some of the nutrient solutions were similar during the two years.

MATERIAL AND METHODS

The research done was undertaken in conjunction with Syngenta Seed B.V. Research was undertaken during two production seasons of 2006 and 2007. The production season stretched from March to the beginning of December. The same production system and structures were used during the two years of research.

3.1 Locality and environmental conditions in 2006 and 2007

Climatic data for 2006 and 2007 are given below in **Table 3.1 A** and **B**. The weather station from which the data was collected is situated ten kilometers from the research locality. The Lutzville weather station is situated at: Latitude - 31.58543° S, Longitude 18.3808° E, Altitude 26m. Both localities are situated within the Lower Olifants river valley.

A comparison of the climatic data of the two years indicates that 2006 received almost the same rainfall than 2007. Total rainfall for 2006 was 141.6 mm compared to 136.5 mm for 2007. Precipitation was, however, more evenly distributed during the winter rainy season (April to September) of 2007. During 2006 the early part of the rainy season (April and May) received more rain compared to the same time period in 2007. However, June and July of 2007 (41.5 mm and 27.4 mm respectively) received more rain than June and July 2006 (17.9 mm and 14.0 mm respectively). The relative wetter early part of 2006 might have contributed to the heavy infestation of *Sclerotinia* during 2006.

Table 3.1 A Climatic data for Lutzville during 2006

Station name: Lutzville Bottom Latitude -31.58543 S Longitude 18.3808 E Altitude 26m									
Month	Day	Rain mm	Tmax °C	Tmin °C	Tave °C	U2 M/s	Rhavg %	ETo mm/day	Rs MJ/m ² /day
Jan	Total	2.3	934.8	464.9	673.5	86.8	2066.1	213.3	855.9
	Average	0.1	30.2	15	21.7	2.8	66.6	6.9	27.6
	Highest	1	39.5	18.7	25.1	3.8	80.6	10.4	36
	Lowest	0	23.1	10.2	18.9	1.8	51.6	3.1	9.3
Feb	Total	0	862.1	426.5	619.3	57.8	1883.1	176.7	731.9
	Average	0	30.8	15.2	22.1	2.1	67.3	6.3	26.1
	Highest	0	43.6	18.1	32.1	3.2	84.3	10.6	30.2
	Lowest	0	24.8	9.6	19.6	1.5	33.4	3.2	14.5
Mar	Total	0.9	927.7	359.7	622.8	64	1790.4	182	714.2
	Average	0	29.9	11.6	20.1	2.1	57.8	5.9	23
	Highest	0.6	40.3	17.6	29	3.1	80.3	9.2	27
	Lowest	0	23.2	6.9	15.6	1.4	28.2	3.7	15.7
Apr	Total	14.7	825.7	336	556.3	48.4	2005	116.5	478.5
	Average	0.5	27.5	11.2	18.5	1.6	66.8	3.9	16
	Highest	8.1	39.4	19.5	27.2	2.5	85.8	6.6	20.3
	Lowest	0	18.2	5.7	13	0.7	36.1	1.6	6.6
May	Total	62.1	701.5	292.3	473.7	51.8	2231.7	82	352.3
	Average	2	22.6	9.4	15.3	1.7	72	2.6	11.4
	Highest	22.7	33.2	14.6	21.6	4.7	92	6.1	15.7
	Lowest	0	16.7	3.2	10.8	0.6	36.7	1.1	4.8
Jun	Total	17.9	712.1	238.2	452.1	58.6	1913.4	89.1	333.3
	Average	0.6	23.7	7.9	15.1	2	63.8	3	11.1
	Highest	7.5	31.1	14.8	20.7	4.2	90.8	5.8	13
	Lowest	0	17	1.1	8.6	0.8	34.1	1.2	5.9
Jul	Total	14	646.7	238	401.5	49.8	2402.8	71	347.4
	Average	0.5	20.9	7.7	13	1.6	77.5	2.3	11.2
	Highest	3.7	30.3	10.9	18.9	3	89.9	5.2	15.2

Aug	Lowest	0	14.5	3	9.3	0.8	40.2	1.2	4.3
	Total	17.4	646.4	242.4	421	62.8	2319.8	96	491.3
	Average	0.6	20.9	7.8	13.6	2	74.8	3.1	15.8
	Highest	5.3	30	14.3	19.3	5.2	90.4	9	23.8
Sep	Lowest	0	14.3	1.3	9.9	0.9	27.4	1.3	4.4
	Total	5.7	773.9	274	499.2	59.1	1889.8	143.3	634.4
	Average	0.2	25.8	9.1	16.6	2	63	4.8	21.1
	Highest	3.5	37.6	17.9	24.9	2.8	82.8	8.1	29.8
Oct	Lowest	0	15.6	0	10.6	1	25	1.4	4
	Total	1.6	815.1	310.6	465.7	58.6	1721.4	182.1	874.2
	Average	0.1	26.3	10	17.9	2.3	66.2	5.9	28.2
	Highest	1.3	38.3	15.5	23.7	3.6	77.9	9.4	32.7
Nov	Lowest	0	19.1	2.6	12.9	1.6	43.4	3.6	18.8
	Total	4.7	847.9	371.4	601.3	72.1	1857.5	206.5	904.1
	Average	0.2	28.3	12.4	20	2.4	61.9	6.9	30.1
	Highest	4.4	39.4	18.1	27.3	4.5	75.7	13.5	33.4
Dec	Lowest	0	19.1	6.4	15	1.6	20.1	4.2	20.3
	Total	0.3	838.9	395.1	616.8	77.8	1998.7	207.6	980
	Average	0	27.1	12.7	19.9	2.5	64.5	6.7	31.6
	Highest	0.3	38.2	16.4	25.4	3.4	75.8	10.2	34.1
	Lowest	0	22.8	9.9	17.9	1.9	39.1	3.8	16.2
Annual Total		142	9533	3949	6403	748	24080	1766	7697

Rain	mm/day	Rainfall
Tave	°C	Average Daily Temperature
Eto	mm/day	Evaporation calculated by Penman-Monthieth (FAO-56)
Rs	MJ/m ² /day	Radiation
Tmax	°C	Daily Maximum Temperature
Tmin	°C	Daily Mean Minimum Temperature
U2	M/s	Wind Speed
Rhave	%	Relative Humidity

*Data received from Agromet (2008)

Table 3.1 B Climatic data for Lutzville during 2007.

Station name: Lutzville Bottom Latitude -31.58543 S Longitude 18.3808 E Altitude 26m

Month	Day	Rain mm	Tmax °C	Tmin °C	Tave °C	U2 M/s	Rhave %	ETo mm/day	Rs MJ/m ² /day
Jan	Total	0.3	950.3	464.3	683.4	72.9	2035.8	220.9	934.8
	Average	0	30.7	15	22	2.4	65.7	7.1	30.2
	Highest	0.3	42	19.8	27	4	87.6	9.9	34.4
	Lowest	0	23.7	7.6	18.4	1.8	44	3.1	14.7
Feb	Total	9.3	788.5	400.6	579.5	61.1	1933.8	165.8	759.4
	Average	0.3	28.2	14.3	20.7	2.2	69.1	5.9	27.1
	Highest	4.4	36.8	20.2	23.5	3	80.7	7.6	31.1
	Lowest	0	21.6	8.2	16.5	1.6	58.6	3.2	15.4
Mar	Total	2.6	949	391.1	641.4	60.7	1918.5	183.3	725.2
	Average	0.1	30.6	12.6	20.7	2	61.9	5.9	23.4
	Highest	2.6	42.7	19.1	28.7	4.6	78.4	11	26.9
	Lowest	0	21.5	7.5	15.5	1.3	22.9	3.7	17.1

Apr	Total	2.4	818.4	322.6	529.4	46.8	2122.9	117.1	519.1
	Average	0.1	27.3	10.8	17.6	1.6	70.8	3.9	17.3
	Highest	1.8	37.9	16.9	23	2.2	85.7	6.3	20.4
	Lowest	0	18.2	4.1	12.1	0.7	46.5	2.1	6.2
May	Total	6.2	811.3	294.5	509.3	54.9	2069.3	105.6	407.1
	Average	0.2	26.2	9.5	16.4	1.8	66.8	3.4	13.1
	Highest	4.4	39.8	16.3	23.3	4.9	88.4	7.1	16.6
	Lowest	0	15.4	1.4	9.1	1	20.3	1.6	5.6
Jun	Total	41.5	641.6	241.3	406.2	60.3	2161.3	73.9	305.7
	Average	1.4	21.4	8	13.5	2	72	2.5	10.2
	Highest	14.1	31.4	13	18.5	4	87.6	5.8	12.8
	Lowest	0	14.9	3.9	9.4	0.9	36.2	1.2	3.5
Jul	Total	27.4	668.6	194.8	410.1	59.6	2063.9	88.6	362.1
	Average	0.9	21.6	6.3	13.2	1.9	66.6	2.9	11.7
	Highest	19.4	29.8	12.4	18.3	3.9	90.5	6.1	15.3
	Lowest	0	14.4	2.9	9.3	0.8	28.2	1	5.3
Aug	Total	19.9	659.2	234.1	420.4	59.8	2201.2	97.6	466.4
	Average	0.6	21.3	7.6	13.6	1.9	71	3.1	15
	Highest	9.9	32.7	11.3	19.7	4	84.1	6.3	18.9
	Lowest	0	15.5	3.5	10.2	1	36.9	1.7	6.6
Sep	Total	2	719.9	228.8	456.4	55.1	2041.4	126.3	598.8
	Average	0.1	24	7.6	15.2	1.8	68	4.2	20
	Highest	1.4	36.9	14	20.4	3.6	79	7.5	26.4
	Lowest	0	18.6	1.4	12.1	1.1	44.9	2.2	9.4
Oct	Total	10	815.5	334.8	575.1	75.6	1896.4	149.6	765.8
	Average	0.32	26.3	10.8	18.6	2.44	61.2	4.83	24.7
	Highest	3.9	37.1	17.2	27.2	3.91	77.9	8.1	28.7
	Lowest	0	15.5	3.4	11.3	1.72	32.8	2.5	15.2
Nov	Total	1.6	787.4	317	182.7	24.8	682.1	176.7	803.6
	Average	0.2	26.2	10.6	18.3	2.5	68.2	5.9	26.8
	Highest	0.8	37.7	14.1	22.2	4.1	76.9	9.6	34.8
	Lowest	0	20.3	6.6	16.7	1.5	48.1	3.3	13.7
Dec	Total	21.7	899.2	436.7	651.9	69.9	2052.4	207.5	925.8
	Average	0.7	29	14.1	21	2.3	66.2	6.7	29.9
	Highest	10.7	40.4	17.8	28.4	3.4	81.8	10.8	33.9
	Lowest	0	22.9	6.6	17.1	1.5	37.6	4.7	18
Annual Total		137	9509	3836	5936	685	23004	1745	7682

Mm Rainfall
 °C Average Daily Temperature
 Mm/day Evaporation calculated by Penman-Monthieth (FAO-56)
 MJ/m²/day Radiation
 °C Daily Maximum Temperature
 °C Daily Mean Minimum Temperature
 M/s Wind Speed
 % Relative Humidity
 *Data received from Agromet (2008)

The temperature, wind speed, relative humidity, evaporation and radiation data for 2006 and 2007 did not indicate major differences.

3.2 Agronomical practices in 2006 and 2007

The research during 2006 and 2007 was done in a net structure of 40 m x 27 m. The net colour used was white with a 60% knitting construction delivering 16-18% shade. The broccoli plants were planted in 20 liter black plastic bags filled with sand. The sand was coarse and is usually used for building purposes in the area. The bags had 4 drainage holes approximately one centimeter in diameter located on the side about 1 cm above the bottom (floor level) of the bag. During 2006 the sand was sterilized with 50% hydrogen peroxide. The hydrogen peroxide was mixed with water to a concentration of 0.16% peroxide. Each bag was drip irrigated with 4 liters of the hydrogen peroxide mixture and left to stand for 48 hours where after it was rinsed with clean irrigation water.

The same bags and substrate was used during the two years of experimentation. Because heavy infestation of *Sclerotinia* was a problem during 2006, the bags were sterilized with hot water prior to planting during 2007. Roots were removed after the first season and before hot water treatment. The method used was to heat water in a special geyser to a temperature of about 80°C. The hot water was then piped to each individual pot and administered until it drained from the pot and the temperature increased to >60°C in the bottom of the bag. In general temperatures of >70°C were reached. This sterilization (watering) process lasted 16 minutes per pot. The soil was analyzed before planting in 2006 (**Table 3.2**), but not in 2007. The soil sample was taken from a representative number of sand bags in the net structure.

Table 3.2 Analysis of sand used as growth medium (2006)

pH (KCl)	5.2	
Resistance	820	Ohms
Texture		Sand / Sand
Acidity	0.15	cmol(+) kg ⁻¹
Ca	0.27	cmol(+) kg ⁻¹
Mg	0.21	cmol(+) kg ⁻¹
K	73	mg kg ⁻¹
Na	12	mg kg ⁻¹
P (citric acid)	258	mg kg ⁻¹
Total Cations	0.87	cmol(+) kg ⁻¹
Cu	0.18	mg kg ⁻¹
Zn	0.83	mg kg ⁻¹
Mn	17.9	mg kg ⁻¹
B	0.11	mg kg ⁻¹
C	0.29	%
S	19.03	mg kg ⁻¹

Source: Production Technology Laboratory, Department of Agriculture: WC, Private Bag x1, Elsenburg, 7607.

The sand was typical of washed sand samples. Very low total cations (T-value) indicated very low cation exchange capacity (CEC) with low or no clay and organic matter (carbon). The pH was satisfactory with Mg and Ca levels being very low. The K levels were satisfactory for some crops in a normal soil sample but the total amount available per plant per bag was insignificant. P was surprisingly high, especially in sand. The sample could have been contaminated. The total amount of P available per plant per bag was significant if it is assumed that no washing through over irrigation of the sand took place. P was however not one of the nutrition elements varied in the treatments. P was kept at constant levels. The nutrient solutions were not adjusted for the level of P in the sand growth medium. The sand contained some S but the total amount available is insignificant. Na was at a low level and so were the minor elements except Zn

and Mn which were higher (Pers. Comm., 2009, Dr G.R.C. Cooper, Private Bag x1, Elsenburg, 7607). It was not expected that the nutrient elements present in the medium would have exerted an influence on the treatments. The total amounts available were low, CEC was very low and constant washing through over irrigation of the medium occurred. P in all treatments was the same, but probably at higher levels than P levels in the nutrient solutions alone.

As hybrid seed was produced both “male” and “female” plants were planted in rows next to each other. The “female” plants were sterile as they do not produce any pollen. The “male” plants produce pollen and self pollinate as well as cross pollinate with the “female” plants. Only the “female” plants that had been cross pollinated were harvested. The “male” plants were taken out of the net house after the end of the flowering period. The broccoli cultivars used during 2006 were EK 351 for the “female” plants and EK 358 for the “male” plants. During 2007 the “male” cultivar was 2B030 and the “female” cultivar was 2B123.

All nutritional elements were applied with the irrigation water from premixed solutions. Fertigation took place from 7 premixed 5000 L drums. The drums were mixed according to the prescriptions of the different nutrient solutions and samples were analyzed regularly.

The drainage water from 1 bag in all “female” rows was measured for EC, pH and volume on a weekly basis. These measurements were used to determine whether irrigation needed to be adjusted and/or the EC of the nutrient solutions needed to be adjusted. The pH of each solution was adjusted throughout by

adding nitric acid at 35.7 ml 1000L⁻¹ nutrient solution. Management of pH was aimed at producing drainage water with a pH range of 6.0 to 7.5. The electrical conductivity of the nutrition solutions were 1.65 mS cm⁻¹ but were lowered or increased as circumstances dictated. When too little drainage water (less than 10% of irrigated water) was collected the duration of irrigation was increased. Irrigation started at 10 minutes per day and increased to half an hour as plants developed. Occasionally flushes of an hour were applied. The nutrient solutions were applied as plants needed moisture and this was guided by the use of one low tension tensiometer. This meter utilizes a special ceramic tip that allows for the use in sand. Up until flowering, nutrient solution was applied when a measurement of – 15 kPa to –20 kPa was detected. From flowering onwards – 10 kPa was taken as the point to irrigate. Frequency of irrigation was primarily determined by the readings of the tensiometer. A build up of EC in the drainage water were countered by increasing irrigation length and/or lowering EC in the nutrient solution when mixed. The pH of the drainage water tended to be high with measurements ranging from 6.1 to 8.6 but mostly in the range of pH 7. EC ranged from 0.1 to 5.4. The EC of drainage fluid was clearly influenced by rainfall and evaporation as the containers were not completely covered. The general trends of the measurements were used to make adjustments primarily in duration of irrigation and EC when new batches were mixed. The irrigation water was sourced from the Olifants river canal system.

Table 3.3 Analysis of irrigation water source in 2006.

pH (H ₂ O)	7.0
EC (mS cm ⁻¹)	0.2
Anion (mmol L ⁻¹)	
NO ₃	<0.2
Cl	1.1
SO ₄	<0.2
HCO ₃	0.3
P	<0.02
Cation (mmol L ⁻¹)	
NH ₄	<0.1
K	<0.2
Na	1.1
Ca	<0.2
Mg	<0.2
Si	<0.10
Trace Elements (micromole L ⁻¹)	
Fe	0.2
Mn	<0.2
Zn	<0.2
B	2
Cu	<0.2
Mo	<0.2

Source: Relab, den Haan, Postbus 38, 2290 AA Wateringen, Nederland

The water was very pure with an EC of 0.2 mS cm⁻¹ and very satisfactory for hydroponic purposes. All elements were very low with Na and Cl being the highest but still at insignificant levels. The pH of 7 indicates the non aggressiveness of the water. It was very suitable for root growth (Pers. Comm., 2009, Dr G.R.C. Cooper, Private Bag x1, Elsenburg, 7607). The same water source was used in 2006 and 2007. Many years of experience with the water have shown that differences in the quality of the water over time are negligible

“Female” plants were transplanted on 31 March 2006 and 23 March 2007 respectively. The seedlings were prepared by a commercial seedling nursery and were grown in 242 count seedling trays. The “male plants” were

transplanted using a staggered approach. Early “male” and late “male” plants were planted at different dates. This staggered planting approach was used to lengthen the period of availability of viable pollen for cross pollination purposes.

A standard program for disease and pest control was applied during the two seasons. The heads of broccoli were cut at maturation. Three portions (florets) of the head were left on the plants. At cutting the wounds were dusted with Dusting Sulfur mixed 1:1 with Iprodione (Rovral Talc). This action may have contaminated sample readings for S content. At flowering two bee hives were put in the net house. The net house was bee proof so that bees could not enter or exit. The first hive was put in during August and the hives were left in the net house till the end of flowering. The “male” plants were removed from the net house during October. The “female” plants were harvested on 21 November 2006 and 28 November 2007 respectively.

3.3 Treatments applied in 2006 and 2007

The treatments during 2006 and 2007 were not exactly the same and will therefore be discussed separately.

3.3.1 Major elements in 2006

The nutrient solution treatments (**Table 3.4**) were based on the universal solution as suggested by Steiner and adapted for South African conditions (Combrink, 2005). In six nutrient solution treatments the concentration of NO_3 , S, K and Ca were changed according to the treatment applied. These elements were increased or decreased in six of the nutrient solution treatments. Only NH_4 , Mg

and P remained the same in all the nutrient solution treatments. Nutrient solution 1 (Std) is the standard solution and is similar to the solution proposed for tomato production in South Africa (Combrink, 2005).

Table 3.4 Composition and explanation of nutrient solution treatments in 2006.

Nutrition Solutions	Explanation	mmol _c L ⁻¹						
		NH ₄ ⁺	K ⁺	Ca ²⁺	Mg ²⁺	NO ₃ ⁻	H ₂ PO ₄ ⁻	SO ₄ ²⁻
1. Std	Standard.	1	7	8.5	3.5	12.5	1.5	6
2. Std + K	Increase K, decrease Ca.	1	10.5	5	3.5	12.5	1.5	6
3. Std+ N	Increase N, decrease S.	1	7	8.5	3.5	17.5	1.5	1
4. Std – K	Decrease K, increase Ca.	1	3.5	12	3.5	12.5	1.5	6
5. Std – N	Decrease N, increase S.	1	7	8.5	3.5	7.5	1.5	11
6. Std + S	Increase S, decrease N.	1	7	8.5	3.5	10	1.5	8.5
7. Std – S	Decrease S, increase N.	1	7	8.5	3.5	15	1.5	3.5

The nutrient solutions contained five levels of N concentration as well as 5 levels of S concentration. The following N : S ratios were investigated: 7.5 : 11; 10 : 8.5; 12.5 : 6; 15 : 3.5; 17.5 : 1.

Furthermore the nutrient solutions contained three levels of K and Ca. The following K : Ca ratios were investigated: 3.5 : 12; 7 : 8.5; 10.5 : 5.

3.3.2 Major elements in 2007

During 2007, research was continued. Seven treatments were used. The Standard Solution (1 Std) was the same as in 2006. Though seven treatments were applied, samples were collected only from the four replications of solution 1 (Std), the Standard solution. The other treatments were applied in order to determine their effect on seed yield and quality measurements. This is discussed in detail in Chapter 4. **Table 3.5** is included for information.

Table 3.5 Composition and explanation of nutrient solution treatments in 2007.

Nutrient Solutions – 2007	Explanation	mmol L ⁻¹						
		NH ₄ ⁺	K ⁺	Ca ²⁺	Mg ²⁺	NO ₃ ⁻	H ₂ PO ₄ ⁻	SO ₄ ²⁻
1. Std, Spray nothing	Standard	1	7	8.5	3.5	12.5	1.5	6
2. Std – K, Spray nothing	Lowest K, High Ca	1	3.5	12	3.5	12.5	1.5	6
3. Std – N, Spray Ammonium Nitrate	Lowest N, Highest S	1	7	8.5	3.5	7.5	1.5	11
4. Std - N, Spray nothing	Lowest N, Highest S	1	7	8.5	3.5	7.5	1.5	11
5. Std – N + P, Spray Ammonium Nitrate	Low N, High S+ Highest P	1	7	8.5	3.5	8.5	3.5	8
6. Std - N + P, Spray nothing	Low N, High S+ Highest P	1	7	8.5	3.5	8.5	3.5	8
7. Std - N, Spray Calcium	Lowest N, Highest S	1	7	8.5	3.5	7.5	1.5	11

3.3.3 Minor elements in 2006 and 2007

During both years of experimentation the minor elements added to the nutrient solutions were kept constant for all nutrient solution treatments (**Table 3.6**). The composition was based on the solution proposed for tomato production in South Africa (Combrink, 2005).

Table 3.6 Minor element composition of nutrient solution treatments in 2006 and 2007.

	Fe	Cu	Zn	Mn	B	Mo
mg L ⁻¹	0.85	0.05	0.3	0.55	0.44	0.05

The actual composition of the seven nutrient solution treatments was determined through analysis on 21 June 2006 and is presented in **Table 3.7**. Nutrient treatment Std-S contained low concentrations of K and NO₃. The Std nutrient solution returned a very high value for B. These large discrepancies were not found in subsequent analysis but general trends indicated that Mg and S concentrations tended to be correct or slightly higher whereas the other major elements tended to be slightly lower in concentration in the analyzed solutions (compared to calculated theoretical concentrations).

Table 3.7 Analysis of nutrient solutions – 21/06/2006.

			Major Elements (mmol L ⁻¹)						
Nutrition Solutions	pH	Conductivity (mS cm ⁻¹)	NH ₄ ⁺	K ⁺	Ca ²⁺	Mg ²⁺	NO ₃ ⁻	H ₂ PO ₄ ⁻	SO ₄ ²⁻
1. Std	4.1	2.06	0.6	6.4	6.6	3.9	9.5	1.3	6.3
2. Std + K	4.5	2.12	0.6	7.5	4.3	3.5	9.5	1.3	6.4
3. Std+ N	4.2	2.02	0.6	5.8	6.7	3.5	12.7	1.2	1.4
4. Std – K	4.8	2.08	0.8	3.4	11.9	4.1	9.5	1.4	6.8
5. Std – N	4.2	2.00	0.7	6.5	6.9	3.8	6.0	1.3	11.2
6. Std + S	4.1	2.02	0.8	6.2	7.0	3.8	6.8	1.3	8.7
7. Std – S	4.5	1.86	0.8	4.9	6.6	3.5	9.0	1.2	3.7

			Minor Elements (mg L ⁻¹)					
Nutrition Solutions	pH	Conductivity (mS cm ⁻¹)	Fe	Cu	Zn	Mn	B	Na
1. Std	4.1	2.06	0.86	0.09	0.5	0.54	11.92	25
2. Std + K	4.5	2.12	0.79	0.08	0.31	0.42	0.46	25
3. Std+ N	4.2	2.02	0.76	0.08	0.28	0.43	0.42	25
4. Std – K	4.8	2.08	0.78	0.09	0.35	0.42	0.43	25
5. Std – N	4.2	2.00	0.81	0.07	0.28	0.39	0.42	25
6. Std + S	4.1	2.02	0.84	0.08	0.33	0.42	0.43	24
7. Std – S	4.5	1.86	0.76	0.07	0.31	0.37	0.38	25

Source: Production Technology Laboratory, Department of Agriculture: WC, Private Bag x1, Elsenburg, 7607, Report reference – PW-2006.06.27.

3.4 Data collected in 2006 and 2007

2006: Plant samples were taken at four growth stages during the growing cycle (**Table 3.8**). Two plants were harvested per sample. The first set of samples was taken at buttoning (the start of the development of the curd). The second set of samples was taken at the time of head (curd) maturation. With the first two sampling sessions the entire plant above ground was harvested. The roots were left in the bag. The third set of samples was taken while the plants were in full flower. The last set of samples was taken at harvest when the pods were mature and ready to be cut. In the case of the last two samplings, the plants were divided into top and bottom parts. As in the previous samples, the whole above ground plant was used as the sample. The top parts consisted of the “shoots” or stems growing from the head, flowers and/or pods and seeds. The bottom parts

consisted of the leaves and the stalk (stem). The top and bottom parts were weighed, dried, milled and analyzed separately. With the last set of samples taken in 2006 only one plant was harvested per sample. This was necessitated since a high number of plants were killed by Sclerotinia. Where two plants were analyzed per sample, weight per plant or moisture content per plant was determined by using the average of the two plants.

During 2007 plant analysis differed from 2006. Samples were only taken from nutrient solution treatment 1 (Std), the Standard solution. Samples were taken from all four replications at all sampling events. The first set of samples was only taken at full flower. Two plants were harvested per sample. The samples were divided into top and bottom parts as described before and the roots were left in the bag. The handling of the samples were the same as in 2006 as explained above. The second set of samples was taken 28 days after the first samples at the "green pod stage". The last samples of 2007 were taken at harvest. Beside the separate analysis of top and bottom parts as previously described seed pods were also harvested and analyzed at the green pod and harvest stages. Two pods per plant were randomly selected from ten individual plants and used as one sample from each of the four replications. The entire pod with the seed inside was dried and crushed. From this a representative sample was taken and analyzed. The purpose of the analysis was to determine the concentration of elements in the different plant parts at the different growth stages focusing on the period from flowering to harvest. It was also done so that the data from 2006 could be compared to 2007.

Table 3.8 Explanation of plant sample harvesting stage and data collected at these sampling times in 2006 and 2007.

2006	Days after plant	Data collected
Planting date	31-03-2006	
1. Buttoning	55	Wet weight, dry weight, moisture content, major and minor element concentration and mass for 7 nutrient solutions. 28 Samples per stage.
2. Mature Head	101	
3. Full flower	145	The same data as above but split into top and bottom samples. 56 Samples per stage.
4. Harvest	237	
2007 (Data only from the Standard nutrient solution treatment)		
Planting date	13-04-2007	Only Std
1. Full flower	158	Major and minor element concentration, split into top and bottom samples. Only the Standard nutrient solution. 8 Samples per stage.
2. Green pod	186	Same as above and analysis of green pods added. 12 Samples per stage.
3. Harvest	233	Same as above with ripe seed pod analysis added. 12 Samples per stage.

In both years analysis of samples was done at the Production Technology Laboratory, Department of Agriculture: Western Cape, Private Bag X1, Elsenburg, 7607. Samples were received at the laboratory within 24 hours of harvest and the weight was determined. The samples were then dried for at least 72 hours in an oven at 60°C. Dry weight was determined after removal of the moisture. A weighted amount of sample was placed in a crucible and ashed by heating in a muffle furnace at 450 °C. A minimum quantity of 1:1 HCl was added to dissolve the ash and made up to a final volume with deionized water. Elements were determined by direct aspiration on an ICP-OES Spectrometer. The minerals determined in this fashion were Ca, P, Mg, K, Na, Cu, Zn, Mn, B, Fe and Al. Ammonium N was determined using the Kjeldahl method (Jones,

2000). S was determined using a IPC-OES Spectrometer. A weighted amount of sample was microwave digested in 65% nitric acid. Samples were then filtered and made up to a final volume with deionized water. Sulphur was determined by direct aspiration on ICP.

3.5 Experimental layout and statistical analysis in 2006 and 2007

A randomized complete block experimental design with 7 treatments replicated in four blocks was used. The plants were planted in rows with “female” and “male” rows next to each other. There were 28 rows of “female” plants randomly placed in each of the four blocks. Each row consisted of 68 plants except that the last block on the north western side of the net house had 2 “female rows” which contained 53 plants per row. This was done as a result of the dimensions of the net house. The aim was to harvest 40 random plants from each row, but heavy infestation of *Sclerotinia sclerotiorum* prevented that during 2006. All the healthy plants from each row were harvested (except those plants used for analysis). Analysis of variance was performed using GLM (General Linear Models) Procedure of SAS version 9.1 (SAS, 2000). Shapiro-Wilk test was performed to test for normality (Shapiro, 1965). Student’s t-least significant difference was calculated at the 5% level to compare treatment means. A probability level of 5% was considered significant for all significance tests.

RESULTS AND DISCUSSION

3.6 Dry mass production and moisture content of plants in 2006

Results of the ANOVA done on the plant dry mass and moisture content of plants at buttoning and mature head stages are shown in **Table 3.9**. During the next two stages, full flower and harvest, the plants were split into top parts and bottom parts, but only the bottom parts were analyzed in this ANOVA. Results of the ANOVA done on the mean plant dry mass and mean moisture content at full flower and harvest stages, but determined separately for top and bottom parts are shown in **Table 3.10**. Dry mass and moisture content were only determined during 2006.

Table 3.9 Analysis of variance (ANOVA) of plant dry mass and moisture content measured at buttoning, mature head, full flower and harvest in (bottom parts only at last two stages) 2006.

Source of Variation	DF	Plant Dry Mass	Moisture Content
		Pr>F	Pr>F
Block	3	0.1613	0.5443
Treatment	6	0.5349	0.6287
Error	18		
Stage	3	<.0001	<.0001
Treat x Stage	18	0.7242	0.4473
Error		63	60
CV		22.18	1.91

Table 3.10 Analysis of variance (ANOVA) of plant dry mass and moisture content of plants measured separately in bottom and top plant parts and measured at 2 stages, full flower and harvest during 2006.

Source of Variation	Mass Plant ⁻¹		Moisture %
	DF	Pr>F	Pr>F
Block	3	0.0851	0.6755
Treatment	6	0.2108	0.4638
Error (a)	18		
Stage	1	<.0001	<.0001
Treat x Stage	6	0.2666	0.5775
Error (b)	21		
Position	1	<.0001	<.0001
Pos x Treat	6	0.3290	0.2045
Pos x Stage	1	<.0001	<.0001
Pos x Treat x Stage	6	0.3744	0.5470
Error		42	41
CV		24.30	2.31

Nutrient solution treatments used in 2006 did not have any significant effects on plant dry mass or moisture content (**Table 3.9**). Significant differences in dry mass per plant and moisture percentage were, however, noted at the different stages. No significant interactions were observed. Significant differences in dry mass per plant and moisture percentage in relation to position (top or bottom) and stage (full flower or harvest) were found (**Table 3.10**). Significant interaction between sampling position and stage was noted in 2006.

At all growth stages the dry mass per plant showed no significant response to the treatments (nutrient solutions, $P=0.5349$, $P=0.2108$) in spite of major differences in N content between different solutions. It appears that even at the lower levels enough N was still available so that plants could use what they needed and higher level availability did not translate into more dry matter production.

3.6.1 Dry mass production in 2006

Table 3.11 Means for dry mass per plant (g) and moisture content (%) in the bottom plant parts using combined data of 4 stages during 2006.

Stage	Dry mass (gram plant ⁻¹)	Moisture content (%)
1. Buttoning	34.82 d	89.89 a
2. Mature Head	135.59 a	90.75 a
3. Full Flower	102.60 b	88.79 b
4. Harvest	58.80c	85.66 c
LSD	9.83	0.92

Means with the same letter are not significantly different

The mean plant dry mass increased from 34.8 g at buttoning (stage 1) to 135.5 g at mature head (stage 2) (**Table 3.11**). This is the stage at which normal harvesting of the mature broccoli head would take place. Significant differences in mass occurred between all stages, but plant dry mass seemed to decrease after mature head stage, because the means for full flower and harvest represented only the bottom samples (bottom part of the above ground plant). The mean dry mass per plant (bottom parts) decreased from 102.6 g at stage 3 (full flower) to 58.8 g at stage 4 (harvest). These results indicated that the plants have lost plant material such as leaves from the bottom parts and/or have translocated dry matter to the top plant parts and/or roots as total weight increased up until stage 4. In general plants tend to shed leaves after the leaves had turned yellow and dried up. This process accelerated after flowering and at harvest the plants had lost most of their leaves.

Mean plant dry mass values for top and bottom parts at full flower (stage 3) showed no significant differences (**Table 3.12**). At harvest top plant parts yielded 246.9 g plant⁻¹ compared to a significant lower 58.8 g plant⁻¹ for the bottom parts.

Table 3.12 Mean dry mass (g) plant⁻¹ and moisture content (%) in plants (bottom and top plant parts) at two growth stages in 2006.

Pos x Stage	Dry mass	Moisture content
	(gram plant ⁻¹)	(%)
3. Full Flower – Bottom	102.60 b	88.79 a
3. Full Flower – Top	117.58 b	89.15 a
4. Harvest – Bottom	58.80 c	85.66 b
4. Harvest – Top	246.94 a	78.15 c
LSD	17.23	1.07

Means with the same letter are not significantly different

Total plant dry mass (top and bottom parts) showed significant increases from buttoning to harvest stages (**Figure 3.1**). Total plant weight was determined by adding mean- top and bottom weights per stage together. From mature head stage which is the normal harvesting time of broccoli heads the dry weight still increased by 225% to harvest (of seed).

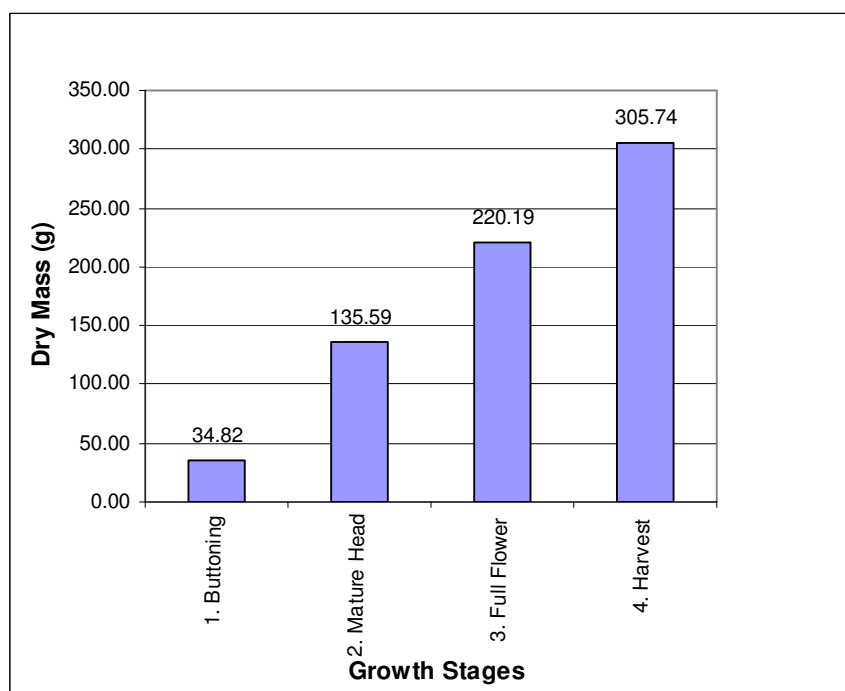


Figure 3.1 Mean dry mass (g) plant⁻¹ at four growth stages in 2006

3.6.2 Moisture in 2006

Table 3.11 indicated a plant moisture content of 89.89% at buttoning (stage 1) which did not differ significantly from the mature head stage (90.75%). The moisture content in the bottom plant parts at full flower (stage 3) and harvest (stage 4) were, however, significant lower at 88.97% and 85.60% respectively.

From **Table 3.12** it is clear that at full flower the moisture percentage in the top plant parts did not differ significantly from the bottom parts. At harvest however the moisture percentage of the top plant parts dropped to 78.14%. This was in accordance of what was observed in the field during the harvest stage. At harvest the top plant parts appear brittle and dry. The means for the top and bottom parts together dropped to 81.9% at stage 4. In **Figure 3.2** the mean moisture content (%) at the four growth stages during 2006 is displayed.

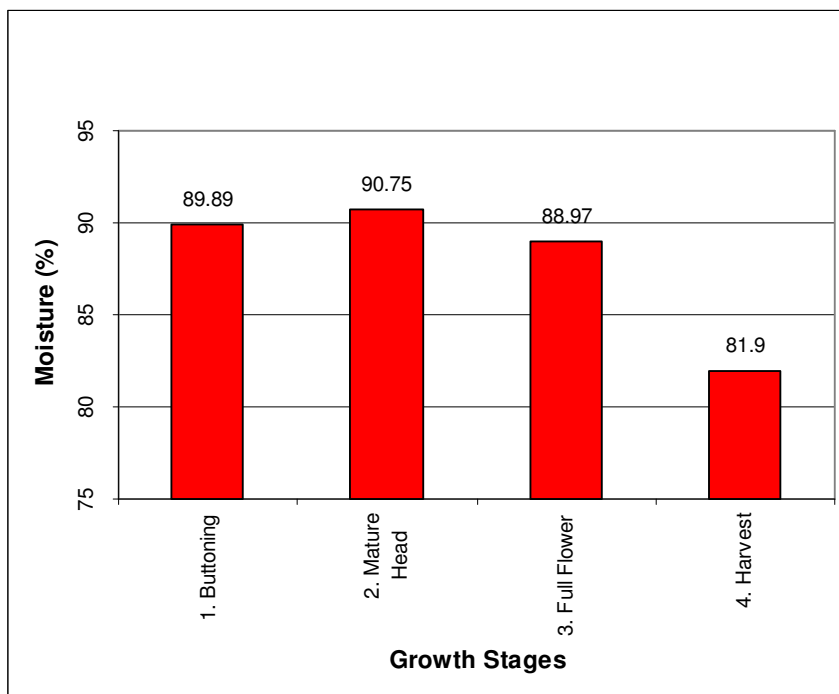


Figure 3.2 Mean moisture content (%) at four growth stages in 2006.

3.7 Nutrient assimilation in 2006 and 2007

3.7.1 Nutrient concentration in 2006

Major element concentration in 2006

The ANOVA done on the concentration (%) of major elements is given in **Table 3.13**. It was determined for the entire plant at buttoning and mature head stages. During the next two stages, full flower and harvest, the plants were split into top parts and bottom parts, but only results of the bottom parts were statistically analyzed. Though information about the bottom parts at stages full flower and harvest is referred to in **Table 3.13**, the information is particularly relevant to the first 2 growth stages, buttoning and mature head.

The results of the ANOVA in **Table 3.17** refer to major element concentrations (%) determined at full flower and harvest, but determined separately for top and bottom parts. This period is of particular importance as it is the period of seed formation.

Table 3.13 Analysis of variance (ANOVA) of major element concentration in plants (bottom plant parts at stages 3 and 4) measured at buttoning, mature head, full flower and harvest stages during 2006.

Source of Variation	DF	N (NH ₄) Pr>F	P Pr>F	K Pr>F	Ca Pr>F	Mg Pr>F	S Pr>F
Block	3	0.0074	0.0143	0.0132	<.0001	0.0057	0.9754
Treatment	6	0.4044	0.1379	0.0045	0.0941	0.1383	0.0068
Error	18						
Stage	3	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Treat x Stage	18	0.3861	0.9887	0.0474	0.9044	0.2317	0.0756
Error	63	61	61	61	63	60	62
CV		9.83	27.98	14.13	33.37	12.72	9.30

Buttoning and mature head stages (Bottom parts of plants at full flower and harvest) in 2006 - major elements

From **Table 3.13** it is clear that significant differences occurred between blocks for all major elements except for S. In terms of the interaction between treatment (nutrient solutions) and stage, significant differences were only shown for K. Significant differences for measurements at different stages occurred for all major elements. Nutrient solution treatments significantly influenced measurements of K and S but not the other major elements. Though there were large differences in the concentration of N ($\text{NO}_3\text{-N}$) and Ca in the solutions, this did not result in significant differences in the concentration of N and/or Ca in the plant samples.

The highest K content (12.69%) was found during the buttoning phase (stage 1) with the application of the standard solution plus K (St+K) (**Table 3.14**). The lowest value for K (4.88%) was found at full flower in the bottom parts of plants receiving solution 3 (Standard -K). The highest K contents were measured at buttoning. Low concentrations of K (3.5 mmol L^{-1}) in the nutrient solution did result in low contents (%) of K in the plant samples at buttoning (stage 1) and full flower (stage 3) when compared to where high levels of K (10.5 mmol L^{-1}) were applied. The concentrations of K in plant samples were not significantly different between the standard solution (7 mmol L^{-1} K) and the solution St+K which contained 10.5 mmol L^{-1} K.

Table 3.14 Potassium concentration (%) in plant parts (bottom parts at stages 3 and 4) at different growth stages in 2006.

Factor	Nutrient Solutions						
	1 Std	2 St + K	3 St+N	4 St - K	5 St - N	6 St + S	7 St - S
Stage	K Concentration (%)						
Entire plant analyzed							
1. Buttoning	11.59 ba	12.69 a	12.40 a	8.93 c	10.56 b	12.07 ba	11.51 ba
2. Mature Head	6.53 dgef	5.55 hgf	5.79 hgef	5.42 hg	6.58 dgef	5.39 hg	5.45 hg
Bottom plant part analyzed							
3. Full Flower	5.83 hgef	7.02 def	6.81 dgef	4.87 h	7.24 de	6.68 dgef	6.25 hdgef
4. Harvest	6.33 hdgef	6.67 dgef	5.49 hg	6.06 hdgef	7.49 dc	6.57 dgef	6.79 dgef
LSD	1.5215						

Means with the same letters are not significantly different.

In **Table 3.15** means for stages are displayed. The means for buttoning and mature head are for the whole plant, but means for full flower and harvest are for the bottom plant parts only.

Table 3.15 Concentration (%) of major elements in plant parts (bottom parts at full flower and harvest) at different growth stages in 2006.

Stage	Major element concentration (%)					
	N	P	K	Ca	Mg	S
Entire plant analysed						
1. Buttoning	3.06 b	0.95 a	11.48 a	2.81 a	0.31 d	0.52 a
2. Mature Head	3.18 b	0.70 b	5.82 c	1.13 c	0.36 c	0.52 ab
Bottom plant part analysis						
3. Full Flower	1.99 c	0.46 c	6.41 b	1.98 b	0.43 b	0.50 ab
4. Harvest	3.35 a	0.60 b	6.48 b	0.62 d	0.46 a	0.43 c
LSD	0.15	0.10	0.57	0.29	0.03	0.02

Means with the same letters are not significantly different.

The highest percentage N (3.35%) was measured in bottom parts of plants at harvest. N content (%) at buttoning did not differ from that at mature head, but values for both stages were significantly higher than at full flower and significantly lower than at harvest.

P concentration was highest at buttoning (0.95 %). Mature head was significantly lower and the second highest. The bottom plant parts at full flower had the

lowest level of %P. Mature head and harvest values were not significantly different.

K concentration was the highest at buttoning (11.4%) and it was significantly higher than at full flower and harvest which were not significantly different. Lowest levels occurred at mature head.

Ca concentration was the highest at buttoning (2.81 %). All stages differed significantly. The lowest level of Ca concentration occurred at harvest in the bottom plant parts. All stages were significantly different.

The highest levels of Mg concentration occurred at harvest (0.46%). All stages were significantly different. The lowest value was measured at buttoning.

The highest concentration S occurred at buttoning (0.52%). The lowest level was at harvest. Buttoning, mature head and full flower were not significantly different.

Table 3.16 Mean concentration (%) of S and K (bottom parts at stages 3 and 4) in 2006.

Nutrient Solutions	Element concentration (%)	
	K	S
1. Std	7.69 a	0.51 ab
2. Std + K	7.98 a	0.53 a
3. Std+N	7.63 a	0.43 c
4. Std – K	6.15 b	0.51 ab
5. Std – N	7.97 a	0.51 ab
6. Std + S	7.68 a	0.53 a
7. Std – S	7.50 a	0.46 bc
LSD	0.83	0.05

Means with the same letters are not significantly different.

With the exception of a significantly lower concentration K in plants which received the Std-K treatment, no significant differences in K concentration were found as a result of the nutrient solution treatments (**Table 3.16**). This meant that decreasing the K concentration to 50% of the Standard solution (3.5 mmol L⁻¹ K vs. 7.0 mmol L⁻¹ K), resulted in a significantly lower K concentration. Higher K concentrations in the nutrient solutions did not lead to significantly higher K levels in plant samples if compared to the Standard solution.

The means for S concentrations in **Table 3.16** indicate that the highest value (0.53 %) was achieved with the nutrient solution Std+S. This was not significantly higher than most of the solutions except Std-S and Std+N. The S concentration in the solutions Std-S was 3.5 mmol L⁻¹ and in Std+N, 1 mmol L⁻¹ which were the lowest of all the solutions. Again as in the case of K concentration, increasing the S concentration in the nutrient solutions to higher levels than in the Standard solution did not lead to significantly higher S concentrations in plant samples.

In the case of K and S concentrations in plant samples this study indicates that low levels of K and S concentrations in nutrient solutions do lead to lower levels in plant samples, but higher concentrations, compared to the Standard solution (K = 7 mmol L⁻¹; S = 6 mmol L⁻¹) do not lead to higher concentrations in plant samples. Other major elements which were administered at different concentrations in the solutions (Ca and N) did not significantly affect the concentration of those major elements in plant samples. Major elements which were kept at constant concentrations in all solutions did not have any significant influence on plant sample concentrations. From these results we can conclude

that if the objective is to increase the concentration of major elements in plant samples, it would be pointless to increase the levels above that found in the Standard solution. This is applicable to a hydroponic production system where sand is used as a growth substrate. Care should be taken with lower concentrations of K and S in nutrient solutions, compared to the Standard solution. It could lead to lower concentration of K and S in plant samples.

Full flower and harvest stages in 2006 - major elements

The results of the ANOVA in **Table 3.17** refer to major element concentrations (%) determined at stages full flower and harvest, but determined separately for top and bottom plant parts. This period is of particular importance as it is the regenerative period. From **Table 3.17** it is clear that N and K concentrations differed significantly between blocks. Significant interactions between position, treatment and stage occurred only for S. Position and stage interactions were significant for all major elements except K. No significant interactions between position and treatments occurred. Position significantly influenced all major element concentrations at stages 3 and 4. Stage significantly influenced N and Mg concentrations at these stages. No significant interactions between nutrient solution treatments and stage occurred during stages 3 and 4. Nutrient solution treatments had a significant effect on the concentration of K and S during full flower and harvest.

Table 3.17 Analysis of variance (ANOVA) of major element concentrations in plants (bottom and top plant parts) measured at full flower and harvest stages in 2006.

Source of Variation	DF	N	P	K	Ca	Mg	S
		Pr>F	Pr>F	Pr>F	Pr>F	Pr>F	Pr>F
Block	3	0.0093	0.2234	<.0001	0.0527	0.4366	0.5417
Treatment	6	0.1782	0.8597	0.0172	0.2131	0.2484	0.0016
Error (a)	18						
Stage	1	<.0001	0.2431	0.2326	0.3320	<.0001	0.1265
Treat x Stage	6	0.2842	0.9276	0.8144	0.0655	0.6623	0.4324
Error (b)	21		21	21			
Position	1	0.0041	0.0086	<.0001	0.0273	<.0001	<.0001
Pos x Treat	6	0.6461	0.4010	0.5761	0.0765	0.3601	0.8445
Pos x Stage	1	<.0001	<.0001	0.1608	<.0001	<.0001	<.0001
Pos x Treat x Stage	6	0.4614	0.3747	0.2684	0.5205	0.1277	0.0354
Error		42	41	40	42	41	42
CV		10.36	14.63	13.01	24.07	11.89	11.31

Table 3.18 Sulphur concentration (%) in the bottom and top plant parts at the last two growth stages as affected by nutrient solution treatments in 2006.

Position & Stage	Nutrient Solutions						
	1 Std	2 Std + K	3 Std+N	4 Std - K	5 Std - N	6 Std + S	7 Std - S
S (%) – Top							
3. Full Flower	0.55 def	0.59 cd	0.55 def	0.66 bc	0.56 de	0.57 de	0.56 def
4. Harvest	0.79 a	0.79 a	0.49 hgef	0.73 ab	0.72 ab	0.75 a	0.66 bc
S (%) – Bottom							
3. Full Flower	0.53 dgef	0.54 dgef	0.43 h	0.54 dgef	0.54 dgef	0.48 hgef	0.44 h
4. Harvest	0.43 h	0.49 hgef	0.34 i	0.48 hgef	0.45 hg	0.47 hgf	0.41 hi
LSD	0.09						

Means with the same letters are not significantly different.

The highest S concentration was found at harvest in the top parts of plants irrigated with the Standard nutrient solution (**Table 3.18**). The lowest S concentration was also found at harvest, but in the bottom plant parts irrigated with the Std+N nutrient solution. The S concentration in the top plant parts were consistently higher than in the bottom plant parts except for the Std+N treatment

at harvest. The nutrient solution Std+N contained the lowest concentration of S in the solution namely 1 mmol L⁻¹. Compared to harvest, S concentration in the top plant parts at full flower were significantly lower. In general, S concentration in the bottom plant parts were lower than in the top parts, but no clear trend in S concentration as a result of the nutrient solutions applied were found in bottom parts at full flower and harvest stages.

Table 3.19 Concentration (%) of N, P, Ca, Mg and S in the bottom and top plant parts at full flower and harvest stages in 2006.

Position & Stage	Major elements concentration (%)				
	N	P	Ca	Mg	S
	Top				
3. Full Flower	3.17 b	0.62 a	0.82 b	0.27 c	0.58 b
4. Harvest	2.50 c	0.53 b	2.08 a	0.47 a	0.71 a
	Bottom				
3. Full Flower	1.99 d	0.47 c	1.98 a	0.44 b	0.50 c
4. Harvest	3.35 a	0.61 a	0.63 c	0.47 a	0.44 d
LSD	0.15	0.04	0.18	0.03	0.03

Means with the same letters are not significantly different.

Significant differences in the concentration (%) of all elements analyzed, except K, were observed at different stages of sampling and in different plant parts (**Table 3.19**), but N and P increased from full flower to harvest stage in bottom parts while Ca and S increased from full flower to harvest stage in the top parts. Mg increased from full flower to harvest stage in both plant parts.

Table 3.20 Concentration (%) of N, P, K, Ca, Mg, S in the bottom and top plant parts at full flower and harvest stage in 2006.

Position	Major element concentration (%)					
	NH ₄	P	K	Ca	Mg	S
Top	2.83 a	0.58 a	5.01 b	1.45 a	0.37 b	0.64 a
Bottom	2.67 b	0.54 b	6.45 a	1.31 b	0.45 a	0.47 b
LSD	0.11	0.03	0.29	0.13	0.02	0.02

Means with the same letter are not significantly different.

The highest concentrations occurred in the top parts except for %K and %Mg (**Table 3.20**). The values indicate that the top plant parts are strong sinks for the indicated nutrients. All top and bottom values differed significantly.

Table 3.21 Treatment: The effect of nutrient solution treatments on the concentration (%) of K in the whole plant at the last two stages in 2006.

Treatments (Nutrient Solutions)	Element concentration (%)
	K
1. Std	5.68 ab
2. St + K	6.13 ab
3. S t+ N	5.44 bc
4. St – K	4.91 c
5. St – N	6.34 a
6. St + S	5.94 ab
7. St – S	5.64 abc
LSD	0.75

Means with the same letters are not significantly different.

In **Table 3.21** mean values of K concentration at full flower and harvest (averaged) in relation to treatments is displayed. Treatments at full flower and harvest significantly influenced K concentration. The five highest means for K concentration were not significantly different. The second highest value was for St+K and the smallest value was St-K. The three smallest values were not significantly different. At full flower and harvest the low level of K in the nutrition solution did not appear to significantly affect the K concentration in plant samples although the solution with the lowest concentration of K (3.5 mmol L^{-1}) did return the lowest value. The Standard solution contained 7 mmol L^{-1} . The smallest value was significantly smaller than the values of the Standard and St+K solutions (treatments). This indicates that compared to the Standard solution, the St-K solution led to a decrease in K concentration in plant samples. Increasing the concentration of K in the nutrition solution to 10.5 mmol L^{-1} compared to the

standard solution (7 mmol L⁻¹) did not significantly affect the K concentration in plant samples.

Mean values of the concentration (%) of major elements at the four growth stages are summarized in Table 3.22.

Table 3.22* Mean concentrations of major elements at different growth stages and top to bottom ratios in 2006.

Stage of Analysis	Major elements (%)					
	N	P	K	Ca	Mg	S
(1) Buttoning	3.06	0.95	11.49	2.81	0.31	0.53
(2) Mature Head	3.18	0.70	5.82	1.14	0.37	0.52
(3) Full Flower - Bottom	1.99	0.47	6.41	1.98	0.44	0.50
(3) Full Flower – Top	3.17	0.62	4.79	0.82	0.27	0.58
(3) Full Flower - Ratio of Top / Bottom	1.6	1.3	0.7	0.4	0.6	1.2
(4) Harvest – Bottom	3.35	0.61	6.49	0.63	0.47	0.44
(4) Harvest – Top	2.50	0.53	5.22	2.08	0.47	0.71
(4) Harvest - Ratio of Top / Bottom	0.7	0.9	0.8	3.3	1.0	1.6

*Table compiled from Table 3.15, Table 3.19 and original statistical analysis.

At buttoning the N concentration was 3.06% (in the whole plant) increasing to 3.18% at mature head stage. Nitrogen concentration in the bottom at full flower was at 1.99%, increasing significantly to 3.35% at harvest. In the top of the plant N concentration decreased significantly from 3.17% at full flower to 2.49% at harvest. The ratio of N concentration in the top part compared to N in the bottom part of the plant decreased from 1.6 at full flower to 0.7 at harvest. The ratios give a relative indication of the concentration comparison between top and bottom parts at the specific stage. Furthermore a comparison of the ratios between full flower and harvest gives an indication of the relative increase/decrease of concentration of the element in the top/bottom plant parts as the plants grow to maturity at harvest. The N values indicate a relative decrease of N concentration in the top plant parts at harvest.

P concentration was at 0.95% at buttoning and 0.70% at mature head (**Table 3.22**). At the bottom of the plant at full flower the concentration was 0.47% increasing significantly to 0.61% at harvest. The concentration of P in the top of the plants decreased significantly from 0.62% at full flower to 0.53% at harvest. The ratio of P concentration in the top of the plant compared to P in the bottom decreased from 1.3 at full flower to 0.9 at harvest.

K concentration for the whole plant was 11.49% at buttoning and 5.82% at mature head. K concentration was at 6.41% in the bottom at full flower increasing slightly to 6.49% at harvest. The K concentration in the top of the plant was 4.79% at full flower increasing significantly to 5.22% at harvest. The ratio of K concentration in the top of the plant compared to K in the bottom increased slightly from 0.7 at full flower to 0.8 at harvest, the ratio remaining relatively unchanged.

Ca concentration for the whole plant at buttoning was at 2.82% and at 1.14% at mature head stage. Ca concentration was at 1.98% in the bottom at full flower decreasing significantly to 0.63% at harvest. The Ca concentration in the top of the plants increased significantly from 0.82% at full flower to 2.08% at harvest. The ratio of Ca concentration in the top of the plant compared to Ca concentration in the bottom of the plant increased from 0.4 at full flower to 3.3 at harvest. Ca is transported through the xylem mainly through the transpiration stream. Ca also moves with water through root pressure. This was proved to be an important mechanism for Ca transport to plant parts that do not transpire

much such as the inner leaves of cabbage, thus preventing tip burn as a result of a lack of Ca (Palzkill *et al.*, 1976). It moves preferentially towards the growing apices of growing plants. Ca is also transported through the phloem in very small amounts (Jones, 2003). This explains to an extent the increase in Ca concentration in the top parts towards harvest. The decrease in Ca concentration in the bottom parts probably occurred as a result of the plant losing mature leaves in the period full flower to harvest. New growth of small leaves also occur during this stage. Lower concentration of Ca in the young tissue is expected (Jones, 2003). Jones (2001), also notes that one sign of maturity in leaves is an increasing concentration (accumulation) of Ca and Mg, and a decreasing concentration (reduction) of N, P and K in leaf tissue. As tissue mature, changes occur due to the movement of mobile elements from the older tissue to newly developing tissues and an accumulation of non-mobile elements.

At buttoning the Mg concentration in the whole plant was 0.31% and at mature head stage, 0.37%. Mg concentration was at 0.44% in the bottom at full flower increasing significantly to 0.47% at harvest. The Mg concentration in the top of the plants was at 0.27% at full flower increasing significantly to 0.47% at harvest. The ratio of Mg in the top of the plant compared to Mg in the bottom increased from 0.6 at full flower to 1.0 at Harvest. These numbers indicate a relatively large increase of Mg concentration in the top parts compared to the bottom at harvest but not as strong as in the case of Ca.

At buttoning the S concentration in the whole plant was 0.53% and at mature head stage it was at 0.52%. S concentration in the bottom of the plants at full

flower was 0.50% decreasing significantly to 0.44% at harvest. The S concentration in the top of the plants was 0.58% at full flower increasing significantly to 0.71% at harvest. The ratio of S in the top of the plant compared to S in the bottom increased from 1.2 at full flower to 1.6 at harvest. These numbers also indicate a relatively large increase of S concentration in the top parts compared to the bottom at harvest.

Minor element concentration in 2006

The ANOVA for the concentration of minor elements as affected by nutrient solution treatments is given in **Table 3.23**. The concentrations were measured per plant at buttoning and mature head stages, while plants were split into bottom and top parts at the full flower and harvest stages. Only the results of the bottom plant parts at full flower and harvest were used in this ANOVA. Results of the ANOVA which included the position of measurement at full flower (stage 3) and harvest (stage 4) is given in **Table 3.24**.

Table 3.23 Analysis of variance (ANOVA) of minor element concentration in plants (bottom plant parts at Stage 3 & 4) measured at buttoning, mature head, full flower and harvest stage in 2006.

Source of Variation	DF	Na	Fe	Cu	Zn	Mn	B
		Pr>F	Pr>F	Pr>F	Pr>F	Pr>F	Pr>F
Block	3	0.0006	0.5666	0.5160	0.2973	0.9553	0.0493
Treatment	6	0.0035	0.7715	0.8073	0.0315	0.8507	0.2401
Error	18						
Stage	3	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Treat x Stage	18	0.0725	0.7510	0.7313	0.2237	0.0977	0.4436
Error	63	63	59	63	61	63	63
CV		29.02	147.21	24.05	19.44	22.93	7.72

Table 3.24 Analysis of variance (ANOVA) of the concentration of minor elements in bottom and top plant tissue at full flower and harvest stages in 2006.

Source of Variation	DF	Na	Fe	Cu	Zn	Mn	B
		Pr>F	Pr>F	Pr>F	Pr>F	Pr>F	Pr>F
Block	3	0.0036	0.8231	0.0462	0.8879	0.7662	0.0287
Treatment	6	0.0163	0.8482	0.2627	0.2452	0.5020	0.0105
Error (a)	18						
Stage	1	<.0001	0.0004	<.0001	<.0001	0.3293	0.0002
Treat x Stage	6	0.1199	0.7677	0.3456	0.7653	0.2986	0.5252
Error (b)	21						
Position	1	<.0001	0.0214	0.0124	<.0001	<.0001	<.0001
Pos x Treat	6	0.0617	0.3462	0.9479	0.7816	0.108	0.2116
Pos x Stage	1	0.0007	0.0699	0.6531	0.0012	<.0001	<.0001
Pos x Treat x Stage	6	0.6052	0.3341	0.6599	0.0763	0.0684	0.0657
Error	42	42	42	42	41	42	41
CV		30.36	78.18	24.61	16.63	15.86	10.02

Buttoning and mature head stages (bottom parts of plants at full flower and harvest) in 2006 - minor elements

The mixture of minor elements was kept constant in all nutrient solutions (treatments) and this must be kept in mind in interpreting the results. In **Table 3.23** blocks as sources of variation were significant for Na and B concentrations. Interactions between treatment and stage were not significant. Stage had a significant influence on all minor element concentrations. Treatments significantly influenced the concentrations of Na and Zn.

Table 3.25 Concentrations (mg kg^{-1}) of minor elements at different stages in 2006 (bottom parts only at stage 3 and 4).

Stage	Minor elements (mg kg^{-1})					
	Na	Fe	Cu	Zn	Mn	B
1. Buttoning	3311.70 c	100.83 b	3.10 b	25.86 a	64.19 a	32.62 b
2. Mature Head	3331.10 c	88.41 b	3.74 a	23.40 b	28.41 c	29.25 c
3. Full Flower	4412.20 b	485.27 a	3.78 a	23.08 b	34.58 b	44.08 a
4. Harvest	6740.30 a	82.62 b	2.19 c	12.93 c	13.80 d	16.71 d
LSD	689.71	155.09	0.41	2.23	4.32	1.26

Means with the same letters are not significantly different.

Concentration of all minor elements differed significantly at different growth stages (**Table 3.25**). Na concentration was highest in the bottom plant parts at harvest. It increased significantly as plants matured from mature head to harvest. Fe, Cu and B concentrations were highest in the bottom parts at full flower, while that of Zn and Mn were the highest at buttoning. Zn and Mn decreased as plants matured. Large variations in Fe concentrations were observed but remain unexplained.

Table 3.26 Influence of nutrient solution treatments on the concentration (mg kg^{-1}) of Na and Zn in plant tissue (bottom plant parts at Stage 3 and 4) measured at four growth stages and combined in 2006.

Treatments (Nutrient Solutions)	Element concentration (mg kg^{-1})	
	Na	Zn
1. Std	4165.20 bc	21.29 a
2. Std + K	3714.90 c	20.76 ab
3. Std + N	4966.20 ab	21.40 a
4. Std – K	5683.40 a	20.97 a
5. Std – N	3798.20 c	23.63 a
6. Std + S	3528.10 c	22.88 a
7. Std – S	5286.00 a	17.75 b
LSD	1134.9	3.16

Means with the same letters are not significantly different.

In **Table 3.26** the mean concentrations of Na and Zn in response to treatments are displayed. The highest Na concentration was found in response to nutrient treatment Std-K. The smallest concentration was found for nutrient treatment Std+S which was significantly lower. The highest 3 Na concentration values were not significantly different. The smallest 4 values were not significantly different. The highest Zn concentration was found in response to nutrient treatment Std-N and this was significantly higher than the smallest value which was found in response to nutrient treatment Std-S. The top 6 values were not significantly different. As all minor elements were kept constant, the reasons for the differences remain unclear.

Full flower and harvest stages in 2006 - minor elements

The ANOVA in **Table 3.24** which refers to the full flower and harvest stages only indicates that block as a source of variation significantly influenced Na, Cu and B. Interactions between position, treatment and stage were not significant. Position and stage interactions occurred for all minor elements except Fe and Cu, which were affected by position as a main effect. All minor element concentrations with exception of Mn were significantly influenced by stage. Treatments significantly influenced Na and B concentrations.

Na concentration was highest in the bottom parts at harvest (stage 4) and the smallest in the top parts at full flower (stage 3) (**Table 3.27**). In general Na content in top parts was significantly lower than in bottom parts. In the case of Zn, Mn and B the highest concentrations were found in the top plant parts at harvest (stage 4), while concentrations in bottom parts were generally smaller. The Mn and B concentrations were higher in the bottom plant parts at full flower than at harvest. Na and Zn indicated the opposite trend.

Table 3.27 Concentrations (mg kg^{-1}) of Na, Zn, Mn and B at full flower and harvest stages in 2006.

Position & Stage	Minor elements (mg kg^{-1})			
	Na	Zn	Mn	B
Top				
3. Full Flower	2049.40 c	19.82 c	26.63 c	27.33 c
4. Harvest	2698.90c	25.61 a	44.36 a	47.62 a
Bottom				
3. Full Flower	4412.20 b	12.93 d	34.58 b	44.08 b
4. Harvest	6740.30 a	23.08 b	13.80 d	16.71 d
LSD	651.10	1.83	2.55	1.84

Means with the same letter are not significantly different

In **Table 3.28** the means for Fe and Cu concentrations in the bottom and top parts at full flower and harvest is displayed. All values were significantly different. Fe and Cu concentrations were significantly higher in the top parts than the bottom parts of the plants.

Table 3.28 Concentrations of Fe and Cu in the bottom and top plant parts at full flower and harvest stages in 2006.

Position	Minor elements (mg kg ⁻¹)	
	Fe	Cu
Top	405.73 a	3.37 a
Bottom	283.95 b	2.99 b
LSD	102.83	0.30

Means with the same letters are not significantly different.

In **Table 3.29** the means for Fe and Cu concentrations at full flower and harvest stages are displayed. All means are significantly different. The concentration of both Fe and Cu were higher at full flower than at harvest. Large variations in the Fe concentrations were observed.

Table 3.29 Concentrations (mg kg⁻¹) of Fe and Cu as affected by the last two sampling stages in 2006.

Stage	Minor elements (mg kg ⁻¹)	
	Fe	Cu
3. Full Flower	498.77 a	3.94 a
4. Harvest	190.90 b	2.42 b
LSD	150.39	0.40

Means with the same letter are not significantly different.

In **Table 3.30** the mean concentrations (top and bottom parts at full flower and harvest) of Na and B in response to treatments are shown. In the case of Na the highest 3 values were not significantly different and similarly the smallest 5 values. The highest concentration (Na) was for Std-K (4968.90 mg kg⁻¹) and the

lowest concentration for Std-N (3119.3 mg kg⁻¹). In the case of B the highest 3 values were not significantly different. The middle 5 values were not significantly different. The smallest value which was for the Standard (Std) solution was significantly lower. The Std+N solution had the highest concentration of B at 36.33 mg kg⁻¹. The Std solution delivered the lowest concentration at 30.97 mg kg⁻¹.

Table 3.30 Influence of nutrient solution treatments on the concentrations (mg kg⁻¹) of Na and B as measured at 2 stages (full flower and harvest) and in bottom and top plant parts in 2006.

Treatments (Nutrient Solutions)	Element concentration (mg kg ⁻¹)	
	Na	B
1. Std	3682.90 b	30.98 c
2. Std + K	3597.20 b	33.62 b
3. Std + N	4272.40 ab	36.33 a
4. Std – K	4968.90 a	34.86 ab
5. Std – N	3119.30 b	33.49 b
6. Std + S	3276.30 b	34.29 ab
7. Std – S	4909.50 a	32.94 bc
LSD	1181.20	2.43

Means with the same letter are not significantly different.

Mean values of plant analysis (mg kg⁻¹ minor elements) at the four growth stages are summarized in **Table 3.31**. Means for Na increased as the plants grew to maturity, particularly in the bottom plant parts. At full flower and harvest stages the concentration was significantly higher in the bottom of the plants, compared to the top parts. The ratios between concentration in bottom and top parts indicated a relative constant ratio between bottom and top parts and that an accumulation in the top did not occur.

Fe concentration increased from buttoning to full flower in bottom and top plant parts, but showed a unexpected decrease at harvest. The ratio between

concentration in bottom and top parts indicated a relative increase in the concentration of Fe in the top plant parts.

Cu showed the highest concentration in the top plant parts at full flower stage, but also showed a decrease towards harvest. The ratio between concentration in bottom and top parts, however showed a relative constant ratio at full flower and harvest stages.

Zn concentration was highest at buttoning, but showed a decrease till full flower before increasing again at harvest. The ratio between concentration in bottom and top parts indicated that a reduction at harvest compared to full flower occurred.

Mn concentration showed a similar trend to that of Zn. The ratio between concentration in bottom and top parts indicated a strong increase in concentration in the top plant parts relative to the bottom from full flower to harvest.

B concentration reached the highest value in the top at harvest. The ratio between concentration in bottom and top parts also increased strongly from full flower to harvest.

The concentration of minor elements in the bottom plant parts generally decreased from full flower to harvest, except for Na and Zn. This indicated possible translocation to top plant parts or perhaps the roots. From the ratios of concentration in bottom and top plant parts for minor elements it became clear

that a strong increase in the concentration of elements in the top part of the plants compared to the bottom parts from full flower to harvest happened for Fe, Mn and B.

Table 3.31* Mean concentrations of minor elements at different growth stages and top to bottom ratios in 2006.

Stage of Analysis	Na mg kg ⁻¹	Fe mg kg ⁻¹	Cu mg kg ⁻¹	Zn mg kg ⁻¹	Mn mg kg ⁻¹	B mg kg ⁻¹
(1) Buttoning	3311.7	100.83	3.11	25.86	64.19	32.62
(2) Mature Head	3331.1	88.41	3.74	23.40	28.41	29.25
(3) Full Flower - Bottom	4412.2	485.27	3.78	12.93	34.58	44.08
(3) Full Flower – Top	2049.4	512.28	4.10	19.82	26.63	27.33
(3) Full Flower – Ratio of Top / Bottom	0.5	1.1	1.1	1.5	0.8	0.6
(4) Harvest – Bottom	6740.3	82.62	2.19	23.08	13.80	16.71
(4) Harvest – Top	2698.9	299.18	2.64	25.61	44.36	47.62
(4) Harvest - Ratio of Top / Bottom	0.4	3.6	1.2	1.1	3.2	2.8

*Table compiled from Table 3.25, Table 3.27 and original statistical analysis.

3.7.2 Nutrient concentration in 2007

Major element concentration in 2007

Concentration of major and minor elements in the bottom and top parts of plants irrigated with the standard nutrient solution was determined at full flower and harvest stages in 2007 to gain information on the flow of elements to the reproductive organs and the relative importance of the different elements. Concentrations were also determined at the green pod stage when pods were green and fully formed. The element concentrations at the three growth stages sampled during 2007 are summarized in **Table 3.32**.

Table 3.32 Mean concentration of major (%) and minor (mg kg⁻¹) elements at full flower, green pod and harvest stage of the standard solution in 2007.

Major Elements		Standard Solution					
Sample	Growth stage	N	P	K	Ca	Mg	S
		Major Elements (%)					
Top	Full Flower	2.63	0.53	3.83	1.02	0.28	0.54
Bottom	Full Flower	2.10	0.32	6.11	3.95	0.60	0.94
Ratio of top /bottom part of plants		1.3	1.6	0.6	0.3	0.5	0.6
Top	Green Pod	2.07	0.54	3.60	1.01	0.27	0.58
Bottom	Green Pod	1.63	0.38	5.69	2.48	0.39	0.80
Pods	Green Pod	2.40	0.54	1.55	2.01	0.45	0.70
Ratio of top /bottom part of plants		1.3	1.4	0.6	0.4	0.7	0.7
Top	Harvest	1.33	0.42	3.78	1.79	0.37	0.61
Bottom	Harvest	1.58	0.45	4.21	0.56	0.34	0.40
Pods	Harvest	1.80	0.47	1.81	2.33	0.44	0.68
Ratio of top /bottom part of plants		0.8	0.9	0.9	3.2	1.1	1.5
Minor Elements		Standard Solution					
Minor Elements	Standard Solution	Na	Fe	Cu	Zn	Mn	B
		mg kg ⁻¹					
Top	Full Flower	1567.50	59.00	1.27	21.60	31.80	23.00
Bottom	Full Flower	4737.50	129.90	3.50	19.40	133.30	60.10
Ratio of top /bottom part of plants		0.3	0.5	0.4	1.1	0.2	0.4
Top	Green Pod	1350.00	126.28	1.62	26.20	45.60	36.53
Bottom	Green Pod	3662.50	146.50	2.78	19.63	86.45	55.15
Pods	Green Pod	530.00	676.56	3.71	54.07	64.34	40.47
Ratio of top /bottom part of plants		0.4	0.9	0.6	1.3	0.5	0.7
Top	Harvest	2662.50	177.00	1.53	25.08	53.90	52.18
Bottom	Harvest	3875.00	75.48	1.68	21.40	15.60	18.90
Pods	Harvest	1329.75	243.39	2.11	87.18	64.44	50.24
Ratio of top /bottom part of plants		0.7	2.3	0.9	1.2	3.5	2.8

Nitrogen concentration at full flower was 2.10% in the bottom parts, decreasing to 1.63% at green pod and 1.58% at harvest. The concentration N in the top parts of the plants at the same growth stages were 2.63%, 2.07% and 1.33%. The ratio of the N concentration (%) in the top parts compared to the bottom parts were 1.3, 1.3 and 0.8 at full flower, green pod and harvest stages respectively.

Phosphorus concentration in the bottom parts (at full flower, green pod and harvest stages) ranged from 0.32% to 0.38% to 0.45%. Concentrations in the top parts of the plants at the same growth stages were 0.53%, 0.54% and 0.42%.

Ratios between concentrations in top to bottom parts at the same growth stages were 1.6, 1.4 and 0.9.

K concentration in the bottom parts ranged from 6.11%, 5.69% to 4.21% at the different growth stages compared to 3.83%, 3.60% and 3.78% in the top parts at full flower, green pod and harvest stages. Ratios between concentrations in top to bottom parts at the same growth stages were 0.6, 0.6 and 0.9.

The concentrations of Ca in the bottom of the plants were 3.95%; 2.48% and 0.56%. In the top parts Ca concentration increased from 1.02% at full flower to 1.01% at green pod to 1.79% at harvest. Ratios between concentrations in top to bottom parts at the same growth stages were 0.3; 0.4 and 3.2. This indicated a strong concentration increase of Ca in the top parts compared to the bottom parts quite late in the growing season. The samples taken at the green pod stage were taken at 17 October 2007 and plants were harvested 46 days later at 3 December 2007. The high evaporation rates indicated during this time (Table 3.1 B) probably influenced these values as Ca moved with the transpiration stream (Palzkill *et al.*, 1976).

Magnesium concentrations in the bottom parts were 0.60%; 0.39% and 0.34%. Mg concentrations in the top parts at the full flower, green pod and harvest stages were 0.28%; 0.27% and 0.37%. Ratios between concentrations in top to bottom parts were 0.5; 0.7 and 1.1.

Sulphur concentrations were 0.94%; 0.80%; 0.40% in the bottom parts at full flower, green pod and harvest stages compared to S concentrations in top parts of the plants which were 0.54%; 0.58% and 0.61%. Ratios between concentrations in top to bottom parts at the same growth stages were 0.6; 0.7 and 1.5.

Studying the ratios between concentrations in top to bottom parts at the same growth stages a decrease in concentration of elements in the top parts compared to the bottom parts as the plant mature became evident for N and P, while an increase in element concentration in the top parts compared to the bottom parts for Ca, Mg and S occurred. K indicated little change and the largest increases were noted in Ca and S.

Minor element concentration in 2007

Table 3.32 data indicate that all minor elements increased in concentration in the top part of the plant at harvest compared to full flower. The opposite occurred with minor elements in the bottom of the plants. All minor elements except Zn decreased in concentration in the bottom of the plants from full flower to harvest. The ratios between concentrations in top to bottom parts at full flower and harvest increased in the case of Fe, Mn and B, indicating a strong flow of these elements to the top parts of the plant at harvest.

Seed pod element concentration in 2007

The analysis of seed pods (at harvest and green pod stages) was only done in 2007 on plants that were irrigated with the Standard solution (**Table 3.32**). The following refers to the analysis done at the harvest stage:

N concentration was somewhat higher in the pods (1.80%) than in the rest of the plant (top - 1.33% and bottom - 1.58%). P concentration (0.47%) was very similar in all parts and K concentration was lower in the pods (1.81%) compared to the rest of the plant (3.78% - top and - 4.21% bottom). Average concentration Ca (at harvest) in the bottom parts were 0.56%, 1.79% in the top parts and 2.33% in the pods. This increase in concentration was not reflected at the green pod stage where the concentration of Ca in the bottom of the plant (2.48%) was still higher than in the pods (2.01%) or top parts (1.01%). This shows an increased Ca concentration effect in the top parts of the plant not only from the full flower stage, but also from the green pod stage to harvest. Magnesium concentration (0.44% - pods, 0.34% - bottom, 0.37% - top) and S concentration (0.68% - Pods, 0.40% - Bottom, 0.61% - Top) were higher in the pods compared to the rest of the plant. At harvest all major element concentrations except K were highest in the pods.

Na concentration was lower in the pods (1329 mg kg⁻¹) compared to the whole top (2662 mg kg⁻¹) and bottom (3875 mg kg⁻¹) parts of the plant. Marschner (1995) found that whereas Ca is rapidly transported to the shoot (of a maize plant), translocation of Na towards the shoot is severely restricted. It appears that a similar process was evident here. At harvest Fe concentration was higher in the pods (243.39 mg kg⁻¹) than in the whole top (177 mg kg⁻¹) and bottom part

(75.48 mg kg⁻¹) of the plants. Cu concentration was higher in the pods (2.11 mg kg⁻¹) compared to the rest of the plants (1.68 mg kg⁻¹ – bottom; 1.53 mg kg⁻¹ – top). Zn concentration appeared to be much higher in the pods (87.18 mg kg⁻¹) compared to the rest of the plant (21.40 mg kg⁻¹ – bottom; 25.08 mg kg⁻¹ - top) but the original data is somewhat divergent. The mean values are displayed above but the individual values per block do not consistently follow the trend indicated by the means. Manganese (Mn) concentration was higher in the pods (64.44 mg kg⁻¹) compared to the top (53.90 mg kg⁻¹) and bottom parts (15.60 mg kg⁻¹) of the plant. B concentration in the pods (50.24 mg kg⁻¹) was very similar to that in the top part of the plant (52.18 mg kg⁻¹), but much higher than in the bottom of the plant (18.90 mg kg⁻¹).

In general, concentrations of both major and minor elements in the pods indicated an increase compared to the rest of the above ground plant parts at harvest. An exception to this is K and Na concentration which were lower in the pods at harvest.

3.7.3 Comparison of 2007 and 2006 data

The ANOVA for the comparison of concentrations of major and minor elements in plant samples for the Std solution in 2006 and 2007 is summarized in **Table 3.33**.

Table 3. 33 Analysis of variance (ANOVA) of concentrations of major and minor elements in plants (bottom and top parts) measured at full flower and harvest stages for the standard solution in 2006 and 2007.

Source of variation	N		P		K		Ca		Mg		S	
	DF	Pr>F	Pr>F	Pr>F	Pr>F	Pr>F	Pr>F	Pr>F	Pr>F	Pr>F	Pr>F	
Yr	1	0.0017	0.103	<.0001	0.0024	0.1986	0.3689					
Yr(Rep)	6	0.2242	0.6248	0.3995	0.0116	0.2692	0.3815					
Stage	1	0.1282	0.4604	0.0045	0.0015	0.1112	0.1207					
Yr x Stage	1	0.008	0.6103	0.1816	0.0004	0.0326	0.0171					
Error (a)	6	6	6	6	6	6	6					
Pos	1	0.0386	0.0049	0.0009	0.2572	0.0011	0.1112					
Yr x Pos	1	0.5823	0.0641	0.6614	0.0012	0.0324	0.0001					
Stage x Pos	1	<.0001	<.0001	0.0238	<.0001	<.0001	<.0001					
Yr x Stage x Pos	1	0.0057	0.6484	0.8551	0.0131	0.0239	0.0264					
Error	12		11	11	12	11	12					
CV		9.89	9.39	17.20	28.34	9.27	12.36					

Source of variation	Na		Fe		Cu		Zn		Mn		B	
	DF	Pr>F	Pr>F	Pr>F	Pr>F	Pr>F	Pr>F	Pr>F	Pr>F	Pr>F		
Yr	1	0.1891	0.0027	0.0158	0.6072	0.0006	0.0141					
Yr(Rep)	6	0.0694	0.8901	0.6105	0.5192	0.1474	0.7193					
Stage	1	0.4799	0.2055	0.0096	0.1287	0.0033	0.0253					
Yr x Stage	1	0.7111	0.0639	0.0102	0.4152	0.0008	0.8015					
Error (a)	6	6	6	6	6	6	6					
Pos	1	0.0004	0.001	0.8997	0.0211	0.1938	0.661					
Yr x Pos	1	0.7067	0.0034	0.0890	0.3472	0.0004	0.0803					
Stage x Pos	1	0.9881	0.0065	0.8966	0.5496	<.0001	<.0001					
Yr x Stage x Pos	1	0.0639	0.633	0.2156	0.3147	0.0003	0.0003					
Error	12	12	12	11	12	12	11					
CV		39.66	31.85	26.74	23.45	32.52	10.96					

Table 3.33 indicate that significant interactions occurred for Year x Stage x Position for N, Ca, Mg and S. This implies that significant differences occurred and this is of importance where the results of 2006 and 2007 are being compared for similarities. For P and K no significant differences occurred implying that similar results for the two years were obtained. Means will be studied in order to gain a better understanding.

The values for minor elements in **Table 3.33** indicate that significant differences occurred for Mn and B for Year x Stage x Position interactions. No significant differences occurred for Na, Fe, Cu and Zn.

It must be kept in mind that two different broccoli cultivars were used in the two years. In research done by Kopsell *et al.* (2004), it was clear that different cultivars of kale and collards showed significant variability in elemental accumulation in plant tissue. Elements included were Ca, Mg, K, Fe, and Zn. On average a two fold difference in elemental accumulation were observed. There were also differences between different seasons. One would expect broccoli cultivars to display similar tendencies. This is confirmed when **Table 3.34** is studied and the means of P and K at the same plant locations during the two years are compared, as they were generally significantly different.

Trend comparisons

Table 3.34: Year x Stage x Position: Concentrations (%) of major and minor elements in bottom and top plant parts of the Std solution at 2 stages: full flower and harvest for 06 and 07.

Concentration (%)									
Stage	Flower				Harvest				
Year & Position	06 Top	07 Top	06 Bot	07 Bot	06 Top	07 Top	06 Bot	07 Bot	LSD
Major Elements									
NH₄	3.19 a	2.63 b	2.01 c	2.09 c	2.59 b	1.33 d	3.29 a	1.58 d	0.36
P	0.56 a	0.52 a	0.43 b	0.32 c	0.53 a	0.42 b	0.59 a	0.45 b	0.07
K	5.40 bc	3.83 d	7.66 a	6.11 b	5.37 bc	3.78 d	6.33 ab	4.21cd	1.44
Ca	0.88 d	1.01 cd	1.57 bc	3.94 a	2.21 b	1.79 b	0.57 d	0.55 d	0.68
Mg	0.30 ef	0.28 f	0.39 cd	0.51 a	0.48 ab	0.37 d	0.44 bc	0.34 de	0.06
S	0.55 c	0.54 cd	0.53 cd	0.94 a	0.79 b	0.60 c	0.43 de	0.40 e	0.11
Minor Elements									
	mg kg⁻¹								
Na	2715.8 bcd	1567.5 d	4286.0 ab	4737.5 ab	2086.3 cd	2662.5 bcd	5643.5 a	3875.0 abc	2106.0
Fe	422.75 a	58.96 d	305.5 b	129.91cd	348.2 ab	177.00 c	103.20 cd	75.48 d	99.40
Cu	4.77 a	1.99 c	3.99 ab	3.12 bc	2.49 c	2.41 c	2.34 c	2.64 c	1.30
Zn	20.75 a	21.59 a	11.52 b	19.42 a	25.98 a	25.07 a	22.55 a	21.40 a	7.60
Mn	26.64 c	31.84 bc	27.29 c	133.30 a	51.32 b	53.90 b	15.65 c	15.60 c	22.30
B	27.26 d	23.02 de	41.11 c	60.07 a	42.28 c	52.17 b	16.09 f	18.90 ef	6.10

Means with the same letters are not significantly different.
Bot = Bottom

In **Table 3.34** the mean concentrations for 2006 and 2007 at different plant locations and growth stages are given. The following trends can be observed:

Studying the **major elements** in **Table 3.34** it is clear that there were increases in the concentrations of Ca, Mg and S in the **top** parts of the plant at harvest compared to full flower during both 2006 and 2007. This increase in concentration in the top part of the plant did not happen for all elements. For N, K and P there was an opposite effect with a decrease in concentration of the elements in the top part of the plant at harvest versus full flower during 2006 and 2007. During both years the concentration of K, Ca and S in the **bottom** of the plant decreased significantly from full flower to harvest. P displayed an opposite reaction and increased significantly in concentration in the bottom during both

years. N and Mg displayed opposite reactions during the two years and a trend was not established.

3.7.4 Nutrient mass per plant in 2006

Nutrient mass per plant was calculated from the dry mass per plant and element concentration at different sampling stages in 2006, but not in 2007 because plant analyses was done only on the standard nutrient treatment in 2007.

Major elements

At full flower and buttoning stages block as a source of variation was significant for most of the major elements (**Table 3.35**). Treatments were not significantly different except for K at the buttoning stage where nutrient solution St-K which had the lowest concentration of K in the solution, showed significantly lower K mass per plant compared to other treatments (**Table 3.36**). This trend was however not repeated at other sampling stages as plants grew towards maturity. It appears that the total amount of K available to the plants was still sufficient so that significantly lower K concentration in the solution caused no significant response during the last 3 sampling stages.

Table 3.35 Analysis of variance (ANOVA) for the effect of nutrient solution treatments on major element mass per plant at different growth stages in 2006.

STAGE: BUTTONING							
Source of Variation	Df	N	P	K	Ca	Mg	S
		P>F	P>F	P>F	P>F	P>F	P>F
Block	3	0.0061	<.0001	0.4106	<.0001	0.0001	0.0145
Treatment	6	0.8770	0.1119	0.0188	0.1468	0.1344	0.4267
Error	18						
LSD (P=0.05)		0.282	0.087	1.024	0.318	0.020	0.327
CV		17.82	17.46	17.91	21.42	11.95	12.08
STAGE: MATURE HEAD							
Block	3	0.2243	0.4196	0.6691	0.1774	0.1268	0.6793
Treatment	6	0.4982	0.4992	0.1357	0.8146	0.5295	0.9347
Error	18						
LSD (P=0.05)		1.144	0.310	1.886	0.584	0.163	0.240
CV		17.62	21.64	16.17	24.93	21.49	22.85
STAGE: FULL FLOWER							
Block	3	0.0091	0.5811	0.0002	0.0026	0.0073	0.1905
Treatment	6	0.0506	0.2197	0.1161	0.1140	0.3870	0.1457
Error	18						
LSD (P=0.05)		1.400	0.317	3.257	1.179	0.214	0.311
CV	27	16.21	17.68	17.73	25.93	18.56	17.56
STAGE: HARVEST							
Block	3	0.5476	0.3940	0.3994	0.6442	0.5259	0.3343
Treatment	6	0.2084	0.8803	0.1140	0.8451	0.3184	0.4450
Error	18						
LSD (P=0.05)		3.837	0.823	5.402	2.913	0.553	0.958
CV		31.36	32.77	21.92	35.91	25.65	32.09

Table 3.36 Potassium mass per plant (g) at buttoning in response to nutrient solution treatments applied in 2006.

Treatment	K (g)
1. Std	3.81 a
2. St + K	4.23 a
3. St + N	4.33 a
4. St - K	2.46 b
5. St - N	4.22 a
6. St + S	3.86 a
7. St - S	4.02 a
LSD	1.02
CV	17.90

Means with the same letters are not significantly different.

It is clear that the different nutrient solutions applied, did not influence the total amount of major elements assimilated by plants in this study. It might be argued

that once the “optimum” level of major elements is reached, increasing their levels does not necessarily lead to higher levels in plant tissue samples. Taking solution number 1 (Standard Solution) as a benchmark it seems that increasing the concentration of major elements does not necessarily lead to higher levels of those elements in plants. Lower levels did also not lead to significantly lower levels of elements in the plants (except for K at buttoning). These results are somewhat different to what was found when concentrations of elements were investigated because S and K concentration in plant samples were influenced by low concentrations in nutrient solutions. The total amounts of elements administered to the plants were high as expected in hydroponic solutions.

Minor elements

Table 3.37 indicate that block as a source of variation was significant for some minor elements (Na, Fe, Cu, Zn, B) at the buttoning, mature head and full flower stages, but not at harvest. Only Na displayed significant differences in mass during mature head, full flower and harvest in response to treatments (nutrient solutions) applied. The minor element composition was the same in all nutrient solutions and significant responses was not expected. Studying the means at each stage, no clear trends emerge.

Table 3.37 Analysis of variance (ANOVA) for the effect of nutrient solution treatments on minor element mass per plant at different sampling stages in 2006.

STAGE: BUTTONING							
Source of variation	df	Na P>F	Fe P>F	Cu P>F	Zn P>F	Mn P>F	B P>F
Block	3	0.0342	0.0006	0.2748	0.0047	0.0584	0.0058
Treatment	6	0.1006	0.3412	0.1046	0.3201	0.3788	0.1986
Error	18						
LSD (P=0.05)		67.429	0.841	0.031	0.258	0.730	0.229
CV		38.42	16.08	19.53	18.95	22.06	13.57
STAGE: MATURE HEAD							
Block	3	0.0243	0.9157	0.7178	0.1653	0.7097	0.1549
Treatment	6	0.0094	0.9644	0.9573	0.7593	0.5654	0.4755
Error	18						
LSD (P=0.05)		176.90	13.545	0.232	0.973	1.230	0.917
CV		26.24	63.64	30.40	20.53	21.27	15.42
STAGE: FULL FLOWER							
Block	3	0.0018	0.7400	0.0406	0.1763	0.1615	0.0175
Treatment	6	0.016	0.8644	0.1755	0.6059	0.8688	0.1279
Error	18						
LSD (P=0.05)		339.44	144.04	3.287	12.626	25.184	21.703
CV	27	31.85	87.86	25.31	23.49	25.29	18.73
STAGE: HARVEST							
Block	3	0.6093	0.9112	0.6078	0.6187	0.7655	0.2987
Treatment	6	0.032	0.3799	0.5638	0.8765	0.6265	0.5079
Error	18						
LSD (P=0.05)		517.6	53.746	0.395	5.182	6.322	5.737
CV		33.13	45.22	33.65	43.93	36.09	29.80

3.7.5 Nutrient mass in plants at different growth stages- 2006

In **Figures 3.3** and **3.4** the mass of the major and minor elements in the plants at the four growth stages are shown. Values for top and bottom plant parts were summed to calculate the totals per plant. Mass of both major and minor elements, with the exception of Fe and Cu, increased as plants matured to reach their maximum values at harvest. The decrease in total content of Cu and Fe is unexpected and not easily explained. It must be mentioned that during the last growth stages before harvest and after flowering, the plants produced new growth in the form of small leaves and new flowers/pods that do not carry any

seed. This obviously adds to plant mass but do not contribute to seed production and might have an effect on mass of elements.

Normal harvesting of mature broccoli heads occur at the mature head stage which indicates the end of the production period when producing for the fresh vegetable market. When producing seed, mature head to harvest stretches for a period of approximately 5 months (03 July 2006 to 21 November 2006). From these results one can assume that the plants need sufficient nutrition during this 3 month period. The highest total major element mass per plant at harvest was noted for K, followed by N, Ca, S, P and Mg in descending order (**Figure 3.3**).

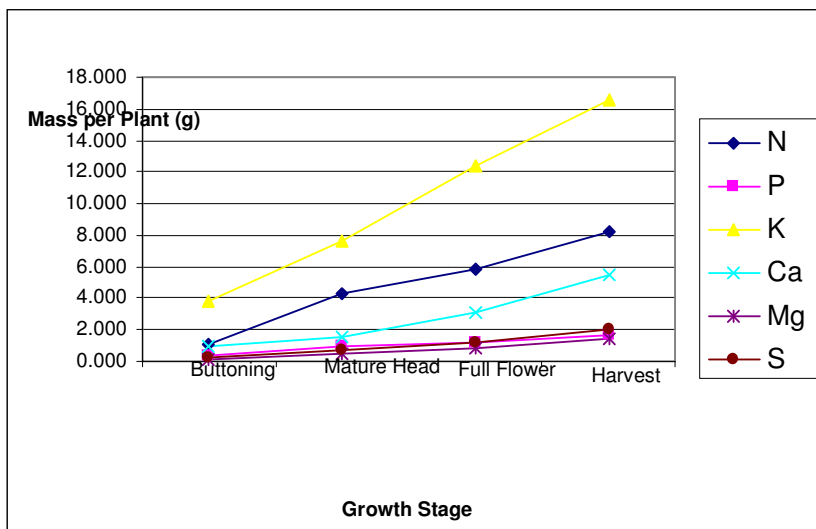


Figure 3.3: Uptake of major elements per plant in 2006.

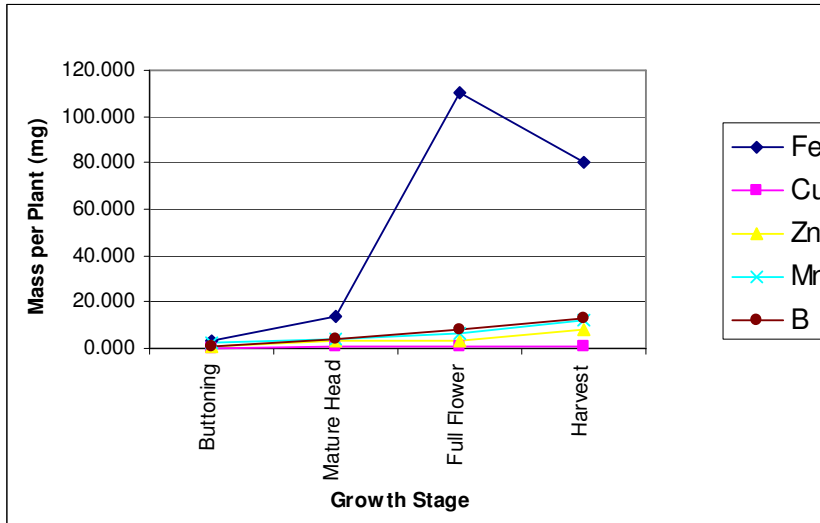


Figure 3.4: Uptake of minor elements per plant in 2006.

3.7.6 Element mass per hectare in 2006

Table 3.38 Major and minor element mass of above ground plant parts ha⁻¹.

Growth Stage	Average Mass Hectare ⁻¹ Element ⁻¹					
	Major Elements - 21 000 plants Hectare ⁻¹					
	N	P	K	Ca	Mg	S
	kg ha ⁻¹					
Buttoning	22.4	6.8	80.8	21.0	2.2	3.8
Mature Head	89.3	19.2	160.4	32.2	10.4	14.4
Full Flower	122.1	25.3	259.7	64.3	16.3	25.1
Harvest	173.0	35.5	348.4	114.7	30.5	42.2
Growth Stage	Average Mass Hectare ⁻¹ Element ⁻¹					
	Minor Elements - 21 000 plants Hectare ⁻¹					
	Na	Fe	Cu	Zn	Mn	B
	g ha ⁻¹					
Buttoning	2480.8	73.9	2.3	19.2	46.8	23.9
Mature Head	9272.0	292.7	10.5	65.1	79.5	81.8
Full Flower	15063.0	2317.6	18.4	76.0	140.8	163.8
Harvest	22083.9	1680.0	16.6	166.7	247.6	272.2

The mass (kg) of major elements that were incorporated in the above ground plant parts of broccoli plants ha⁻¹ at the different growth stages are summarized in **Table 3.38**. The calculations were made for 21 000 plants ha⁻¹ as this is the

recommended planting density for the cultivar used in this study. From the table it became clear that the plants kept on utilizing the major elements as it matured. Maximum mass per element was reached at harvest. Comparing the masses at the mature head stage to harvest, it is evident that N, P and K increased about twofold in total mass ha^{-1} , while Ca, Mg and S showed an approximate three fold increase in mass over the same period.

Comparing the mass ha^{-1} of the different major elements at mature head stage to values given in the nutrition guidelines for broccoli produced for the fresh market (**Table 2.1 & Table 2.2**) it appears that the level of N suggested to be applied is high compared to that which was found in this study. The Mayford guideline is 120 kg ha^{-1} but FSSA advises $160 \text{ to } 260 \text{ kg ha}^{-1}$. The number of plants per hectare which can be as high as $40\,000$, obviously is an important determining factor. When producing broccoli for seed this data shows that it is unlikely that more than 120 kg N ha^{-1} N is needed during the season till the mature head stage for this broccoli cultivar. Plant population and soil fertility would be important determining factors.

Phosphorus incorporation in the plants were low compared to the application rates recommended in **Tables 2.1** and **2.2** which ranged from 40 kg ha^{-1} to 150 kg ha^{-1} , while only 21.3 kg ha^{-1} at mature head and 35.5 kg ha^{-1} at harvest was incorporated in the plants in this study. If the whole plant (above ground) is removed, only 35.5 kg P would be removed per hectare during seed production. The mass of K incorporated in the plants at mature head was 166.3 kg ha^{-1} . This increased to 348.4 kg ha^{-1} at harvest. Application rates for K in **Tables 2.1 and**

2.2 for producing mature heads ranged from 60 kg to 160 kg ha⁻¹. Depending on the contribution of soil K, the recommended application rate of K up to mature head correlate with the amount that is removed per hectare. If all the above ground plant material is removed per hectare a relatively high quantity of K is removed.

Table 3.38 shows that the total mass of minor elements incorporated per hectare were small, but a large increase in total mass per hectare from mature head to the full flower and harvest stages for all elements became evident.

CONCLUSIONS

The different nutrient solutions applied in 2006 did not significantly affect the total biomass produced per plant. Total dry weight increased by 225% during the period of mature head to harvest.

In general plants did not respond significantly to the different nutrient solution treatments of 2006. Concentrations of elements as well as the mass of elements in plants were largely unresponsive. It appears likely that the total quantities of elements available to plants were still sufficient to negate any significant responses. During 2006 low levels of S and K in the nutrient solutions resulted in significantly lower concentrations in plants, but this did not translate into element mass per plant as well.

The element mass per plant at the four growth stages (2006) indicates that from the mature head stage until harvest the plants assimilated relatively large

quantities of elements. The total major element mass that was incorporated ha^{-1} (21 000 plants ha^{-1}) by the above ground plant parts were 173 kg N, 35.5 kg P, 348 kg K, 114 kg Ca, 30.5 kg Mg and 42.2 kg S. Comparing the masses at the mature head stage to harvest, one can see that N, P and K increased about twofold in total mass ha^{-1} , while Ca, Mg and S showed an approximate three fold increase in mass over the same period.

An increase in concentration of both major and minor elements in the pods compared to the rest of the above ground plant parts at harvest were observed during 2007. An exception to this is K and Na concentration which were lower in the pods at harvest. This identifies the seed pods as strong sinks in plants.

In response to the Standard solution, the concentrations of major elements in plant parts at harvest and flowering stages in the same plant parts differed significantly when 2006 and 2007 is compared. This result supported that of Kopsell *et al.* (2004). The minor element concentrations of Na, Cu and Zn were essentially similar during 2006 and 2007.

Similar trends observed during 2006 and 2007 were increases in the concentrations of Ca, Mg and S in the **top** parts of the plant at harvest compared to full flower. This might have been a normal occurrence as less mobile elements tend to increase in concentration in older plant tissue as plants matured (Jones, 2000). For N, K and P there was an opposite effect with a decrease in concentration of the elements in the top part of the plant at harvest versus full flower.

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CHAPTER 4

THE INFLUENCE OF DIFFERENT NUTRIENT SOLUTIONS AND TREATMENTS ON SEED YIELD AND QUALITY CHARACTERISTICS OF BROCCOLI, *Brassica oleracea* L. var. *italica* Plenck SEED.

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ABSTRACT

During 2006 and 2007 Broccoli plants were grown in trials for seed production in a net structure. The plants were grown in sand bags utilizing a drain to waste hydroponic system. The experimental design was a randomized complete block with 7 treatments replicated in four blocks. During 2006 seven nutrient solutions were utilized. The Standard solution was based on Steiner's universal solution and different levels of N, S, K and Ca were used in the experimental solutions. During 2007 the trial was continued and three of the 2006 solutions were used again including the Standard solution. Seven treatments were administered including foliar sprays with Ammonium Nitrate and Calcium Metalosate. One new nutrient solution was utilized during 2007. During both years the broccoli seed harvested were measured in terms of quality and quantity (yield). During 2006 no significant differences were found in terms of quality measurements. Yield plant⁻¹ differed significantly with the four highest yielding solutions performing significantly better than the rest. The yields of these four did not differ significantly. During 2007 no significant differences were found for seed quality measurements, except for size (of the cotyledons) with three solutions performing equally in this measurement and significantly better than the rest. Yield plant⁻¹ differed significantly with two nutrient solutions performing equally and significantly better than the other solutions. During both years the two best nutrient solutions in terms of yield plant⁻¹ were the same. They were the Standard solution and Standard less K. The results indicate that no special adjustments need to be made to the Standard solution in order to produce good quality and quantity broccoli seed. Substantial differences in nutrient solution composition did not significantly affect the quality of broccoli seed produced. The yield per plant was significantly influenced by the composition of the nutrient solutions.

Key words: Brassica seed, Broccoli seed, Broccoli nutrition, Hydroponic production, Broccoli production.

INTRODUCTION

Over the past ten years the production of F1 hybrid broccoli and cauliflower seed has steadily increased in the Olifants river irrigation area of the West Coast. The seed crop is of considerable economic importance in the region.

Knowledge about the nutritional needs of broccoli plants grown for seed production is not known. Thorough knowledge and experience about production for fresh markets exist. Growers speculate that certain nutrients might be especially important for the production of high seed yields of good quality. The quantities and relation of these elements are not known.

Literature information concerning nutrition of seed producing cole crops is very scarce. In the Olifants river valley broccoli- and cauliflower seed have been produced for the past 10 years. Although no research has been done previously, the following plant nutrition program, based on practical experience, is used as a general guideline: 165 kg N ha⁻¹; 100 kg P ha⁻¹; 400 kg K ha⁻¹; 160 kg Ca ha⁻¹ (Pers. Comm., 2006: G.J. Kersop, PO Box 463, Lutzville).

Literature guidelines for the production of seed from Chinese cabbage indicate that supplying a sufficient amount of N at the initial stage of flowering is most effective in increasing seed yield. Side dressing of N at this stage is recommended. K also has to be supplied at this stage. B supplementation is also necessary where soil content is low. For artificially vernalized Chinese cabbage plants, it is suggested that 150 kg N ha⁻¹ be supplied in a split application with half applied before planting and the second half applied two

weeks after planting. Further application of 30 kg N, 13 kg P and 16.6 kg K at bolting time with another side dressing at mid flowering time of 15 kg N and 8.3 kg K is suggested. Total N recommended was 195 kg ha⁻¹. Borax at 10 kg ha⁻¹ is applied before planting in cases of low B content (Opeña *et al.* 1988).

Research results (Mishra, 1992) showed that N fertilization had a significant effect on cauliflower plant height, number of branches, number and length of pods, number and weight of seeds and seed yield. It was found that the optimum level of N fertilization in that situation was 150 kg ha⁻¹ and 10 kg ha⁻¹ for B. This level also brought about maximum seed germination. The time of N application did not have any effect on seed yield or quality. In contrast Sharma and Rastogi, (1992) found that N fertilization at 200 kg ha⁻¹ delivered the best yield of cauliflower seed per hectare. Different levels of boron application significantly affected number of branches, number of pods, 1000 seed weight and seed yield.

Lyons *et al.*, (2009) investigated the response of *Brassica rapa* L. to a low dose of Selenium (as sodium selenite) in terms of growth responses and seed production. No change in total biomass was found but the Se treatment was associated with a 43% increase in seed production. It was further found that Se treated plants produced pollen that had 2% unviable grains compared to 14% unviable grains for the control plants. Se-treated plants produced seed with a mean germination rate of 92% compared to a mean of 81% for the control. (Terry *et al.*, 2000). Se was not investigated in this study.

Through the utilization of different nutrient solutions in a hydroponic system with varying major element relations and content it was hoped to gain basic knowledge of broccoli seed quality and quantity responses to these variables. By varying the content of N, K, S and Ca in the nutrient solutions and studying seed quality and quantity results the aim was to gain understanding of the relative importance of the elements in relation to broccoli seed production.

MATERIAL AND METHODS

The research done was undertaken in conjunction with Syngenta Seed B.V., an international seed company. Research took place during two production seasons of 2006 and 2007. The same location, production system and structures as described in Chapter 3 were used during the two years of experimentation.

4.1 General

4.1.1 Climate Data

In general no major differences were experienced during the two production years and major influences on the growth and production due to climatic conditions were not expected. Detailed discussion of climatic data was done in Chapter 3.

4.1.2 Cultivation

The cultivation process from planting to harvest was described in Chapter 3. During both years the male plants were removed from the net house during October. The females were harvested during November. The harvested plants

were put on tripods for curing for a period of 2 weeks. Seed was harvested with a mechanical thresher during early December. The seed was then cleaned by sifting it by hand through a 2.5 mm sieve and lastly with a 1.4 mm sieve to get rid of all the debris. The 28 seed samples were thereafter sent for seed testing to the laboratories of the international seed company in Holland.

4.2 Treatments Applied

4.2.1 2006

The nutrient solutions used (treatments applied) during 2006 were described in Chapter 3 and are summarized in **Table 3.4**. For convenience's sake it is repeated in this chapter. Treatments consisted of high and low levels of N, K, S and Ca in the nutrient solutions.

Table 3.4 Composition and explanation of nutrient solution treatments in 2006.

Nutrition Solutions	Explanation	mmol L ⁻¹						
		NH ₄ ⁺	K ⁺	Ca ²⁺	Mg ²⁺	NO ₃ ⁻	H ₂ PO ₄ ⁻	SO ₄ ²⁻
1. Std	Standard.	1	7	8.5	3.5	12.5	1.5	6
2. Std + K	Increase K, decrease Ca.	1	10.5	5	3.5	12.5	1.5	6
3. Std + N	Increase N, decrease S.	1	7	8.5	3.5	17.5	1.5	1
4. Std – K	Decrease K, increase Ca.	1	3.5	12	3.5	12.5	1.5	6
5. Std – N	Decrease N, increase S.	1	7	8.5	3.5	7.5	1.5	11
6. Std + S	Increase S, decrease N.	1	7	8.5	3.5	10	1.5	8.5
7. Std – S	Decrease S, increase N.	1	7	8.5	3.5	15	1.5	3.5

4.2.2 2007

Seven treatments were applied in 2007 (**Table 4.1**). The Standard solution 1 (Std) was the same as that used during 2006. Solution 4 (Std-K) of 2006 was also retested as solution (2). This solution differed from the Standard solution only in that it had less K, (3.5 mmol L⁻¹) and more Ca (12.0 mmol L⁻¹) compared

to the Standard solution which had 7.0 mmol L⁻¹ K and 8.5 mmol L⁻¹ Ca. This solution had the highest level of Ca. This solution produced good results in 2006 and plant analysis indicated a definite increase in Ca in plants as they developed to harvest. In 2007 this solution's influence on seed quality and quantity was investigated again.

Table 4.1 Composition and explanation of nutrient solutions and treatments in 2007.

Nutrient Solutions – 2007	Explanation	mmol L ⁻¹						
		NH ₄ ⁺	K ⁺	Ca ²⁺	Mg ²⁺	NO ₃ ⁻	H ₂ PO ₄ ⁻	SO ₄ ²⁻
1. Std, Spray nothing	Standard	1	7	8.5	3.5	12.5	1.5	6
2. Std – K, Spray nothing	Lowest K, High Ca	1	3.5	12	3.5	12.5	1.5	6
3. Std – N, Spray Ammonium Nitrate	Lowest N, Highest S	1	7	8.5	3.5	7.5	1.5	11
4. Std - N, Spray nothing	Lowest N, Highest S	1	7	8.5	3.5	7.5	1.5	11
5. Std - N + P, Spray Ammonium Nitrate	Low N, High S+ Highest P	1	7	8.5	3.5	8.5	3.5	8
6. Std - N + P, Spray nothing	Low N, High S+ Highest P	1	7	8.5	3.5	8.5	3.5	8
7. Std - N, Spray Calcium	Lowest N, Highest S	1	7	8.5	3.5	7.5	1.5	11

Solution (3) and (4), Std – N, had the same composition as number 5 (Std-N) of 2006. Solution 3 included a different treatment compared to solution 4 in that Ammonium Nitrate was applied as a foliar spray on the “female” plants every 14 days from 30% flowering onwards until harvest. Ammonium Nitrate (21) was used at a 3% solution. A wetting agent was used with it. Spraying was done with a backpack sprayer during the morning between 08H00 and 12H00. The influence of this foliar application of Ammonium Nitrate in conjunction with this nutrient solution treatment was investigated. The plants of solution 4 were not sprayed with Ammonium Nitrate and it was essentially the same treatment as in 2006. This solution was tested again because of the high levels of Sclerotinia infection during 2006 and since this solution produced the biggest total yield. The influence of lower N content on susceptibility to Sclerotinia infection and seed

quantity and quality parameters were investigated again. The lower levels of infection during 2006 for this solution gave an indication that less N in the solution assisted plants against *Sclerotinia* infection. It must be kept in mind that different *Brassica* cultivars differ in N efficiency and yield in response to N supply (Schulte auf'm Erley *et al*, 2010).

Solutions (5) and (6), Std – N + P, had the same composition. Solution (5) received the same foliar spray with Ammonium Nitrate in the same manner as solution (3) described above. Solution (6) was not sprayed with Ammonium Nitrate. The composition of solutions (5) and (6) were different to those used during 2006. In these solutions N was lowered but S was not increased so much (8 mmol L⁻¹) compared to solutions (3) and (4) (11mmol L⁻¹). Instead P was increased to 3.5 mmol L⁻¹. The lower levels of N coupled with somewhat lower increase in S (compared to 2006) and higher P content was investigated.

Solution 7, Std – N, had the same composition as solutions (3) and (4) but the treatment differed in that a foliar spray with Calcium Metalosate was applied at 14 days interval to the “female” plants from 30% flowering until harvest. The Calcium Metalosate (Liquid Amino Acid Chelate for foliar application) used contained 60 g kg⁻¹ Calcium. It was sprayed at a 1% concentration using a backpack sprayer during mornings between 08H-00 and 12H00. A wetting agent was applied with it. Specifically the lower levels of N coupled with a Ca foliar spray was investigated.

4.3 Data collected in 2006 and 2007

4.3.1 Seed quality test

All treatments and repetitions were kept separately and seed quality testing was done in Enkuizen (The Netherlands) in the laboratories of the international seed company. Germination testing on the broccoli seed during both years was done as follows:

The sample size: 100 seeds

Growing medium: peat based soil (commercial)

Test conditions: 3 days in a germination room at 18 °C, dark with a high relative humidity (RH > 95 %). After this period the samples were transferred to a glasshouse with a minimum temperature of 17 °C.

Assessments:

Assessments of germinating seed were done once after about 7 days depending on seedling size. Assessments were made by using a digital camera and automated data interpretation.

Assessment classes were:

Normal: means good sized, usable seedling

Small: means good seedling, however small. Still usable in practice

Abnormal: seedling showing malformations (e.g. only one cotyledon), discolorations, chlorosis, etc. This category is regarded not usable in practice.

Not germinated: Seed did not germinate.

Size: This is related to the number of pixels and is a measure for the surface of the cotyledons. This is a measure of the vigor of the seed. It gives an indication of the growth rate of the cotyledons. A size reading of less than 375 means that plants are regarded as too small to be assessed and assessment is delayed till

this threshold is passed. Generally measures should best be between 400 and 550.

Uni (uniformity): is calculated by the software and is a measure for uniformity based on the leaf surfaces. It is the relation of cotyledon sizes and is presented as a percentage. A value of 100 would mean 100% uniform. A value of 60% is considered as good.

KE = Kiem Energie (Germination Energy). It includes only the Normal seedlings. It is mostly a measure for uniformity - the higher the figure the more uniform the seedlings and emergence.

KK = Kiem Kracht (Total Germination). This figure includes the Normal Seedlings + Small Seedlings. It represents the total percentage of usable plants. (Pers. Comm., 2007: Mr. B. Mantel, PO Box 2, 1600 AA Enkhuizen, The Netherlands).

4.3.2 Seed yield

Total yield (grams) per replication was measured. The number of plants harvested per replication was recorded because the same number of plants could not be harvested from each plot as Sclerotinia infections prevented that during 2006. For this reason the yield was presented as yield per plant in gram. During 2007 disease did not pose any problems and 160 plants were harvested per nutrient solution.

4.4 Experimental layout and statistical procedures

The experimental design was a randomized complete block with 7 treatments replicated in four blocks in both years. Analysis of variance was performed using

GLM (General Linear Models) Procedure of SAS version 9.1 (SAS, 2000). Shapiro-Wilk test was performed to test for normality (Shapiro, 1965). Student's t-least significant difference was calculated at the 5% level to compare treatment means. A probability level of 5% was considered significant for all significance tests.

RESULTS AND DISCUSSIONS

4.5 2006

4.5.1 Seed yield

The effect of the different nutrient solution treatments on seed yields in 2006 are presented in **Table 4.2**.

Table 4.2 Analysis of variance of seed quantity measurements (Total Yield, Plants Harvested, Yield Plant⁻¹) in response to different nutrient solution treatments in 2006.

Source of variation	Df	Yield	Plants	Yield/Plant
		P>F	P>F	P>F
Block	3	<.0001	<.0001	0.3143
Treatment	6	0.1093	0.1697	0.0158
Error	17			
Corrected				
Total	26			

Table 4.3 Means of seed quantity measurements (Total Yield, Plants Harvested, Yield /Plant⁻¹) in response to different nutrient solution treatments in 2006.

Treatment	Yield (g)	Plants	Yield/Plant (g)
1. Std	106.00	9.75	11.13 a
2. Std + K	79.75	10.25	6.68 c
3. Std + N	66.75	8.00	8.50 abc
4. Std - K	77.67	8.33	10.07 abc
5. Std - N	128.75	14.50	8.93 abc
6. Std + S	86.00	12.25	6.43 c
7. Std - S	98.50	12.75	7.93 bc
LSD (P=0.05)	ns	ns	2.66
CV	30.78	30.11	20.61

Means with the same letter are not significantly different.

Significant differences between blocks for total yield and number of plants harvested were found. Total yield varied between 66.75 g (Std+N) to 128.75 g (Std – N), but the yield obtained with (Std – N) was not significantly higher than that obtained with the standard Steiner solution (Std) or any of the other solutions containing high or low contents of N, K or S (**Table 4.3**). Total yield was however affected by the number of plants harvested as a result of *Sclerotinia sclerotiorum* infection in the crop during 2006. No significant differences in the number of plants harvested were found.

Although the number of plants harvested in response to treatments did not differ significantly ($P = 0.1700$), the results presented in **Table 4.3** gave an indication of the extent of *Sclerotinia* infection in the crop during 2006. The number of female plants planted was 1874 and only 306 plants could be harvested. Nutrient solution 3 (Std+N) which had the highest N content also had the lowest number namely a mean of 8.0 plants that could be harvested. This is what one would expect in a situation where high disease pressure is coupled with a high N content in the nutrient solution. Std-N contained the lowest concentration of N and had the highest number of plants harvested. The differences were not significant but could indicate a trend. Fordham & Biggs (1985) mentioned that N encourages growth but excessive amounts encouraged the development of soft tissues which are easily damaged by diseases. It is also confirmed by research done by Sandhu (1992) who found that *Sclerotinia* could be controlled by lowering the use of synthetic N and increasing the use of kraal manure.

Yield per plant showed significant differences ($P = 0.0158$) in response to the different nutrient solutions used in 2006 (**Table 4.3**). Seed yield per plant varied between 6.43 g (Std + S) and 11.13 grams (Std). Seed yield per plant obtained with the Std solution was not significantly different from the seed yield per plant produced with solution 3 (Std + N), solution 4 (Std-K) or solution 5 (Std-N). Smallest yield per plant in 2006 was produced with Solution 6 (Std+S), Solution 2 (Std+K) and Solution 7 (Std-S). It is noteworthy that the Standard solution (based on Steiner's universal solution) produced the highest yield per plant and that large variation in nutrient composition with regard to N, K, Ca and S did not result in significant differences between the best four solutions. The results of 2006 therefore suggested that the standard solution can be used for the production of broccoli seed.

4.5.2 Seed quality

The ANOVA and mean values of seed quality measurements for 2006 are summarized in **Tables 4.4, 4.5, 4.6** and **4.7**. From the ANOVA it became clear that significant differences between Blocks occurred with regard to Normal seedlings, Size count, Uni, KE and KK. Nutrient solution treatments did not have a significant effect on any of the seed quality measurements. Very large coefficients of variance for small and abnormal seedlings indicated that the numbers of these seedlings were very variable.

No significant differences were found during 2006 in seed quality in response to the different nutrient solution treatments applied. Normal seedlings ranged between 93.3% and 88.5% while small seedlings ranged between 1.5% and

4.3%. Abnormal seedlings ranged from 0.5% to 2%. Average size counts ranged from 436 to 458 and were well within the acceptable range. Average uniformity ranged from 58.0 to 60.5 (%) and is quite good. Average KE ranged from 93.3% to 88.5%. Average KK ranged from 95.8% to 92.8%. Germination measurements were in general better than that found among commercial growers, growing the same cultivar during the same season (Pers. comm., 2007: Mr. G. J. Kersop, PO Box 463, Lutzville).

Table 4.4 Analysis of variance of seed quality measurements (Normal, Small, Abnormal, Size count) in response to different nutrient solution treatments in 2006.

Source of Variation	Df	Normal P>F	Small P>F	Abnormal P>F	Size count P>F
Block	3	0.0045	0.7367	0.1102	0.0491
Treatment	6	0.5924	0.3712	0.1855	0.5592
Error	18				
Corrected Total	27				

Table 4.5 Means of seed quality measurements (Normal seedlings, Small seedlings, Abnormal seedlings, Size count) in response to different nutrient solution treatments in 2006.

Treatment	Seedling development (%)			
	Normal (%)	Small (%)	Abnormal (%)	Size count
1. Std	92.50	3.25	1.00	437.50
2. Std + K	91.50	2.25	1.50	449.00
3. Std + N	91.00	2.00	1.00	436.00
4. Std - K	93.25	2.00	1.00	447.00
5. Std - N	88.50	4.25	2.00	458.25
6. Std + S	93.25	1.50	0.50	454.00
7. Std - S	91.50	3.50	0.75	441.00
LSD (P=0.05)	ns	ns	ns	Ns
CV	4.04	69.20	69.45	4.11

Table 4.6 Analysis of variance of seed quality measurements (Uniformity (Uni), Germination Energy (KE) and Total germination (KK)) in response to different nutrient solution treatments in 2006.

Source of variation	Df	Uni	KE	KK
		P>F	P>F	P>F
Block	3	0.0296	0.0045	0.0008
Treatment	6	0.959	0.5924	0.6806
Error	18			
Corrected Total	27			

Table 4.7 Means of seed quality measurements (Uniformity (Uni), Germination Energy (KE) and Total germination (KK)) in response to different nutrient solution treatments in 2006.

Treatment	Uni (%)	KE (%)	KK (%)
1. Std	60.50	92.50	95.75
2. Std + K	59.00	91.50	93.75
3. Std + N	59.75	91.00	93.00
4. Std - K	58.00	93.25	95.25
5. Std - N	58.75	88.50	92.75
6. Std + S	60.50	93.25	94.75
7. Std - S	58.75	91.50	95.00
LSD (P=0.05)	ns	ns	Ns
CV	6.63	4.05	3.02

Although not statistically significant, Nutrient Solution 5(Std – N) which had a low level of N with an oversupply of S showed a slightly lower percentage normal and slightly higher percentage small and abnormal seedlings (**Table 4.5**). Malik *et al.* (2004) shows that S is important to increase the oil content of rapeseed. Jones (1982) also notes that S is important in the plants synthesis of oils. Grant *et al.* (2003) confirms these results and adds that the increase in S and oil concentration is accompanied by lower chlorophyll and seed N concentration. The oil content of rapeseed therefore shows an inverse relation to the N concentration in the seed. With increased N fertilization it is found that the oil content of the seed decreases (Smith *et al.*, 1988). Oil in the seed serves as a source of energy and carbon in germinating seed (Kimber & McGregor, 1995).

Janzen & Bettany (1984) estimated the optimal ratio of N to S in the soil to be 7:1. Ratios below 7 resulted in inefficient utilization of assimilated S and ratios exceeding 7 resulted in reduced seed yields. Results (**Tables 4.5** and **4.7**) however showed no significant differences in seed vigor and germination in response to N and S levels and all quality parameters were at acceptable levels. Mean size was the highest in response to solution 5 (Std – N).

4.6 2007

4.6.1 Seed yield

The effect of different treatments on seed yield and the size of cotyledons are presented in **Tables 4.8** and **4.9**. Significant differences occurred between blocks for total yield and yield plant⁻¹ but not for size or any other quality measurements (**Tables 4.8** and **4.10**).

Table 4.8 Analysis of variance of seed quality and quantity measurements (Size, Total Yield, Yield Plant⁻¹) in response to different nutrient solutions and treatments in 2007.

Source of Variation	df	Size count	Total Yield	Yield Plant ⁻¹
		P>F	P>F	P>F
Block	3	0.4969	0.0319	0.0318
Treatment	6	0.0137	<.0001	<.0001
Error	18			
Corrected				
Total	27			

Table 4.9 Means of seed quality and yield measurements (Size, Total Yield, Yield Plant⁻¹) in response to different nutrient solutions and treatments in 2007.

Treatment	Size count	Total Yield (g)	Yield Plant ⁻¹ (g)
1. Std, Spray nothing	562.00 bc	711.25 a	17.79 a
2. Std – K, Spray nothing	545.75 c	760.00 a	19.00 a
3. Std – N, Spray Ammonium Nitrate	611.75 a	513.75 b	12.85 b
4. Std - N, Spray nothing	589.00 ab	562.50 b	14.07 b
5. Std - N + P, Spray Ammonium Nitrate	567.25 bc	510.00 b	12.75 b
6. Std - N + P, Spray nothing	591.25 ab	542.50 b	13.57 b
7. Std - N, Spray Calcium	566.75 bc	551.25 b	13.79 b
LSD (P=0.05)	34.10	82.89	2.07
CV	3.98	9.41	9.40

Means with the same letter are not significantly different.

Total yield and yield plant⁻¹ showed similar trends (**Table 4.9**). In contrast to 2006, *Sclerotinia* posed no major problems during 2007. Yield per plant ranged from 12.75 g (Solution 5, Std –N+P, Spray ammonium nitrate) to 19.00 g (Solution 2, Std - K, No spray). The two treatments which yielded most, namely solution 1 (Std, No Spray) and 2 (Std-K, No Spray) were not significantly different (**Table 4.9**). They however, yielded significantly more compared to all other treatments which did not differ significantly from each other. The composition of the highest yielding solutions differed only in that Std-K had more Ca, 12.0 mmol L⁻¹ compared to 8.5 mmol L⁻¹ in the Standard solution and less K, 3.5 mmol L⁻¹ compared to 7.0 mmol L⁻¹ in the Standard solution. All other elements in the two solutions were the same including the N content. The N content was higher in these two solutions than in all other solutions used during 2007. With regards to the higher Ca content in solution 2, Brennan *et al.* (2007) found large seed yield responses to applied Ca with two canola cultivars. Direct comparison is however not possible, because broccoli was used in this study.

The results show that the “new” nutrient solution (5 and 6 – Std-N+P) did not result in higher yields. Yields were also not enhanced by using foliar sprays containing ammonium nitrate and calcium metalosate. The two treatments that were sprayed with ammonium nitrate showed the lowest yields. It is possible that the spraying action may even have decreased the yield. As spraying started during the flowering (pollination) period, it might have negatively affected the bees or pollen, causing lower yields.

4.6.2 Seed quality

The ANOVA for treatments and the means of seed quality measurements for 2007 are presented in **Tables 4.10** and **4.12**. No significant differences between blocks or treatments occurred.

Table 4.10 Analysis of variance of seed quality measurements (Normal, Small, Abnormal) in response to different nutrient solutions and treatments in 2007.

Source of Variation	Df	Normal seeds	Small	Abnormal
		P>F	P>F	P>F
Block	3	0.2939	0.6981	0.2092
Treatment	6	0.4123	0.2070	0.8989
Error	18			
Corrected Total	27			

Table 4.11 Means of seed quality measurements (Normal, Small, Abnormal) in response to different nutrient solutions and treatments in 2007.

Treatment	Normal seeds (%)	Small (%)	Abnormal (%)
1. Std, Spray nothing	93.75	4.75	1.00
2. Std – K, Spray nothing	96.00	2.25	0.75
3. Std – N, Spray Ammonium Nitrate	95.75	2.50	1.00
4. Std - N, Spray nothing	94.50	4.75	0.75
5. Std - N + P, Spray Ammonium Nitrate	94.25	3.75	1.50
6. Std - N + P, Spray nothing	92.50	4.75	1.75
7. Std - N, Spray Calcium	95.00	3.25	1.00
LSD (P=0.05)	Ns	ns	Ns
CV	2.45	46.29	114.93

Table 4.12 Analysis of variance of seed quality measurements (Uni, KE, KK) in response to different nutrient solutions and treatments in 2007.

Source of Variation	Df	Uni	KE	KK
		P>F	P>F	P>F
Block	3	0.3068	0.2939	0.1290
Treatment	6	0.3259	0.4123	0.6002
Error	18			
Corrected				
Total	27			

Table 4.13 Means of seed quality measurements (Uni, KE, KK) in response to different nutrient solutions and treatments in 2007.

Treatment	Uni (%)	KE (%)	KK (%)
1. Std, Spray nothing	62.25	93.75	98.50
2. Std – K, Spray nothing	62.00	96.00	98.25
3. Std – N, Spray Ammonium Nitrate	66.75	95.75	98.25
4. Std - N, Spray nothing	60.00	94.50	99.25
5. Std - N + P, Spray Ammonium Nitrate	60.50	94.25	98.00
6. Std - N + P, Spray nothing	62.25	92.50	97.25
7. Std - N, Spray Calcium	60.25	95.00	98.25
LSD (P=0.05)	ns	ns	Ns
CV	6.65	2.45	1.38

Similar to 2006, no significant differences in seed quality measurements were found except for Size count. The quality measurement, mean size, indicating seed vigour, is given in **Table 4.9**. The results ranged from 545 units (Std-K, No Spray) to 611 units (Std-N, Spray Nitrate). The differences were significant ($P = 0.0137$). However the three best performers (Std-N, Spray Nitrate; Std-N+P, No Spray; Std-N, No Spray) did not differ significantly. All three these solutions contained high levels of S (11 mmol L^{-1} and 8 mmol L^{-1}). One other treatment containing a relatively high S level, number 5, Std-N+P, Spray Ammonium Nitrate, does not form part of this group. During 2006 the nutrient solutions containing the highest levels of S (Std-N, Std+S) also produced the highest size

(seed vigour) counts. The differences of 2006 were not significant. Though it is not irrevocably proved it appears that relative high S content in the nutrient solution assist in seed vigour (growth of the cotyledons).

Average normal seedlings ranged from 92.50% (Std-N+P, No Spray) to 96.0% (Std-K, No Spray). Average small seedling ranged from 2.25% (Std-K, No Spray) to 4.75% (Std, No Spray; Std-N, No Spray; Std-N+P, No Spray). Average abnormal seedlings ranged from 0.75% (Std-K, No Spray; Std-N, No Spray) to 1.75% (Std-N+P, No Spray). Average Uni (Uniformity) ranged from 60.0% (Std-N, No Spray) to 66.75% (Std-N, Spray Nitrate). Average KE (Kiem Energie, Germination Energy) ranged from 92.50% (Std-N+P, No Spray) to 96.00% (Std-K, No Spray). Average KK (Kiem Krag, Total Germination) ranged from 97.25% to 99.25%. KK was very uniform and at good levels. Levels were better than in 2006, but a different cultivar was used and there were seasonal differences as well.

Studying these seed quality results it is clear that results of 2007 were similar to that of 2006. With the exception of size, none of the nutrient solutions used during the two years influenced seed quality parameters significantly. Nor did any of the treatments incorporating foliar sprays with ammonium nitrate and calcium metalosate significantly influence the quality of the seed. The one nutrient solution of 2007 which was not tested during 2006, number 5 and 6 (Std-N+P) did not significantly influence any of the quality parameters except size as stated above. The most important quality measurement KK (Total germination) was not at all affected by die treatments. All nutrient solutions performed equally.

CONCLUSIONS

During 2006 and 2007 no significant seed quality differences were found (except size) in response to treatments. Only one seed quality measurement, size, indicating seed vigor showed significant differences in response to the treatments during 2007. Despite large variations in nutrient solution composition, seed quality measurements were at good levels. Plants were able to cope with the differences without negatively influencing seed quality.

During both 2006 and 2007 yield per plant responded significantly to the nutrient solution treatments indicating that nutrient solution composition is an important determining factor for seed yield. The two best performing solutions in terms of yield per plant during both 2006 and 2007 were the Standard solution and Std-K solution. Both these solutions had good results as well in terms of KK (Kiem Kracht- Total Germination), but were not significantly better. The composition of the two solutions differed only in that Std-K contained more Ca, (12.0 mmol L^{-1} compared to 8.5 mmol L^{-1}) and less K (3.5 mmol L^{-1} compared to 7.0 mmol L^{-1}) than the Standard solution. All other elements in the 2 solutions were the same. During 2007 these two solutions contained the same and highest concentration of N.

The foliar applications with Ammonium Nitrate and Calcium Metalosate during 2007 did not increase yield but appeared to have a negative influence on yield.

The results indicates that producing broccoli for seed in a bagged sand substrate with a drain to waste hydroponic system is possible and that the Standard solution (based on Steiner's universal solution) is capable of producing good quality broccoli seed at good yields. The Std-K solution is equally capable of this. No special adjustments need to be made to the Standard solution in order to increase seed yield or quality.

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CHAPTER 5

SUMMARY AND GENERAL CONCLUSIONS

The production of broccoli seed requires a much longer growth period when compared to producing broccoli for the fresh market. Information about the nutritional requirements of the plants over this much longer period is limited and no research on this subject has previously been done in production areas of the Olifants river valley of the Western Cape Province of the RSA. Little information is also available on the influence of nutrients, quantities and relations on the quality and yield of broccoli seed.

To determine the effect of nutrient treatments on the growth, nutrient assimilation, seed yield and quality of broccoli, trials were conducted in a net structure at Lutzville in the Olifants river valley during 2006 and 2007. Broccoli plants were grown in sand bags utilizing a drain to waste hydroponic system. During 2006 seven nutrient solutions were tested. The Standard solution was based on Steiner's universal solution and different levels of N, S, K and Ca were used in the experimental nutrient solutions. During 2007 the trial was continued and three of the 2006 solutions were used again including the Standard solution. Four new treatments were tested, including foliar sprays with Ammonium Nitrate and Calcium Metalosate. The influence of different nutrient solution treatments and foliar applications was investigated with regard to total biomass, nutrient element concentration, nutrient assimilation, seed quality and seed yield.

Biomass production, nutrient assimilation

The nutrient solution treatments of 2006 did not significantly affect the total biomass produced per plant (total dry weight). This occurred despite the relatively large differences in N concentration in nutrient solution treatments. On average, total dry weight increased by 225.4 % during the period of mature head to harvest of seed. This was surprising and illustrated that the plants need sufficient nutrition during all of the 8 months needed for seed production.

Nutrient concentration in plant samples were not influenced by treatments except where low levels of K and S in nutrient solutions led to significantly lower levels of K and S concentrations. Higher levels of N, S, K and Ca in nutrient solutions had no significant effect on concentrations in plant samples.

The mass of the different nutrient elements at the four growth stages indicated that from the mature head stage until harvest the plants assimilate relatively large quantities of elements. Sufficient nutrition during this period is therefore important. All major elements reached their maximum weight in the plants at harvest. At the planting density of 21 000 plants per hectare major elements assimilated per hectare by above ground biomass was: N 173.0 kg, P 35.5 kg, K 348.4 kg, Ca 114.7 kg, Mg 30.5 kg, S 42.2 kg.

All the treatments of 2006 were not repeated during 2007 but the standard solution (treatment) was the same and plant analysis of element concentration at different growth stages at different plant parts were done during 2006 and 2007. Results from plant analysis of the standard solution were compared. Similar

trends emerged during the two production seasons. As the plants developed towards maturity there was a relative increase in concentration in the top plant parts for Ca, Mg and S. This was most probably a normal occurrence of immobile elements. This was especially true for Ca. Contrary, N and P concentration declined. The minor elements, Fe, Mn and B also increased in concentration in the top plant parts at harvest indicating a strong relative flow of these elements to the top plant parts towards maturation. Element concentrations in the seed pods which were investigated during 2007 were in general higher than in the rest of the plant, indicating that the pods act as strong sink on the plants.

Seed quality and quantity

In spite of large variations in the composition of the nutrient solutions used in 2006 (high and low levels of N, K, S and Ca), no significant differences in terms of quality measurements for the seed produced were found. Although a new cultivar and four new treatments (including foliar sprays with Ammonium Nitrate and Calcium Metalosate) were tested during 2007 together with three of the 2006 treatments, only one seed quality measurement namely size which affected seed vigor, was affected. From the seed quality results of 2006 and 2007 it is therefore clear that none of the nutrient solutions or foliar spray treatments used influenced seed quality measurements significantly (with the exception of size as stated above). During both years broccoli plants displayed a wide tolerance towards nutrient solution composition as plants produced seed of high quality.

The yield per plant of 2006 and 2007 differed significantly in response to the nutrient solution treatments. Yield per plant was therefore more responsive to treatments than seed quality measurements. During 2006, highest yields were produced by plants receiving the Standard, Std-K, Std-N and Std+N solutions. The Standard solution produced the highest average yield namely 11.13 g per plant.

During 2007, plants receiving the Standard and Std-K solutions produced significantly higher yields than the other treatments. The highest yield of 19.0 g per plant was produced by plants receiving the Std-K solution. On average, in both years highest yield per plant were produced by plants receiving the Standard solution and Std-K solution. Both treatments also resulted in seed of a good quality as measured by KK (Kiem Kracht- Total Germination). The composition of the two nutrient solutions differed only in that Std-K contains more Ca, 12.0 mmol L⁻¹ compared to 8.5 mmol L⁻¹ in the Standard solution and less K, 3.5 mmol L⁻¹ compared to 7.0 mmol L⁻¹ in the Standard solution. All other elements in the solutions were the same. During 2007 the N content of these two solutions were the same and higher than the other five treatments.

The results indicate that producing broccoli for seed in a drain to waste hydroponic system in sand bags is feasible and that the Standard solution, published for the production of tomatoes by Combrink (2005), is capable of producing good quality broccoli seed with good yields. The relation of elements to each other need not be changed from the standard solution in order to enhance quality or yield of broccoli seed.

Addendum 1: Plant analysis – first samples, original data - 2006.

1St Samples: Buttoning	N	NO ₃ ⁻	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn	B	S
Sample	%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	Mg/kg	mg/kg	mg/kg	%
H1-1	3.04	0.01	1.01	10.62	1.56	0.27	2563	125.80	3.06	22.80	60.32	31.53	0.51
H1-2	2.94	0.01	1.10	12.76	1.27	0.29	2026	116.40	2.68	22.87	47.25	30.59	0.56
H1-3	3.06	0.01	1.95	14.28	1.80	0.30	3819	95.41	4.20	23.32	65.11	36.61	0.50
H1-4	3.11	0.01	1.10	9.30	1.83	0.30	4537	115.90	3.64	27.04	79.20	32.69	0.55
H1-5	2.43	0.01	1.09	9.97	1.49	0.21	2047	86.90	2.70	23.64	57.95	29.48	0.51
H1-6	2.82	0.01	1.15	11.80	1.55	0.28	973	89.74	3.24	24.14	56.36	30.68	0.64
H1-7	2.68	0.01	0.50	9.92	1.68	0.29	2934	73.36	2.42	19.29	52.24	29.09	0.41
H2-1	2.94	0.01	1.37	13.00	1.52	0.30	2181	91.20	3.08	25.87	99.99	34.23	0.59
H2-2	3.14	0.01	1.11	12.82	1.62	0.31	2850	82.94	2.89	24.65	59.28	31.01	0.60
H2-3	3.09	0.01	1.19	11.60	1.79	0.31	2999	84.15	3.76	27.40	72.34	33.81	0.50
H2-4	2.71	0.01	1.14	7.94	3.80	0.31	4209	83.65	2.66	21.07	48.11	30.36	0.48
H2-5	2.21	0.01	1.06	9.73	2.64	0.22	2251	83.97	3.58	24.95	60.53	30.31	0.48
H2-6	2.77	0.01	1.17	12.03	2.93	0.30	881	80.72	2.63	22.58	49.57	29.24	0.59
H2-7	3.79	0.01	1.30	13.89	3.73	0.37	4885	109.00	3.09	34.44	54.29	36.77	0.52
H3-1	3.38	0.01	1.13	11.79	3.80	0.37	3809	113.90	2.80	26.38	61.92	31.08	0.58
H3-2	2.94	0.01	1.19	12.45	2.94	0.30	3211	100.60	2.91	22.17	77.47	32.20	0.55
H3-3	3.17	0.01	1.31	11.83	3.83	0.34	2079	104.50	2.85	27.33	57.51	33.59	0.48
H3-4	2.99	0.01	0.98	2.98	3.29	0.30	5426	120.90	3.36	33.73	81.70	34.48	0.47
H3-5	3.12	0.01	1.09	10.54	3.29	0.32	4196	106.60	3.07	28.57	61.80	33.04	0.51
H3-6	3.96	0.01	1.33	13.24	3.74	0.45	4627	108.50	3.63	29.84	60.21	33.90	0.62
H3-7	3.10	0.01	0.58	11.57	3.62	0.30	3175	103.60	2.62	28.23	64.38	34.93	0.49
H4-1	3.16	0.01	0.52	10.97	3.80	0.36	3384	97.24	2.59	28.88	56.66	32.11	0.54
H4-2	3.16	0.07	0.57	12.73	3.01	0.34	2843	91.04	2.91	25.24	59.88	32.22	0.54
H4-3	3.69	0.01	0.53	11.90	3.45	0.39	4972	119.30	3.39	33.37	64.73	33.37	0.48
H4-4	3.11	0.01	0.56	9.57	4.18	0.35	5066	122.70	4.80	26.38	96.51	34.12	0.52
H4-5	3.53	0.01	0.56	12.02	3.87	0.47	5714	109.40	3.02	29.72	47.39	34.43	0.52
H4-6	2.54	0.01	0.50	11.23	3.23	0.32	1675	96.82	2.68	25.26	60.36	31.69	0.52
H4-7	3.15	0.01	0.52	10.66	3.57	0.39	3395	108.90	2.71	23.63	84.29	35.90	0.49
Average	2.49	0.01	0.99	11.18	2.82	0.32	3312	101	3.11	26.17	64.19	32.62	0.53

Source: Production Technology Laboratory, Department of Agriculture: WC, Private Bag x1, Elsenburg, 7607

Addendum 2: Plant analysis – second samples, original data - 2006.

2nd Sample: Mature Head	N	NO ₃ ⁻	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn	B	S
Sample	%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%
H1-1	3.25	0.01	1.72	6.99	1.18	0.39	4081	263.80	4.62	24.56	37.78	28.94	0.56
H1-2	3.33	0.01	0.85	5.64	1.10	0.33	2130	138.70	4.23	24.54	26.65	27.98	0.51
H1-3	2.97	0.01	0.62	5.98	0.97	0.37	3161	69.82	2.49	14.67	25.46	27.36	0.45
H1-4	2.91	0.01	0.59	4.73	0.94	0.34	2572	74.37	3.83	20.70	24.39	24.21	0.51
H1-5	2.64	0.01	0.66	6.32	1.04	0.35	2774	122.10	3.45	19.53	40.01	26.49	0.57
H1-6	3.28	0.01	0.64	6.50	1.13	0.38	2049	113.80	4.46	22.74	28.52	30.47	0.64
H1-7	2.76	0.01	0.55	5.40	0.84	0.31	2099	57.99	2.61	16.71	24.14	26.08	0.25
H2-1	3.18	0.01	0.75	6.21	1.10	0.38	3089	69.89	4.22	24.08	24.64	27.10	0.52
H2-2	3.00	0.01	0.66	6.02	0.94	0.35	1632	76.54	3.14	21.72	26.55	27.67	0.53
H2-3	3.23	0.01	0.70	6.05	1.02	0.38	4986	64.79	2.64	24.83	27.55	33.74	0.40
H2-4	2.74	0.01	0.58	4.83	1.14	0.31	3645	130.50	3.56	25.27	28.07	27.66	0.53
H2-5	2.95	0.01	0.64	5.31	1.04	0.29	1655	71.43	3.40	23.19	35.22	28.80	0.57
H2-6	3.06	0.01	0.69	5.17	1.05	0.33	2815	74.34	3.31	22.72	26.36	27.77	0.51
H2-7	3.37	0.01	0.65	4.83	1.31	0.33	3086	230.50	4.45	24.78	30.89	31.59	0.53
H3-1	3.28	0.01	0.67	5.40	1.01	0.35	2948	84.46	3.71	27.13	29.36	28.69	0.54
H3-2	2.97	0.01	0.58	5.13	1.13	0.39	2988	96.66	3.53	22.49	32.90	29.11	0.52
H3-3	3.48	0.01	0.69	5.54	1.34	0.43	5445	73.54	3.74	23.98	30.53	31.49	0.44
H3-4	3.06	0.01	0.81	5.82	1.17	0.41	5030	65.92	3.46	21.47	26.96	28.12	0.49
H3-5	3.32	0.01	1.10	8.27	1.14	0.37	5300	141.60	4.35	29.67	29.03	31.82	0.50
H3-6	3.11	0.01	0.60	4.87	1.34	0.38	3617	191.10	5.25	30.45	29.65	32.00	0.59
H3-7	3.17	0.01	0.67	5.88	1.29	0.48	3647	74.53	3.57	19.52	24.17	29.68	0.51
H4-1	3.46	0.01	1.02	7.55	1.23	0.37	4870	77.36	3.57	24.69	33.94	30.97	0.52
H4-2	3.65	0.01	0.65	5.41	1.22	0.36	2231	97.90	3.63	26.11	26.18	31.82	0.50
H4-3	3.61	0.01	0.70	5.61	1.54	0.44	4407	124.60	4.44	22.54	26.67	31.98	0.56
H4-4	3.16	0.01	0.84	6.31	1.16	0.35	3579	90.87	3.48	24.57	29.11	29.37	0.53
H4-5	3.54	0.01	0.84	6.45	1.14	0.36	2873	88.27	3.72	24.01	20.06	30.07	0.51
H4-6	3.22	0.01	0.58	5.05	1.05	0.36	2699	92.23	3.53	23.62	27.72	29.14	0.52
H4-7	3.35	0.01	0.59	5.70	1.34	0.46	3864	80.23	4.37	24.98	23.10	28.82	0.58
Average	3.01	0.01	0.74	5.82	1.14	0.37	3331	105	3.74	23.40	28.41	29.25	0.51

Source: Production Technology Laboratory, Department of Agriculture: WC, Private Bag x1, Elsenburg, 7607

Addendum 3: Plant analysis – third samples, original data - 2006.

3 rd Samples:Full Flower													
Sample	N	NO ₃ ⁻	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn	B	S
	%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%
H1-1 top	2.87	0.01	0.65	6.36	0.79	0.28	3757	366.30	3.30	14.37	27.11	26.23	0.55
H1-2 top	3.03	0.01	0.59	3.70	0.70	0.26	1232	220.20	3.68	17.51	22.88	29.26	0.59
H1-3 top	3.14	0.06	0.64	3.94	0.85	0.28	1223	78.04	3.84	14.56	22.63	26.94	0.42
H1-4 top	3.03	0.12	0.58	3.06	1.10	0.30	1913	1574.00	4.28	23.02	34.57	32.15	0.67
H1-5 top	2.60	0.03	0.66	3.40	0.82	0.27	2069	263.10	3.10	16.30	25.85	26.68	0.55
H1-6 top	2.85	0.01	0.58	3.60	0.77	0.25	814	396.50	3.40	22.30	24.22	28.28	0.54
H1-7 top	3.06	0.01	0.58	3.49	0.79	0.25	1318	1091.00	3.24	14.91	29.50	27.38	0.56
H1-1 bot.	1.73	0.03	0.37	3.79	0.57	0.27	1335	252.70	3.51	14.44	34.16	42.49	0.51
H1-2 bot.	1.87	0.06	0.42	5.34	1.90	0.46	3298	356.70	6.00	10.64	29.31	47.93	0.57
H1-3 bot.	2.34	0.11	0.39	5.43	1.95	0.48	2482	229.90	2.94	12.78	35.55	53.21	0.31
H1-4 bot.	2.00	0.02	0.45	2.73	1.88	0.41	5215	302.90	2.73	17.52	37.34	40.45	0.53
H1-5 bot.	1.63	0.01	0.47	6.20	1.75	0.32	917	172.00	2.54	14.18	37.02	42.41	0.54
H1-6 bot.	1.66	0.10	0.44	6.58	1.70	0.42	3462	332.10	3.37	16.50	30.31	42.57	0.57
H1-7 bot.	2.02	0.09	0.41	5.40	2.14	0.41	3949	170.20	3.30	14.04	47.69	45.25	0.44
H2-1 top	3.39	0.03	0.91	5.27	1.04	0.37	2523	632.10	4.67	27.32	27.61	27.38	0.54
H2-2 top	3.33	0.03	0.77	4.64	0.82	0.29	1522	312.80	4.30	22.65	25.22	26.45	0.58
H2-3 top	3.21	0.09	0.72	3.86	0.72	0.28	1961	434.60	3.34	21.32	26.95	26.98	0.54
H2-4 top	2.96	0.02	0.72	4.18	0.93	0.28	2086	440.90	3.31	22.53	23.60	27.20	0.60
H2-5 top	2.90	0.02	0.44	4.41	0.80	0.22	662	337.70	3.55	23.74	27.19	26.23	0.62
H2-6 top	2.44	0.01	0.45	4.32	0.65	0.20	805	605.10	3.59	20.81	29.70	25.71	0.58
H2-7 top	3.21	0.01	0.47	4.06	0.77	0.28	2956	510.40	3.60	19.90	25.15	26.11	0.55
H2-1 bot.	2.11	0.08	0.45	6.25	1.98	0.48	4288	389.00	4.19	14.23	27.56	36.92	0.51
H2-2 bot.	2.11	0.01	0.47	6.94	2.09	0.50	3546	399.80	3.42	12.43	25.09	42.88	0.56
H2-3 bot.	2.30	0.01	0.47	5.83	1.82	0.44	4814	1201.50	3.51	14.29	38.61	42.46	0.45
H2-4 bot.	1.80	0.01	0.45	4.87	2.41	0.44	4506	461.30	2.74	18.58	30.58	42.13	0.58
H2-5 bot.	1.71	0.08	0.61	7.23	1.85	0.32	1382	505.80	3.18	14.69	34.17	42.12	0.56
H2-6 bot.	1.40	0.06	0.44	5.75	1.42	0.29	1762	305.90	2.88	12.33	37.54	36.04	0.45
H2-7 bot.	2.15	0.04	0.45	5.55	1.83	0.44	4813	559.60	3.08	13.57	40.88	47.24	0.40
H3-1 top	3.26	0.09	0.52	4.30	0.70	0.27	2075	269.30	6.78	24.97	27.67	26.65	0.61
H3-2 top	3.23	0.01	0.73	6.42	0.66	0.27	2911	757.90	6.96	21.05	31.00	27.44	0.66
H3-3 top	3.63	0.01	0.77	5.87	0.85	0.31	2958	803.40	4.68	16.88	24.40	29.21	0.61
H3-4 top	3.50	0.10	0.74	5.55	0.84	0.28	3042	318.00	4.00	18.25	22.83	27.87	0.73
H3-5 top	2.68	0.02	0.63	6.72	0.83	0.28	814	502.50	3.65	19.46	24.89	25.05	0.57
H3-6 top	3.12	0.02	0.74	7.05	0.78	0.28	2209	551.70	4.65	19.13	27.23	27.12	0.57
H3-7 top	3.31	0.02	0.67	6.34	0.72	0.30	2467	393.80	3.28	14.24	24.41	24.66	0.60
H3-1 bot.	2.04	0.01	0.45	9.26	1.60	0.40	7270	256.80	3.54	7.31	25.28	42.40	0.58
H3-2 bot.	1.82	0.01	0.48	9.33	1.98	0.40	4840	262.40	3.32	6.75	34.01	44.64	0.54
H3-3 bot.	2.20	0.03	0.50	8.75	1.91	0.46	5818	297.40	3.82	7.50	24.30	43.17	0.49
H3-4 bot.	2.28	0.07	0.56	6.95	1.91	0.44	7848	207.70	3.47	7.74	36.03	44.45	0.55
H3-5 bot.	1.56	0.05	0.46	8.33	1.58	0.31	2027	388.80	2.92	14.43	36.24	41.55	0.53
H3-6 bot.	1.87	0.03	0.41	8.86	1.90	0.46	4944	1480.50	7.82	22.65	49.10	45.70	0.47
H3-7 bot.	2.11	0.01	0.46	8.26	1.52	0.45	4586	325.60	3.08	7.99	29.43	39.25	0.45
H4-1 top	3.23	0.04	0.51	5.68	0.98	0.27	2508	423.30	4.33	16.36	24.18	28.77	0.51
H4-2 top	3.57	0.01	0.47	5.92	0.83	0.27	3036	363.10	5.21	19.76	27.06	27.86	0.55
H4-3 top	3.67	0.01	0.52	4.68	0.87	0.25	2178	355.10	4.02	18.32	25.06	26.63	0.65
H4-4 top	3.18	0.01	0.48	4.66	0.89	0.25	2800	870.20	3.86	20.25	31.02	29.74	0.63
H4-5 top	3.45	0.01	0.57	5.74	0.85	0.28	2606	1111.00	4.91	28.15	35.12	30.19	0.51
H4-6 top	3.44	0.13	0.61	4.62	0.95	0.28	1221	73.15	3.70	20.16	25.25	26.89	0.58

H4-7 top	3.52	0.08	0.64	3.76	0.75	0.26	1717	288.60	3.56	16.66	23.27	24.24	0.53
H4-1 bot.	2.16	0.01	0.45	7.46	2.15	0.43	4251	323.50	4.71	10.10	22.17	42.63	0.53
H4-2 bot.	2.00	0.01	0.44	6.49	2.61	0.59	7858	372.40	4.34	7.63	24.97	43.23	0.48
H4-3 bot.	2.23	0.04	0.47	7.26	3.12	0.55	6182	349.70	3.89	11.11	36.04	51.55	0.48
H4-4 bot.	2.25	0.08	0.62	4.95	2.72	0.54	5806	281.40	3.67	11.99	38.60	53.42	0.51
H4-5 bot.	2.09	0.01	0.55	7.21	3.09	0.48	4535	2791.50	7.08	22.00	53.98	48.86	0.53
H4-6 bot.	2.03	0.01	0.45	5.54	1.57	0.43	3650	211.40	3.13	13.99	36.65	43.71	0.45
H4-7 bot.	2.29	0.01	0.45	5.79	2.62	0.61	8158	399.00	3.66	10.58	35.58	45.50	0.47

Source: Production Technology Laboratory, Department of Agriculture: WC, Private Bag x1, Elsenburg, 7607

Addendum 4: Plant analysis – fourth samples, original data - 2006.

4 th Sample:													
Harvest	N	NO ₃ ⁻	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn	B	S
Sample	%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%
H1-1 top	1.73	<0.01	0.35	5.75	1.33	0.37	1744	447.60	2.38	15.94	32.90	42.57	0.54
H1-2 top	2.21	<0.01	0.43	4.87	1.47	0.40	1438	158.90	2.33	18.70	32.27	45.18	0.70
H1-3 top	2.29	<0.01	0.51	4.10	2.37	0.53	2189	310.40	2.45	19.29	44.37	47.62	0.54
H1-4 top	2.75	<0.01	0.52	4.39	2.69	0.53	2302	279.30	2.75	26.72	49.65	48.19	0.82
H1-5 top	2.00	<0.01	0.52	5.22	1.80	0.43	1051	256.60	2.46	29.15	44.11	48.37	0.80
H1-6 top	2.99	<0.01	0.64	4.92	2.41	0.52	2654	318.90	2.93	33.01	52.38	57.68	0.80
H1-7 top	2.41	<0.01	0.39	5.10	1.34	0.47	2630	234.30	2.77	22.86	35.27	46.63	0.59
H1-1 bot.	2.43	<0.01	0.43	4.94	0.47	0.41	4894	48.25	2.20	13.42	11.23	14.57	0.32
H1-2 bot.	3.55	<0.01	0.62	5.90	0.47	0.44	3500	72.67	2.11	21.86	16.14	16.15	0.49
H1-3 bot.	3.29	<0.01	0.59	4.29	0.52	0.47	5035	57.52	2.15	25.20	14.40	14.18	0.39
H1-4 bot.	2.93	<0.01	0.59	6.10	0.72	0.42	7025	61.88	2.12	22.48	12.53	15.62	0.43
H1-5 bot.	2.98	<0.01	0.73	6.93	0.77	0.47	2990	60.06	2.36	33.45	16.93	17.74	0.53
H1-6 bot.	3.7	<0.01	0.77	6.32	0.80	0.50	5175	72.68	2.60	28.20	18.27	19.03	0.61
H1-7 bot.	2.75	<0.01	0.33	4.73	1.14	0.48	7510	40.11	1.83	10.07	10.09	14.30	0.39
H2-1 top	3.18	<0.01	0.62	4.76	2.64	0.52	2377	201.50	2.50	33.56	55.73	45.41	0.96
H2-2 top	3.04	<0.01	0.51	5.16	2.26	0.56	3409	319.40	2.54	26.33	41.46	39.49	0.88
H2-3 top	2.46	0.09	0.44	4.38	1.52	0.44	2858	259.70	3.03	24.21	37.47	49.47	0.53
H2-4 top	1.33	0.07	0.26	3.64	1.94	0.43	2589	221.90	2.14	12.46	33.86	44.80	0.54
H2-5 top	1.51	0.03	0.44	4.94	1.95	0.40	3195	172.20	3.74	20.07	34.83	40.10	0.53
H2-6 top	1.72	0.03	0.45	4.59	2.29	0.48	2231	296.10	2.17	15.90	47.41	41.64	0.67
H2-7 top	2.68	0.22	0.51	4.68	2.29	0.53	3873	433.90	2.61	24.89	46.05	45.23	0.69
H2-1 bot.	3.12	0.12	0.68	7.50	0.66	0.48	4280	110.50	2.42	30.68	19.04	16.59	0.46
H2-2 bot.	3.61	<0.01	0.66	8.86	0.68	0.48	8085	54.81	1.70	25.08	14.13	18.32	0.47
H2-3 bot.	2.89	0.09	0.47	6.13	0.48	0.44	7760	42.66	2.11	23.61	13.27	16.38	0.39
H2-4 bot.	2.65	<0.01	0.40	4.94	0.55	0.48	6950	116.20	2.00	11.58	10.67	15.10	0.40
H2-5 bot.	2.80	<0.01	0.58	7.53	0.57	0.52	8110	45.20	1.79	22.50	12.15	16.30	0.43
H2-6 bot.	3.76	<0.01	0.65	6.71	0.60	0.81	5270	55.60	2.73	21.14	11.16	15.14	0.45
H2-7 bot.	3.61	<0.01	0.55	7.60	0.63	0.46	8755	456.80	2.75	20.87	14.20	17.12	0.41
H3-1 top	2.45	<0.01	0.39	5.41	2.07	0.53	2617	338.10	2.18	16.86	41.50	38.86	0.66
H3-2 top	2.10	0.01	0.46	6.14	1.56	0.48	2080	227.20	2.22	26.22	36.63	46.04	0.67
H3-3 top	2.98	<0.01	0.55	4.79	1.53	0.44	3200	317.20	2.62	37.34	58.43	64.97	0.33
H3-4 top	2.90	<0.01	0.64	4.00	2.99	0.55	3850	513.00	2.85	28.81	54.91	55.62	0.81
H3-5 top	2.26	0.11	0.70	5.75	1.94	0.43	2450	372.40	3.23	33.15	44.94	53.21	0.78
H3-6 top	2.76	<0.01	0.78	7.60	2.24	0.47	3850	253.10	2.76	40.73	52.87	45.73	0.75
H3-7 top	2.76	<0.01	0.61	5.30	1.54	0.45	2450	233.50	2.41	17.04	34.74	44.92	0.63
H3-1 bot.	3.61	<0.01	0.48	7.05	0.63	0.44	9000	117.00	2.26	14.24	11.61	15.73	0.44
H3-2 bot.	3.38	<0.01	0.73	4.92	0.50	0.51	3700	62.16	2.42	31.14	17.23	17.74	0.51
H3-3 bot.	2.90	<0.01	0.66	4.84	0.60	0.42	6500	43.59	1.78	30.09	20.19	18.33	0.22
H3-4 bot.	3.98	<0.01	0.73	6.75	0.89	0.57	13020	53.84	2.24	23.29	10.13	18.57	0.46
H3-5 bot.	3.64	<0.01	0.75	8.00	0.80	0.42	7500	55.12	3.10	31.04	12.65	15.56	0.45
H3-6 bot.	3.28	<0.01	0.60	7.85	0.64	0.52	8500	37.71	1.85	27.11	14.26	18.85	0.42
H3-7 bot.	3.46	<0.01	0.53	8.10	0.60	0.54	10220	38.97	1.58	13.96	10.38	17.94	0.44
H4-1 top	2.99	<0.01	0.75	5.55	2.81	0.50	1607	405.70	2.90	37.55	75.13	68.06	1.00
H4-2 top	3.15	<0.01	0.65	6.40	1.69	0.50	2400	221.90	2.33	27.33	41.22	48.01	0.90
H4-3 top	2.53	<0.01	0.66	6.15	2.27	0.53	4200	283.00	2.19	19.57	40.29	52.53	0.57
H4-4 top	2.42	<0.01	0.69	5.40	3.06	0.48	4050	315.90	2.40	18.95	44.61	45.12	0.76
H4-5 top	2.41	<0.01	0.59	6.35	2.38	0.45	3100	350.50	2.45	32.57	47.64	43.83	0.79
H4-6 top	2.56	<0.01	0.52	5.40	1.90	0.41	1524	266.20	3.40	28.21	41.05	59.05	0.79

H4-7 top	3.39	<0.01	0.63	5.35	1.88	0.45	3650	368.60	3.33	29.59	40.40	45.47	0.74
H4-1 bot.	4.01	<0.01	0.78	5.85	0.52	0.42	4400	137.10	2.47	31.86	20.72	17.46	0.50
H4-2 bot.	3.95	<0.01	0.66	7.00	0.56	0.49	4700	50.07	1.43	26.98	14.92	17.31	0.49
H4-3 bot.	3.75	<0.01	0.66	6.70	0.57	0.44	9000	58.64	2.02	20.53	11.72	17.69	0.36
H4-4 bot.	4.17	<0.01	0.71	6.45	0.78	0.58	6500	112.50	3.12	22.16	13.14	17.32	0.64
H4-5 bot.	2.97	<0.01	0.56	7.50	0.59	0.48	6500	52.11	1.70	22.61	9.95	17.69	0.41
H4-6 bot.	3.41	0.01	0.55	5.40	0.41	0.36	4350	148.70	2.44	116.80	15.99	15.43	0.41
H4-7 bot.	3.25	<0.01	0.54	6.75	0.46	0.38	9500	50.98	2.09	18.15	9.41	15.76	0.39

Source: Production Technology Laboratory, Department of Agriculture: WC, Private Bag x1, Elsenburg, 7607

Addendum 5: Plant analysis – first samples (full flower), original data - 2007

Sample Description	N	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn	B	Al	S
	(%)	(%)	(%)	(%)	(%)	(mg/kg)	(mg/kg)	(cmol/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(%)
1 Top	3.15	0.54	3.78	1.4	0.36	1700	56.2	2.05	21.98	25.35	21.4	21	0.61
2 Top	2.69	0.49	3.92	1.27	0.32	2650	57.93	2.03	19.46	28.68	21.6	21	0.6
3 Top	2.17	0.54	3.84	0.64	0.2	920	70.13	1.89	23.75	34.24	25.1	47	0.44
4 Top	2.51	0.53	3.77	0.75	0.23	1000	51.59	1.99	21.16	39.1	24	18	0.5
5 Bottom	2.28	0.33	5.55	3.96	0.6	4200	133.6	3.69	21.01	106.3	49	120	0.96
6 Bottom	2.44	0.29	6.75	5.26	0.87	7000	98.34	1.59	13.74	177.4	62.5	83	1.1
7 Bottom	1.76	0.32	5.9	3.31	0.47	4100	135.2	4.08	18.01	120.3	72.6	130	0.84
8 Bottom	1.9	0.34	6.25	3.25	0.47	3650	152.5	12.7	24.94	129.2	56.2	150	0.86

Source: Production Technology Laboratory, Department of Agriculture: WC, Private Bag x1, Elsenburg, 7607

Addendum 6: Plant analysis – second samples (green pod), original data – 2007

Sample Description	N	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn	B	Al	S
	(%)	(%)	(%)	(%)	(%)	(mg/kg)	(mg/kg)	(cmol/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(%)
1 Top	1.98	0.52	3.62	1.19	0.28	1300	115	2.32	21.9	44.3	35.8	31	0.61
2 Top	2.21	0.54	3.81	1.26	0.32	1600	120	2.67	26.6	42.1	38.4	41.8	0.65
3 Top	2.06	0.53	3.55	0.79	0.24	1200	88.1	2.42	27.9	52.7	36.3	35.3	0.52
4 Top	2.01	0.55	3.42	0.79	0.25	1300	182	2.8	28.4	43.3	35.6	56.4	0.53
5 Bottom	1.48	0.35	5.35	2.51	0.39	2950	180	2.73	14.4	79	50.8	115	0.93
6 Bottom	1.64	0.37	6.1	2.68	0.42	4600	161	3.15	19.4	85.9	53.1	126	0.87
7 Bottom	1.73	0.36	5.85	2.49	0.36	3550	109	3.48	23.8	107	58.8	74.3	0.66
8 Bottom	1.65	0.42	5.45	2.25	0.39	3550	136	8.15	20.9	73.9	57.9	103	0.73
9 Pods	2.42	0.54	1.52	1.85	0.41	460	422	5.06	67.6	63.4	41.2	61.4	0.68
10 Pods	2.72	0.55	1.79	2.2	0.45	600	654	5.2	47	67	42	86	0.75
11 Pods	2.3	0.51	1.45	1.69	0.45	500	490.25	5.96	49.69	58.36	39.89	77.37	0.65
12 Pods	2.15	0.55	1.45	2.28	0.47	560	1140	7.12	52	68.6	38.8	228	0.7

Source: Production Technology Laboratory, Department of Agriculture: WC, Private Bag x1, Elsenburg, 7607

Addendum 7: Plant analysis – third samples (harvest), original data - 2007

Sample Description	N	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn	B	Al	S
	(%)	(%)	(%)	(%)	(%)	(mg/kg)	(mg/kg)	(cmol/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(%)
1 Top	1.03	0.43	4.13	1.46	0.35	3150	127	2.34	20.5	38.6	55	118	0.53
2 Top	1.73	0.46	3.39	2.64	0.44	2250	224	2.29	36.1	85.4	46	186	0.8
3 Top	1.27	0.39	3.82	1.5	0.35	2900	163	2.61	23.7	54.7	54.1	144	0.56
4 Top	1.3	0.41	3.79	1.57	0.34	2350	194	2.4	20	36.9	53.6	192	0.53
5 Bottom	1.27	0.41	3.88	0.55	0.32	3500	57.9	2.18	21.5	13.7	19.1	65.9	0.36
6 Bottom	1.82	0.49	4.72	0.6	0.4	4500	43.2	2.5	17.6	15.7	17.4	45.9	0.44
7 Bottom	1.84	0.5	4.05	0.57	0.33	3650	168	2.29	29.6	21.7	21.7	148	0.46
8 Bottom	1.39	0.4	4.2	0.5	0.32	3850	32.8	3.58	16.9	11.3	17.4	38.7	0.35
9 Pods	1.86	0.5	1.94	2.31	0.42	1037	246.05	3.11	166.25	74.61	54.4	95.63	0.63
10 Pods	1.66	0.47	1.64	2.55	0.49	904	199.5	3.38	49.61	64.77	50.41	94.56	0.75
11 Pods	1.96	0.46	2.06	2.02	0.38	2660	340.48	4.15	95.76	58.65	48.15	80.07	0.55
12 Pods	1.72	0.45	1.6	2.43	0.47	718	187.53	2.65	37.11	59.72	48.01	70.76	0.8

Source: Production Technology Laboratory, Department of Agriculture: WC, Private Bag x1, Elsenburg, 7607

Addendum 8: Results of seed yield measurements - 2006

4 Rep. / Nutrient Mix	Nutrient Mix	Total Yield (g)	Number of plants harvested	Average 4 Rep, Seed (g)/plant
	1			
1.1	Standard (Std)	70	8	8.8
1.2		107	8	13.4
1.3		101	8	12.6
1.4		146	15	9.7
	Total	424.0	39.0	
	2			
2.1	Std+K	9	2	4.5
2.2		24	4	6.0
2.3		95	12	7.9
2.4		191	23	8.3
	Total	319.0	41.0	
	3			
3.1	Std+N	32	3	10.7
3.2		17	3	5.7
3.3		57	6	9.5
3.4		161	20	8.1
	Total	267.0	32.0	
	4			
4.1	Std-K	71	9	7.9
4.2		25	2	12.5
4.3		137	14	9.8
4.4		48	11	4.4
	Total	281.0	36.0	
	5			
5.1	Std-N	50	6	8.3
5.2		117	11	10.6
5.3		113	14	8.1
5.4		235	27	8.7
	Total	515.0	58.0	
	6			
6.1	Std+S	27	6	4.5
6.2		32	6	5.3
6.3		66	8	8.3
6.4		219	29	7.6
	Total	344.0	49.0	
	7			
7.1	Std-S	39	5	7.8
7.2		74	9	8.2
7.3		92	11	8.4
7.4		189	26	7.3
	Total	394.0	51.0	

Source: Syngenta Seed B.V., Westeinde 62, P.O. Box 2, 1600 AA Enkhuizen, The Netherlands

Addendum 9: Results of seed quality measurements - 2006

4								
Repetitions	Nutrient	Normal	Small	Ab-	Size	Uni	KE	KK
/ Mix	Mix	seeds		normal				
1.1	1 Standard	94	1	1	440	61	94	95
1.2		89	7	1	421	53	89	96
1.3		100	0	0	452	64	100	100
1.4		87	5	2	437	64	87	92
Average								
2.1	2 Std+K	95	3	1	427	52	95	98
2.2		98	0	1	490	64	98	98
2.3		91	4	1	447	65	91	95
2.4		82	2	3	432	55	82	84
Average								
3.1	3 Std+N	91	2	1	400	61	91	93
3.2		96	1	1	454	60	96	97
3.3		94	1	1	446	65	94	95
3.4		83	4	1	444	53	83	87
Average								
4.1	4 Std-K	92	2	1	430	60	92	94
4.2		92	2	1	474	56	92	94
4.3		96	1	1	455	59	96	97
4.4		93	3	1	429	57	93	96
Average								
5.1	5 Std-N	93	4	0	450	61	93	97
5.2		90	3	3	458	60	90	93
5.3		91	5	3	458	62	91	96
5.4		80	5	2	467	52	80	85
Average								
6.1	6 Std+S	95	1	1	442	65	95	96
6.2		92	3	0	454	59	92	95
6.3		94	2	0	444	61	94	96
6.4		92	0	1	476	57	92	92
Average								
7.1	7 Std-S	96	3	0	426	58	96	99
7.2		88	6	1	461	60	88	94
7.3		93	3	0	467	64	93	96
7.4		89	2	2	410	53	89	91

Source: Syngenta Seed B.V., Westeinde 62, P.O. Box 2, 1600 AA Enkhuizen, The Netherlands

Addendum 10: Results of seed quality and yield measurements - 2007

4 Repetitions / Mix	Nutrient Mix	Normal seeds	Small	Ab- normal	size	uni	KE	KK	Total Yield (g)	Average 4 Rep, Seed Yield (g)/plant
1.1	1 Standard	94	5	1	535	65	94	99	680	17.0
1.2	No spray	98	2	0	580	66	98	100	615	15.4
1.3		93	5	1	554	63	93	98	735	18.4
1.4		90	7	2	579	55	90	97	815	20.4
2845										
2.1	2 Std-K	96	3	0	514	62	96	99	660	16.5
2.2	No spray	98	2	0	540	65	98	100	795	19.9
2.3		95	3	1	562	59	95	98	880	22.0
2.4		95	1	2	567	62	95	96	705	17.6
3040										
3.1	3 Std-N	98	1	0	578	62	98	99	470	11.8
3.2	Spray	93	6	0	621	66	93	99	505	12.6
3.3	Ammonium	97	2	0	626	64	97	99	555	13.9
3.4	Nitrate	95	1	4	622	75	95	96	525	13.1
2055										
4.1	4 Std-N	93	6	1	604	57	93	99	535	13.4
4.2	No spray	97	3	0	608	61	97	100	560	14.0
4.3		94	5	1	556	59	94	99	630	15.8
4.4		94	5	1	588	63	94	99	525	13.1
2250										
5.1	5 Std-N+P	99	1	0	587	64	99	100	530	13.3
5.2	Spray	94	4	1	591	65	94	98	455	11.4
5.3	Ammonium	93	4	3	550	58	93	97	465	11.6
5.4	Nitrate	91	6	2	541	55	91	97	590	14.8
2040										
6.1	6 Std-N+P	94	4	0	571	64	94	98	525	13.1
6.2	No spray	90	5	4	606	62	90	95	460	11.5
6.3		94	6	0	608	63	94	100	600	15.0
6.4		92	4	3	580	60	92	96	585	14.6
2170										
7.1	7 Std-N	94	3	2	566	65	94	97	525	13.1
7.2	Spray	97	2	1	538	63	97	99	505	12.6
7.3	Calcium	93	5	1	591	53	93	98	585	14.6
7.4		96	3	0	572	60	96	99	590	14.8
2205										

Source: Syngenta Seed B.V., Westeinde 62, P.O. Box 2, 1600 AA Enkhuizen, The Netherlands