THE EFFECT OF NITROGEN ON THE YIELD AND QUALITY OF VEGETABLE AMARANTH (*Amaranthus spp.*)

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ABSTRACT

The effect of nitrogen on the yield and quality of three species of vegetable amaranth, namely; *Amaranthus hypochondriacus, A.tricolor* and *A.hybridus* was studied under field conditions for three different planting times during the planting season of 1996/97. In the first experiment seven different nitrogen levels viz. 0. 25, 50, 75, 100, 125 and 150 kg N ha^{-1} were evaluated and only yield data was taken. The last two experiments saw an addition of two more treatments viz. 175 and 200 kg N ha^{-1} bringing the total number of treatments to nine. Data collected in the last experiment consisted of yield data (fresh and dry matter) and quality (nutritional composition and total nitrogen content). Nitrogen fertilizer was found to significantly increase the yield of vegetable amaranth, with all three species showing varietal/genotypic differences in the response to nitrogen fertilizer. The yields declined with delay in planting time and with the last planting lower yields were obtained. Nutritional composition, although not analysed in its entirety, showed vegetable amaranth to compare favourably with other leafy vegetables. Total nitrogen content increased with levels of nitrogen application. Unlike yields, nitrogen content increased with delay in planting date with the autumn crop having a higher nitrogen content than the spring and summer plantings. Varietal/genotypic difference was also confirmed with *A. tricolor* accumulating more nitrogen than the other species. Plant age was also found to play an important role with younger plants containing more nitrogen than older ones.

Key words: *Amaranthus*, Vegetable, Nitrogen, Fertilizer, Yield, Quality, Nutrition

CHAPTER 1

GENERAL INTRODUCTION

1.1. Introduction

Glass (1989) wrote that the total world population of approximately 5.0×10^9 people, depends upon plant productivity for their sustenance. Despite major technological advances throughout the agricultural field, mankind still live in a world which faces increased hunger and malnutrition (Lees, 1983). The problem of feeding people is further exacerbated by the high rate of population growth, which places great pressure on limited resources, such as land on which food must be produced.

Many scientist believe that to improve matters, crops which have been largely ignored by modem day farmers must be exploited (Lees, 1983). Amaranth has been identified as one of the plants with the potential to broaden man's food base. Its attractiveness as a future crop stems from its extremely broad climatic adaptability, a rich germplasm resource with genetic variability exceeding that of most commercial crops, high protein quality in its grain, good grain yield potential and its widespread use in Asia as a cooked leafy vegetable (National Academy of Science, 1975 in Feine *et al.,* 1979). When used as a potherb, amaranthus supplies a substantial portion of the protein, minerals, and vitamins required in the diet (Feine *et al.,* 1979). Amaranth, a member of Amaranthaceae family, has numerous species and varieties, some of which have been designated as species or subspecies (Tindall, 1983). It is one of the oldest crops (about 8 000 years old), an attribute that probably gives it the ability to adapt to new and varied environments. It falls in a group of rare fast growing plants with ultra efficient photosynthetic pathways known as C4 plants, which use less than two thirds of the moisture required by C3 plants (Feine *et al.*, 1979; Lees, 1983; Tindall, 1983). As large areas of Southern Africa are classified as arid to semi-arid, it is possible that the potential of this crop can be beneficially realised under these marginal conditions.

As mentioned earlier, land on which to produce food gets fewer with every passing day and as the population increases, so the need for increased output per unit area increases. Many major crop plants have a far greater genetic yield potential than is realised through current production practices, but it is only possible to obtain such yield potential under the most optimal of growing conditions (Stanford & Legg, 1984). Therefore, the way forward is to optimise those factors of crop production which man can control, and amongst them is the supply of plant nutrients, particularly nitrogen. Deckard *et al.* (1984) stated that nitrogen fertilizer has, and still is being used increasingly to supplement soil nitrogen for producing the needed quantity of food and fiber for an increasing world population. Unfortunately it has not always been associated with improved quality. Nitrates, which lead to nitrite (toxic to humans), have been reported to accumulate in plants grown under conditions of excessive nitrogen nutrition (Deckard *et al.*, 1984).

1.2 Motivation and Objectives

A review of the available literature has revealed that increased nitrogen application has a positive effect on the yield of vegetable amaranth, but it also has a limit above which no significant benefit can be realised from continued addition of fertilizer. On the other hand, increased nitrogen application has both negative and positive effects on the quality of the product. Much of this literature referred to is from countries or regions with different climatic conditions from those commonly found in Southern Africa. Little research has been done on improving productivity of this crop to suit local conditions. The need to collect more relevant data on the effect of nitrogen has justified the research reported in this study.

The objectives were therefore to investigate the following:

1. The effect of different nitrogen levels on the yield .
2. The optimal nitrogen rates for the various planting dates.
3. The effect of different planting dates on the nitrogen utilisation of the crop.

4. The extent to which those optimal rates influence quality (nutritional or internal quality attributes) of vegetable amaranth.

CHAPTER 2
LITERATURE REVIEW

2.1 EFFECT OF NITROGEN ON THE YIELD OF VEGETABLE AMARANTH

2.1.1 Introduction

Nitrogen is one of the sixteen essential elements and one that participates directly as an indispensable requirement for the normal plant life cycle (Glass 1989). Nitrogen deficiency usually has an overriding control of growth and dominates the effect of other elements. Many studies of plant elemental composition with various plants show nitrogen as one of the elements found in high amounts which are termed macro or major elements. Schrader (1984) states that a requirement for nitrogen exists throughout the development of a plant to maintain growth, as nitrogen is a constituent of both structural (e.g. cell walls) and non-structural (e.g. enzymes, chlorophyll and nucleic acids) components of the cell.

2.1.2 Effect of Nitrogen on Growth and Yield

Stanford & Legg (1984) affirmed that the most critical element in promoting extremely high yields, is supplying nutrients especially nitrogen, in sequence with crop demand without creating toxic conditions and affecting quality of the harvestable product. Crops that are harvested before maturity such as forage grasses require high amounts of nitrogen (25 to 30 g N kg^{-1} of dry matter) (Stanford & Legg, 1984) in contrast to mature crops. Vegetative growth consists mainly of growth and formation of leaves, stems and roots; meristematic tissues responsible for these organs have a very active protein metabolism hence photosynthates transported to these sites are used predominantly in the synthesis of nucleic acids and proteins (Mengel & Kirkby, 1987). Therefore, during the vegetative growth stage, the nitrogen nutrition of the plant controls the growth rate of the plant to a large extent (Mengel & Kirkby,1987). This requirement justifies the adequate supply of nitrogen to leafy vegetables such as vegetables amaranth to maintain and ensure a high rate of growth. Under conditions of low nitrogen supply, plants accumulate more carbohydrates and have low protein content; such plants have a shortened life cycle (mature early) and the resulting economic yield is generally poor (Mengel & Kirkby,1987). Fucks & Grossman (1972) in Bergmann (1992) stated that conclusions regarding the effect of nutritive conditions should always be considered critically because it cannot only be assumed that the "optimal" use of fertilizer in terms of economic yield is necessarily also the best from phytopathological point of view. This is attributed to the fact that disease resistance is normally compromised by the increased supply of nutrients particularly if the optimum for plant growth has been exceeded. It is however also acknowledged that in some instances (depending on the disease causing organism) improved nutritional status can either enhance or compromise disease/pest resistance. Amongst the mineral elements, nitrogen is said to have the greatest influence on plant disease resistance. Excessive nitrogen application relative to other elements, increases plant susceptibility to disease almost without exception (Bergman,1992). This is an important factor to be investigated further, but does not fall within the scope of this investigation. Vegetable amaranth as a leafy crop is expected to follow a similar trend in the utilisation of nitrogen.

Increase in forage yield of grain amaranth has been reported by Elbehri *et al.* (1993). Forage yield is reported to have increased linearly with nitrogen rates and reached a plateau at 245, 255, and 265 kg of soil nitrogen per hectare. However, Oji & Ugherughe (1992) found conflicting results in the dry matter yield of millet which was observed to decrease with increased fertilizer application. The decrease in the dry matter yield of millet was attributable to the succulence of the fresh plant material because of less carbohydrate accumulation and more protein synthesis (hence more protoplasm). Leafy vegetables that have similar affinity to nitrogen because of the vegetative volume to be produced have shown positive response to increased nitrogen levels. In a study with Chinese cabbage (*Brassica campestris*), Vavrina & Obreza (1993) recorded a 14.2 % increase in head fresh mass when the nitrogen level was raised from 67 to 112 kg N ha^{-1}.

Spinach (*Spinacia oleracea*), an exotic leafy vegetable closest to vegetable amaranth in taste and quality, responded positively to increased doses of nitrogen (Markovic, Lazic & Djurovka, 1987; Foy & Campbell, 1994; Thompson & Doerge, 1995). No significant differences were observed between yields of spinach fertilized with 150 and 200 kg N ha^{-1} (Markovic & *et al.*, 1987). This observation might indicate that although nitrogen is needed in high amounts, threshold levels exist beyond which no benefit will be realised from continued addition of more fertilizer. Because of the similarity between spinach and vegetable amaranth, early researchers used spinach fertilization rates to study fertilization requirements of amaranth. Several investigations have recorded a strong positive yield response to increased rates of nitrogen fertilizer by vegetable amaranth. Total yields and leaf area are reported to have increased significantly up to a nitrogen application rate of 134 kg N ha^{-1} when five levels of nitrogen (0, 67, 134, 202 & 269 kg N ha^{-1}) were compared (Makus, 1986b). Whitehead & Singh (1994) confirmed the benefits of addition of higher nitrogen rates on vegetable amaranth when they experimented with four levels viz., 0, 45, 90 and 135 kg N ha^{-1}. Yield data from two seasons showed a significant regression for treatments. An optimal level was however, reached at 90 kg N ha^{-1}, which indicates a clear deviation from an optimal level of 134 kg N ha^{-1} previously reported by Makus (1986b). The difference could be due to various factors that were prevailing at and during each experiment

2.1.3 Factors influencing Nitrogen utilisation

The influence of nitrogen on crop growth and yield does not manifest itself in total isolation from other important plant growth factors. Improving conditions for growth by alternating one growth factor can be without effect if another growth factor is limiting (Mengel & Kirkby, 1987). Several factors interact with nitrogen to produce certain results such as increased growth, yield, reproduction, or even the death of a plant itself. Nitrogen on its own cannot start the life of a plant or even sustain it. Some of the factors influencing nitrogen utilization are reviewed below.

2.1.3.1 Soil Texture

The relative proportion of sand, silt and clay found in the soil determines soil texture. In mineral soils, the exchange capacity (ability to hold plant nutrient elements) is related closely to the amount and kind of clay in the soil (Western Fertilizer Handbook, 1985). Cooke (1982) asserted that sandy soils contain little clay and are intrinsically poorer in all nutrient cations, often in micro nutrients too while clays usually have larger reserves of cations in clay fractions. These clay fractions held cations can be released for use by plants and they usually contain more nitrogen. The rate of water percolation also depends on volumetric water content (water holding capacity of soil material) of the soil through which the water percolates and can range from tremendously high for freely drained soils such as sandy soil which have low volumetric water content, to low values in clayey soil material of high volumetric water contents (Pratt, 1984). This percolating water normally carries a lot of cations with it and can have severe consequenses in sandy soils because of their inherently poor cation exchange capacity. Data collected from 25 sites in the USA indicated up to 57% loss of nitrogen through leaching (Pratt, 1984). These high amounts of nitrogen leached, went to waste and never translated into crop yield, and worst of all, it might have ended up contaminating underground water resources. Therefore, various soils supplied with the same amount of fertilizer will produce different yield results due to their differing textures.

2.1.3.2 Soil pH

Soil pH is of paramount importance to plant growth because it influences nutrient availability, solubility of toxic substances, soil microbe activity and the functioning of root cells (which affect the uptake of nutrients and water) (Western Fertilizer handbook, 1985). The pH tolerance limits of different plants vary greatly, but for most commercial crops a neutral range is most suitable, with pH values of soil in water suspension between about 6.3 and 7.5 (Landon, 1991). However, many references give a pH range of 6 to 7.5 as one that gives maximum availability of primary nutrients (nitrogen, phosphorus and potassium, (NPK)) and other essential nutrient elements. In strongly acidic soil, where nitrification is inhibited, ammonium (NH_4^+) may be an important source of nitrogen for plants; however rhizosphere acidification may strongly impair the acquisition of some nutrients (e.g. molybdenum and magnesium) and furthermore may increase the risk of aluminium toxicity (Marschner, 1991). Bernardo *et al.* (1984) reported severe iron deficiency on sorghum (*Sorghum bicolor*) when the growing solution pH reached, and remained above 7. Singh & Whitehead (1992) found yield of vegetable amaranth to increase significantly when pH was raised within the range of 4.7, 5.3 and 6.4. pH values of 4.7 and 5.3 had a comparatively severe detrimental effect on the crop yield whilst a pH of 6.4 was observed to be most favourable.

2.1.3.3 Salinity and Sodicity

Plaster (1992) describes saline and sodic soils by their high levels of soluble salts, pH above 8.5 and inherent poor soil structure. Plant water uptake is reported as being difficult because of a more negative water potential (less water available to plants) due to salts dissolved in the water. High salt concentration in the soil water reduce or even reverse the flow of water into plants by osmosis (Booker Tropical Soil Manual, 1991). In these cases, plants sometimes take up enough of these salts to enable them to build up to levels that may become injurious to plant tissue (Plaster, 1992). Nitrogen uptake might become affected because of unavailability of water, or the effect of salt on root tissues might interfer with water uptake, resulting in poor plant growth and ultimately reduce economic yield. Makus (1989) investigated the effect of soil salinity and nitrogen fertility on vegetable amaranth and observed a reduction in stand, yield, height, leaf area and leaf pigments in soil with 3.11 ds. m^{-1} EC. Addition of more nitrogen resulted in increased leaf area and pigments but reduced plant stand and increased residual soil test ammonium, nitrate, potassium, iron and manganese. Saline conditions would therefore, result in plants being unable to utilise the nitrogen supplied as well as the other essential elements.

2.1.3.4 Soil Moisture/Water

Water is a solvent of many substances such as inorganic salts, sugars and organic anions. The amount of nutrients reaching the root is dependent on the rate of water flow or the water consumption of the plant and the average nutrient concentration of the water (Mengel & Kirkby, 1987). Without water, plants cannot utilise the nutrients supplied by the soil. Leaf expansion is particularly sensitive to water stress and vegetable crops in which the useful portion consists mainly of the product of vegetative growth are generally irrigated (Carr, 1981). The amount of nitrate that leaches from the soil depends on the amount of water that moves through the soil column and the amount of nitrate present in the soil when the water drains through and out of the soil profile (Pratt, 1984). Therefore, irrigation may not necessarily be beneficial if it results in leaching of essential nutrients such as N.

Crop production in arid regions is sensitive to deficiencies in the soil moisture and plant nutrition, especially nitrogen (Pier & Doerge, 1995; Thompson & Doerge, 1996). Improved management practices can ensure a reduction in production costs such as the use of fertilizers and irrigation, as well the risk of ground water pollution due to inefficient utilisation of nitrogen and water. Excessive irrigation resulted in lower yields, low nitrogen uptake and higher unutilized nitrogen fertilizer in an experiment conducted with collard (*Brassica oleracea,* Group Acephala), mustard (*Brassica juncea*) and spinach (*Spinacia oleracea*) in a sandy loam soil (Thompson & Doerge, 1995). Optimum soil water tension associated with high yields were identified as 8 kPa for spinach, 9 kPa for collard and 6 to 10 kPa for mustard. Soil water tension below 5.6 kPa was found to be the most excessive because it resulted in lower yield and more unutilized nitrogen. High soil water tension (7kPa) on a fine loamy sand soil gave better yields of watermelon (*Citrullus lanutas*) and favoured efficient use of nitrogen (Pier & Doerge, 1995). Thompson & Doerge (1995) reported the need for greater amounts of nitrogen under excessive moisture conditions in order to reach optimal yields of lettuce. Rainfall, whether excessive or limited would also impact negatively on nitrogen utilisation by plants.

Vegetable amaranth, as a C4 plant, is expected to require less than two thirds of moisture absorbed by C3 plants such as spinach. Singh & Whitehead, (1992) recorded high yields of vegetable amaranth under 6% moisture content when compared with moisture contents of 4, 12 and 18% in a sandy loam soil. Moisture stress had a greater adverse effect on leaf area than leaf number which might give an explanation for the small leaf size encountered on most indigenous weedy amaranthus species. It might therefore be possible to increase the yield of vegetable amaranth by increasing leaf size through adequate water supply coupled with nutrient supplementation.

2.1.3.5 Temperature

Plant growth is sensitive to temperature. Every species or variety has a minimum and maximum temperature beyond which it will not grow and an optimum temperature at which it grows at a maximum rate (Salisbury & Ross, 1986). Under cool conditions, which are not conducive to a rapid rate of decomposition and nitrification of organic matter, more nitrogen fertilizer is needed than under warm conditions (Ignatieff & Page, 1958). Soil temperature, particularly low temperature have been shown to significantly reduce the plant dry mass of soybean (Duke *et al.*, 1979; Trang & Giddens, 1980 in Mederski, 1983). This reduction was attributed to poor nodulation and severe nitrogen deficiency as the plants are reported to have developed nodules and began to fix nitrogen when soil temperature was increased. Too high temperature has also been indicated to lead to nitrogen losses through denitrification and ammonia volatilisation (Amberger, 1983). These losses would rid the soil of nitrogen which might lead to deficient conditions calling for more nitrogen supplementation in order to prevent retardation of growth in vegetable amaranth.

2.1.3.6 Light

The dependence of ion uptake on light in photosynthetic cells has been documented as far back as 1926 (Glass, 1989). Although acquisition of inorganic nutrients from the external environment by higher plants is mostly through root tissues; such tissues however are actively dependent upon the translocation and subsequent oxidation of carbohydrate from the photosynthetic organ for the energy required to absorb required nutrients (Glass, 1989). The production of carbohydrates by photosynthetic organs is impossible without the supply of light. The unique ability of green plants to absorb light energy and convert it into chemical energy is one of the most important biological processes. This process, called photosynthesis, involves the combination of assimilated carbon dioxide (CO_2) and water (H_2O) driven by the light energy to produce carbohydrates ($C_6H_{12}O_6$) and oxygen (O_2). This process is very efficient within C4 plants which have a lower CO_2 compensation point than C3 plants. This is the major reason why tropical grasses (which are mostly C4 plants) can grow at such an enormous rate under high light intensity and temperature conditions (Mengel & Kirkby, 1987). Vegetable amaranth which is also a C4 plant can be expected to follow a similar trend.

Eze (1986) conducted a study to evaluate the growth of vegetable amaranth (*A. hybridus*) under different daylight intensities (100% full daylight, 70%, 50%.and 20%) and observed a positive response of yield to increased daylight intensity. Fresh mass was greatest in plants grown under some shade of 70% daylight intensity, but total dry matter accumulation was highest in full daylight at which growth was also recorded to be at its best. The favourable effect of increased light intensity or CO_2 concentration or the combined effects of both on CO_2 assimilation has been observed by a number of researchers (Mengel & Kirkby, 1987).

2.1.3.7 Other Nutrients

The level of nitrogen nutrition required for optimum growth during the vegetative period must also be balanced by the presence of other plant nutrients in adequate amounts (Mengel & Kirkby, 1987). The synthesis of organic nitrogen compounds depends on a number of inorganic ions including magnesium for the formation of chlorophyll and phosphate for the synthesis of nucleic acids. Potassium on the other hand, is said to influence both the uptake of nitrate and its assimilation into protein (Mengel & Kirkby, 1987).

The effect of nitrogen (N) is sometimes linked with that of phosphorus (P) such that, with adequate P, the addition of N can make plants grow better (Kommendahl, 1984). Makus (1992) reported bio-mass production of two amaranth cultivars to have been more responsive to increasing levels of P at 90 kg ha^{-1} but less so to increasing levels of potassium (K). It has been found that P level of 24 kg ha^{-1} limit the yield of vegetable amaranth, and at a very low P level (11 kg ha^{-1}), increasing N rates from 0 to 269 kg ha^{-1} did not give any significant increase in yield (Makus, 1986a). The most significant response of amaranth to an interaction of P and N was realised at a P level of 103 kg ha^{-1} and N level of 134 kg ha^{-1} when overall yield increased approximately 2.5 times over that of zero P at the same level of N. Potassium (K) treatment only resulted in increased leaf blade levels of mineral elements such as Fe, Mn and K (Makus, 1986b) which might also suggest improved uptake of these elements when K is adequate.

2.1.3.8 Sources of Nitrogen and Organic Matter

Nitrogen fertilizers are commonly classed into two forms viz. nitrate (NO_3^-) and ammonium (NH_4^+) base, which are also the nitrogen forms in which N is absorbed by plants. Most common nitrogen fertilizers contribute to soil acidity, since their reaction in the soil increases the concentration of hydrogen ions in the soil solution (Western Fertilizer Handbook, 1985). This is true especially with NH_4^+ based fertilizers. Braun & Roy (1983) claimed that there is generally no difference in the efficacy of various types of nitrogenous fertilizers, however differences are observed under certain soil conditions and for some crops. Braun & Roy (1983) also indicated that normally under flooded paddy soils, performance of NO_3^- based fertilizers is poor due to losses by leaching and denitrification.

Bernardo *et al.* (1984) reported an increase in dry matter yield and nitrogen uptake of sorghum plants fertilized with an NH_4^+ source rather than a NO_3^- source. Makus (1984) observed a similar response from vegetable amaranth in trials where nitrogen fertilizers were supplied as NH_4^+, NO_3^- and NH_4NO_3 at rates of 0, 100 and 200 kg N ha^{-1} applied in split form. Plants fertilized with NH_4 grew taller and were higher in yields and leaf pigments than those receiving their N in the other form. Mwamba *et al.* (1992) and Vavrina & Obreza (1992) in their studies with vegetable amaranth and chinese cabbage respectively, found no significant yield differences due to sources of N used. Bernardo *et al.* (1984) asserted that applying N in the form of NO_3^- tends to raise soil pH, while applying it in the form of NH_4^+ did the opposite.

Organic matter is another source of N that can be used to raise crop yield and it does this in two ways; as a physical soil amendment and as a chemical amendment. For organic matter to supply N to plants, it must first undergo microbial decomposition, a process that might make soil N unavailable to plants (Plaster, 1992). In the initial stages of decomposition of organic matter, soil N is rapidly used by microbes (tied up or immobilised) resulting in a temporary loss of free N (Alexander, 1977; Brady, 1984; Foth, 1990; Plaster, 1992; Tate, 1992). This loss of free N can result in slower crop growth, and crops may even exhibit N deficiency symptoms (Plaster, 1992). This nitrogen immobilisation is normally found when organic matter with a high carbon to nitrogen ratio (C:N) such as wheat straw or sawdust is used. This period is termed N depression. It is therefore important to use organic matter that is well decomposed or has a low C:N ratio such as green manure from leguminous plants.

2.1.3.9 Genotype and Plant Density

The potential rate of growth and size of a plant is defined by the genotype. For example, stress tolerant species normally have low growth rates and a slow rate of photosynthesis. These are structural adaptations which minimise loss of essential resources (Lawlor, 1991). Genotypic differences in dry matter accumulation in response to various N sources have been observed in many species of plants and it is also reported that plant genotypes vary in their ability to absorb many major and minor elements (Chevalier & Schrader, 1977; Cox *et al.*, 1985; Markovic *et al.*, 1987; Makus, 1992; Elbehri *et al.*, 1993). Makus (1992) reported differences in the yield responses of two cultivars of vegetable amaranth to N fertilization, with Hinn Choy being superior to RRC241. Elbehri *et al.* (1993) observed similar varietal differences in the yield reation of grain amaranth due to fertilization with N.

High plant density (more plants per unit area), means that more competition takes place amongst plants for essential growth elements such as N. The effect of spacing on total dry or fresh yield has been studied and confirmed to have optimum levels (Dufault & Waters, 1985; Mnzava & Ntimbwa, 1985; Bracy *et al.*, 1992). Dufault & Waters, (1985) and Bracy *et al.*(1992) observed an overall improvement on yield of high density planted broccoli due to increased N fertilizer application levels. Amaranthus is morphologically elastic, being able to adjust its branching pattern according to the space allowed (Hauptli, 1977 in Mnzava & Ntimbwa, 1985). Total yield m^{-2} of vegetable amaranth increased with increasing planting density up to a maximum of 196 plants m^{-2}, while the yield per plant showed a continuous decline. McLachlan *et al.* (1993) found that the decline in canopy transmitted photosynthetic photon flux density (PPFD) resulted in a decreased total dry matter accumulation and a greater relative dry matter distribution to main stem components than to branch components of red root pigweed (*Amaranthus retroflexus*).

2.1.3.10 Application Technique/Method

The main purpose of any method or technique of fertilizer application is to maximise the efficiency of fertilizer. Randall (1984) defines N fertilizer efficiency as either obtaining (i) greater crop yield and N uptake with equal or lesser amounts of N, or (ii) equal crop yield and N uptake with lesser amounts of fertilizer N. Any method of fertilizer application chosen must be selected in light of potential losses of such a fertilizer. Losses of N fertilizer have been identified by several authors as (i) leaching beyond crop rooting zone, (ii) volatilisation of NH_4^+ from surface applied urea fertilizer , (iii) temporary losses due to immobilisation by organic matter decomposing microbes, and (iv) denitrification (Braun & Roy, 1983; Brady, 1984; Randall, 1984; Foth, 1992; Plaster, 1992 & Tate, 1992).

There are several methods of applying fertilizer, but the most common ones are broadcast application and band application (Randall, 1984). Braun & Roy (1983) have listed the approaches which can be used to minimise losses of applied N as; manipulation of application techniques, use of large fertilizer granules and use of chemicals. Manipulation of application techniques involves placing the fertilizer in the root zone in submerged soil, in the moist soil zone under dryland conditions; split applications at times commensurate with crop needs based on growth habit and duration, foliar applications and many more. The use of large sized granules (super granules), and coating the fertilizer with various materials so as to reduce the dissolution rate to offset the leaching loss and using chemicals with an intention to counteract the rate at which the process of nitrification and hydrolysis takes place are some of manipulations of fertilizer application technique mentioned by Braun & Roy (1983) to reduce losses.

The method to be used depends on a set of condtions such as the crop to be grown, variety of the crop, soil, and availability of capital for investments in the crop enterprise (Randall,1984).

2.2 EFFECT OF NITROGEN ON THE QUALITY OF VEGETABLE AMARANTH

2.2.1 Introduction

In an endeavour to address the problem of food shortage and limited area on which to produce it, crop scientists have found it worthwhile to increase output per unit area. Fertilizer N has been, and still is used increasingly to supplement soil N for producing the needed quantity of food, feed and fibre for an increasing world population, but unfortunately this is not always associated with improved quality (Deckard *et al.*, 1984). To be most acceptable to consumers, the product grown by the farmer must be of high external and internal quality (Locascio *et al.*, 1984). Kramer & Twigg (1979) emphasised the importance of consumer satisfaction when they stated that although quality control systems as well as the production system is properly geared to buyers specification, the cycle of quality control needs to begin and end with consumer specifications since the buyer may not necessarily be the ultimate consumer. This statement clearly shows that quality is rather a broad or general term which holds various meanings to different people or situations.

Major external characteristics of quality are product appearance, which includes factors such as size, shape, colour and freedom from blemishes, as well as internal quality attributes which are sensed organoleptic attributes such as texture, taste and flavour and composition (nutritional composition) of both beneficial and harmful substances (Locascia *et al.*, 1984). Finck (1982) also divides quality aspects into two groups which he terms commercial (market) and food quality, characterised by external organoleptic (sensed) characteristics and value for nutrition (nutritive value) respectively. Analysis of vegetables in industrialised countries is mainly based on factors that affect the quality with respect to influences of technical processing and also on factors that influence the commercial value of the product. However, in the tropics where the majority of developing countries are found, there is still high prevalence of protein-energy malnutrition (PEM) and other nutritional deficiencies (Laryea *et al.*, 1994). In the third world therefore, major interest in the analysis of food has focused on such essential nutrients as protein, carbohydrates, amino acids, energy content and vitamins. The preceding statements emphasise the importance of the internal quality (nutritive value) of foods hence it is imperative to deal more with such under this investigation.

The level of nutrient supply in the soil plays an important role in determining product quality. N is particularly important as it forms an integral part of numerous plant compounds such as amino acids, proteins, nucleic acids and chlorophyll (Finck, 1982; Locascio *et al.*, 1984). Fertilization in mineral or organic form can improve quality considerably, but it may also have detrimental effects (Finck, 1982).

2.2.2 Internal Quality Characteristics of Vegetables

The internal quality of food or food products is sometimes referred to as food quality or nutritive value (Finck, 1982). It depends on the energy content and the extent of value determining ingredients, particularly those essential for man. These nutritional constituents are not readily apparent but consumers recognise their importance as essential ingredients (Locascio *et al.*, 1984). Food is said to be of higher nutritive value, the larger its content of vital and beneficial nutrients are and the smaller the content of harmful substances. The nutritional value of fruits and vegetables as vital sources of essential minerals, vitamins and dietary fibre has been well recognised. In addition to these constituents, fair amounts of carbohydrates, proteins and calories are supplied (Salunkhe *et al.*, 1991).

Plants can also contain toxic or harmful substances. Wild growing plants may contain harmful or even carcinogenic substances (Finck, 1982). Finck (1982), Yamaguchi (1983) Locascio *et al.*, (1984) and Salunkhe *et al.*, (1991) recognised several important substances found in crop plants that might have detrimental effects on the quality of the product. Glucosinolates, nitrates and nitrites, neuro-toxins and lathyrogens, glycoalkaloids and oxalates are some of the substances considered to have some toxicological effects in horticultural products.

2.2.3 Internal Quality Attributes of Vegetable Amaranth

Amaranthus compares favourably with other important leafy vegetables in terms of nutritional composition (Salunkhe, 1984) (Tables 1 & 2). Allemann *et al.*, (1996) evaluated Amaranthus as a possible vegetable crop applying nitrogen at a rate of 122 kg N ha^{-1} and found it to be nutritionally more valuable than any other spring and summer leafy vegetable. It is rich in vitamins, fat, protein, fibre and minerals (Table 3).The amino acid composition of *A.hybridus* is reported to be superior to other protein sources such as spinach, soybean, rice and wheat (Fafuso & Bassir, 1976 in Feine *et al.*, 1979).

Table 1. Proximate composition of some important leafy vegetables (Salunkhe, 1984)

	Edible Portion (%)	Moisture (g)*	Protein (g)*	Fat (g)*	Minerals (g)*	Fiber (g)*	Carbohy. (g)*	Energy (kcal)
1. Spinach (*Spinacia oleracea*)	87	92.1	2.0	0.7	1.7	0.6	2.9	26
2. Fenugreek (*Trigonella foenum-graecum*)	59	86.1	4.4	0.9	1.5	1.1	6.0	49
3. Mustard (*Brassica compestris. Var. Sarson*)	-	89.8	4.0	0.8	1.6	0.8	3.2	34
4. Chard or beet greens (*Beta vulgaris*)	51	86.4	3.4	0.8	2.2	0.7	6.5	46
5. Amaranth, tender (*A. gangeticus*)	39	85.7	4.0	0.5	2.7	1.0	6.1	45
6. Ambat chuka (*Rumex vesicarius*)	-	95.2	1.6	0.3	0.9	0.6	1.4	15
7. Colocasia greens (*C. antiquorum*)	-	82.7	3.9	1.5	2.2	2.9	6.8	56

* Values are per 100g edible portion

Table 2. Mineral and vitamin contents of some important leafy vegetables (Salunkhe, 1984)

Vegetables	Minerals			Vitamins				
	Ca	P	Fe	Carotene	Thiamin	Riboflavin	Niacin	Vit. C
1. Spinach (*Spinacia oleracea*)	73	21	10.9	5580	0.03	0.26	0.5	26
2. Fenugreek (*Trigonella foenum graecum*)	395	51	16.5	2340	0.04	0.31	0.8	52
3. Mustard (*Brassica compestris.* Var. Sarson)	155	26	16.3	2622	0.03	-	-	33
4. Chard or beet greens (*Beta vulgaris*)	380	30	16.2	5862	0.26	0.56	3.3	70
5. Amaranth, tender (*A. gangeticus*)	397	83	25.5	5520	0.03	0.30	1.2	99
6. Ambat chuka (*Rumex vesicarius*)	63	17	8.7	3660	0.03	0.06	0.2	12
7. Colocasia greens (*C. antiquorum*)	227	82	10.0	10278	0.22	0.26	1.1	12

Note: All values are mg/100 g edible portion

Table 3. Nutritional value of some amranthus species in Roodeplaat trials (Adapted from Allemann *et al.*, 1996)

Variety	Protein	Fat	Fibre	Fe	Ca	Vit A	Vit C
	%			(mg 100 g^{-1})			
A. hypochondriacus	27.59	2.19	7.59	24.27	3.88	41.92	13.60
A. tricolor	27.36	1.79	6.61	10.38	3.39	33.72	10.99
A. hybridus var. cruentus	28.05	2.04	9.13	61.34	3.35	43.84	6.27
A. hybridus	30.27	1.47	8.29	99.04	2.45	34.44	11.23
A. hybridus (Mayfords)	26.79	2.29	6.24	84.50	2.93	45.84	9.92
Recommended Daily Allowance(Males 14 – 18 years)	60g	-	-	18 mg	1.4 g	5 000 IU*	55 mg

*: 1mg = 3000 IU

Amaranth, like many other rapid growing plants, requires and absorbs large amounts of nitrate which is necessary for protein synthesis (Feine *et al.*, 1979). Under certain conditions, plants can accumulate nitrate to levels that can be toxic if ingested. In vegetables, particularly in spinach, a content of 2 mg NO_3-N per gram dry matter is regarded as a critical level (Mengel & Kirkby, 1987). Absorption of large amounts nitrates is harmful particularly to infants whose digestive system converts nitrates to nitrites that bind with haemoglobin to form methaemoglobin which cannot transport oxygen (Locascio *et al.*, 1984). Another possible adverse effect of these nitrates is the formation of nitrosamines which are known to be carcinogenic, teratogenic and mutagenic (Locascio *et al.*, 1984). Plants for direct consumption such as leafy vegetables should therefore not have a too high NO_3 content.

Another important naturally existing harmful substance in plants is oxalate which is known to influence the calcium absorption in foods (Meena *et al.*, 1987). Green leafy vegetables frequently contain large quantities of oxalates and this is characteristic of vegetable amaranth. In a study on soluble and insoluble oxalates in selected foods, Meena *et al.* (1987) found amaranth to be one of the food plants with the highest total oxalates. National Academy of Science (NAS) (1975, 1985) and Sanchez – Marroquin *et al.* (1980) in Teutonico & Knorr (1985) state that oxalates are found in appreciable quantities in amaranth at about 7,2% of dry mass.

2.2.4 Effect of Nitrogen on Quality

Quality requirements are all influenced by nitrogen nutrition (Locascio *et al.*, 1984). Therefore, fertilization should not only ensure high yields per unit area but also high quality produce by the improvement of either low initial quality caused by insufficient nutrient supplies, or the maintenance of high quality (Finck, 1982). The chemical composition controls the nutritional quality or value, as well as important sensory attributes such as taste and texture of the product. Increased concentration of nitrogen in plants generally results in an increase in some plant compounds such as amino acids, proteins and chlorophyll (Locascio *et al.*, 1984). Schmidt (1971), Vuurmans & Grubben (1977) in Auwalu (1988) observed that nitrogen fertilized vegetables were more succulent than the unfertilized ones.

Makus (1986a) and Walters *et al.* (1988) have recorded increased protein in the leaves of vegetable amaranth due to increased levels of nitrogen in the soil. Leaf blade protein content of vegetable amaranth increased linearly when N levels were raised from 0 kg ha^{-1} to 269 kg ha^{-1} (Makus, 1986a), while Walters *et al.* (1988) also observed a linear response in crude protein but showed the significance to differ with age. Plants harvested at more than 35 days after germination showed a more positive nitrogen influence.

Fibre as measured by neutral detergent fibre concentration (NDF) is adversely affected by nitrogen soil enrichment (Walters *et al.*, 1988). Leaf NDF declined linearly with increased soil nitrogen application levels. Zhang *et al.* (1993) observed a decrease in concentration of non-structural carbohydrates, lipids and other components (largely structural carbohydrate) of maize (*Zea mays* L.) grain grown under higher nitrogen fertility. Since the grains had a higher protein concentration it was not known whether this increase in protein was due to a decrease in the carbohydrates. However, several investigators working with various crops have indicated a decline in lipid and starch concentration due to increased doses of fertilizer N. (Welch, 1969; Beech, 1990 & Randall *et al.*, 1990 in Zhang *et al.*, 1993).

The effect of nitrogen fertilization on the vitamin content of various vegetables differs between vitamins, with the concentration of some vitamins being adversely affected while others are positively influenced. Increased application of N fertilizer has been associated with a decrease in the content of ascorbic acid (Vitamin C) in many plants (Mengel & Kirkby, 1987 ; Mozafar, 1993). However, vitamin A and other vitamins in plants have been shown to be affected positively by an addition of nitrogen.

Accumulation of nitrates, nitrites, related substances and oxalates is singled out as more important in adversely affecting the quality of vegetable amaranth. Build-up of nitrates and related compounds due to increased doses of N have been reported by many researchers (Cantliffe, 1973; Rose & Guillarmod, 1974; Maynard *et al.*, 1976; Eze, 1986; Makus, 1986a; Cserin & Prohászka, 1987; Mengel & Kirkby, 1987; Walters *et al.*, 1988). Nitrate level in leaves of vegetable amaranth increased quadratically when soil N increased from 0 kg ha^{-1} to the highest level of 269 kg ha^{-1} (Makus, 1986a). Soil enriched with fertilizer N produced plants containing nearly twice the concentration of leaf nitrate than those in unfertilized soil (Walters *et al.*, 1988). The magnitude of differences in leaf nitrate content among the different N treatments was found to increase with the age of plants. Addition of sodium nitrate ($NaNO_3$) fertilizer increased NO_3 accumulation in leaf blades of both spinach and table beet (Cantliffe, 1973).

Early experiments found the increase in oxalic acid and decrease in iron content on high fertility plots (Schmidt, 1971; Vuurmans & Grubben, 1977 in Auwalu, 1988). However, Makus (1986a) reports that soluble oxalate levels were not affected by increased nitrogen rate or time of leaf sampling.

2.2.5 Factors Influencing Nitrogen Effect on Quality

The nutrient content of fresh fruits and vegetables usually depends upon factors such as cultivar, environment and maturity. It is synthesised in the plant or plant parts during growth (Salunkhe *et al.,* 1991).

2.2.5.1 Nitrogen Source

Since NH_4 is normally rapidly transformed to NO_3 in the soil, the effects of ammonium or nitrate nitrogen in soil culture can only be tested if the so-called nitrification inhibitor is used (Breimer, 1982). The form of N used would therefore not have any significant difference in the way it influences the quality of the vegetable. However, the difference will only occur where a significant decrease in soil pH takes place (caused by NH_4) which might interfere with the uptake of nutrients by plants. The above case is very rare as indicated by Breimer (1982) that pH was decreased by units of 1.0 -1.5 when NH_4 was used as the form of N fertilizer; however, the low pH-values only caused yields to decline and because nitrification was not suppressed, the NO_3 content in spinach were sometimes even higher than with NO_3 dressings.

2.2.5.2 Nitrogen Supply

Many authors have found a positive correlation between the amount of N used and the accumulation of NO_3 in plants (Cantliffe, 1973; Rose & Guillarmod, 1974; Maynard & *et al.*, 1976; Ryder, 1979; Breimer, 1982; Eze, 1986; Makus, 1986a&b; Mengel & Kirkby, 1987; Cserin & Prohászka, 1987; Walters *et al.*, 1988). Nitrate content in leafy vegetables such as spinach depends largely on the level of NO_3 nutrition at which the plants are grown (Mengel & Kirkby, 1987). Where nitrogen is limited, plants would take up very little of it, with a consequent adverse effect on both quality and yield.

2.2.5.3 Environmental Factors

The speed of chemical reactions is very much dependent on temperature with an increase in temperature of 10°C usually increasing chemical reactions by a factor of two (Marschner, 1986). NH_4^+ is absorbed more readily than NO_3 when the ions are supplied together at the same concentration especially at a low temperature (Clarkson & Warner, 1979). Higher temperatures and lower light intensity (characteristic of a greenhouse in the winter season) gave rise to higher NO_3 contents in spinach (Breimer, 1982). Spinach grown in spring (under favourable conditions such as high light intensity) has a lower NO_3 content than that grown in autumn (Mengel & Kirkby, 1987). Reduction in light intensity significantly increased total N of both spinach and table beet (Cantliffe, 1973). Nitrate was also reported to have accumulated regardless of the treatment when light intensity was reduced. Cantliffe (1973) also observed that any factor which increased the total N concentration of the tissue resulted in a corresponding increment in the NO_3 concentration of that tissue. It is also reported that when N fertilizer was applied the increase in total N due to light reduction was less than the increase in NO_3-N and hence did not fully account for increase in NO_3-N. This phenomenon, Cantliffe (1973) attributed to the possible existence of critical total N levels above which any increase in total N showed up as predominantly NO_3-N, and below which, NO_3-N did not accumulate regardless of the external factors applied. Under conditions of that experiment it was deduced that critical total N values above which NO_3 will start to accumulate could be 1.8% for beet leaves, 1.7% for beet roots and 3.6% for spinach leaves (Cantliffe, 1973).

Seasonal variations in nitrate contents are connected with temperature and especially with day length and light intensity which increase in spring during the development of a crop, but decrease in autumn (Breimer, 1982). A study on interaction between fertilizer addition and temperature increase on NO_3 accumulation in the tissues of spinach and table beet revealed that accumulation occurred at lower temperatures the greater the level of N fertilizer (Cantliffe,1973). A temperature range of 5 to 25°C favoured accumulation while a rise from 25 to 30°C lead to a decrease in accumulation.

Spring conditions are also characterised by lower soil temperature than summer and together with above conditions, spring season is favourable for both dry matter accumulation and nitrate reduction. Eze (1987) found protein accumulation of vegetable amaranth to be greater at 70% daylight intensity; however, total carbohydrates, ascorbic acid and chlorophyll a and b contents per unit dry mass of leaf tissue and the chlorophyll stability index were recorded higher at higher light intensities.

Water stress in plants is one of the major factors limiting crop production throughout the world (Mengel & Kirkby, 1987). Ben-Zioni *et al.* (1967), Mizrah *et al.* (1970) and Bardzik *et al.* (1971) in Mengel & Kirkby (1987) have studied some very important physiological aspects of water stress. Water stress has been shown to inhibit incorporation of amino acids into proteins which in turn has resulted in a decrease in protein content of the tissues. Another physiological aspect of stress is on the enzyme level in plants particularly the decrease in the level of nitrate reductase and this has been related to the suppression of protein synthesis. CO_2 assimilation rate and reduction in the translocation rate of photosynthates from leaves to other plant parts were also observed. Wright & Davison, 1964 in Breimer (1982) have shown that water stress increased the nitrate contents in plants. They also attributed this phenomenon to a decrease in nitrate reductase activity prior to the moment at which uptake starts to decline.

2.2.5.4 Plant Genotype and Age

Genotypic differences relating to the NO_3 content have been reported in several crops. Aloefe (1974) in Elbehri *et al.* (1993) observed a cultivar of maize (*Zea mays* L.) to have a higher concentration of nitrogen than others. Maynard *et al.* (1976) attributed variation in nitrate accumulation to differences in uptake, assimilation or translocation which is genotypically dependent. Makus (1984) studied eight accessions of *A. tricolor* to evaluate the potential of amaranth as a greens crop and observed differences in soluble leaf blade NO_3-N content and other soluble salts including chlorophyll. Amongst six amaranth accessions evaluated, Walters *et al.* (1988) noted significant difference in overall mean leaf crude protein levels. No significant difference was however observed regarding NDF.

Age of the plant has also been observed to play a significant role in plant tissue nitrogen/nitrate content. Amongst the plants gathered as foodstuffs by the Transkein peoples, NO_3-N is prominent in young and immature stages, reaching its highest percentage just before blooming (Rose & Guillarmod, 1974). Walters *et al.* (1988) observed that although leaf NO_3 of vegetable amaranth accessions increased two fold in plants from fertilized plots compared to plants from unfertilized plots, it however declined rapidly with time. Leaf crude protein was observed to follow a similar trend as NO_3. This confirms that nitrogen is a principal component of protein and its building blocks (amino acids). Response of fibre to age vary amongst accessions with three of them showing an increase in NDF concentration at 12 week harvest period.

Based on the information gathered thus far, it is clear that nitrogen fertilizer plays an important role in the growth, yield and quality of leafy vegetables such as vegetable amaranth. However, how much of that fertilizer is optimal and under what conditions can it be considered to be appropriate for local conditions is still to be determined. Nitrogen utilization by plants is sometimes influenced by other factors beyond human control. This study was therefore conducted in order to try and determine the amount of fertilizer that is optimal for local conditions, as well as the effect that application level has on the quality of the final product. It is also hoped that through this study, seasonal influence on nitrogen utilisation for improved yields will be to some extent determined.

CHAPTER 3

THE PRELIMINARY DETERMINATION OF THE EFFECT OF NITROGEN ON THE YIELD OF VEGETABLE AMARANTH

3.1 Introduction

Stanford and Legg (1984) stated that the most critical factor in promoting extremely high yields is supplying nutrients, especially nitrogen in sequence with crop demand without creating toxic conditions and affecting quality of the harvestable product. Crops that are harvested fresh before maturity such as forage grasses require high amounts of nitrogen (Stanford & Legg, 1984). Nitrogen is one of the 16 essential elements required by plants, and is an indispensable requirement for the normal growth cycle of a plant (Glass, 1989). This requirement for nitrogen exists throughout the development of a plant in order to maintain growth, as it is a constituent of both structural (e.g. cell walls) and non structural (e.g. enzymes, chlorophyll and nucleic acids) components of the cell (Schrader, 1984). Nitrogen deficiency, therefore, usually has an overriding control on growth and dominates the effects of other essential elements.

Elbehri *et al.* (1993) reported a linear increase in forage yield of grain amaranth due to increased application of soil nitrogen per hectare. Oji & Ugherughe (1992) observed conflicting results in dry matter yield of millet. This result, however, was attributed to succulence of the fresh plant material because of less carbohydrate accumulation and more protein synthesis (hence more protoplasm). Investigations by Markovic *et al.* (1987), Vavrina & Obreza, (1992), Thompson & Doerge, (1995) have shown a positive response to increased nitrogen application levels by other leafy vegetables that have a similar affinity to nitrogen due to the high volume of vegetative matter produced. Makus (1986 a & b), Mwamba *et al.* (1992), Makus (1992), Whitehead & Singh (1994) all observed a positive yield response of vegetable amaranth to increased rates of nitrogen fertilizer. Makus (1986 a & b) experimented with five levels of nitrogen (0, 67, 134, 202 and 269 kg N ha^{-1}) and found leaf area, leaf protein ha^{-1} and total yields to increase significantly with increased nitrogen application up to 134 kg N ha^{-1}.

Whitehead and Singh (1994), however, indicated that 90 kg N ha^{-1} was the optimal level of N application for vegetable amaranth.

Genotypic differences in dry matter accumulations in response to various nitrogen sources, as well as the ability to take up major and minor elements have been reported by many researchers (Chevalier & Schrader, 1977; Cox *et al.*, 1985; Makus (1992) . Makus (1992) reported that the vegetable amaranth cultivar Hinn Choy had a superior yield response to nitrogen in relation to the cultivar RRC 241. These variatal differences are also found in grain amaranth (Elbehri *et al.*, 1993).

In view of the conflicting reports on the effect of various levels of nitrogen on yield of vegetable amaranth as well as the need to formulate a fertilizer recommendation appropriate for local conditions, it was considered necessary to establish the reaction of local varieties to supplemental N.

This report presents results of a preliminary field experiment on the effects of various levels of nitrogen on the yield of three vegetable amaranth species viz: *Amaranthus hypochondriacus* L, *Amaranthus tricolor* L and *Amaranthus hybridus* L.

3.2 Materials and Methods

The experiment was established at the Agricultural Research Council (ARC)-Roodeplaat Vegetable and Ornamental Plant Institute at Pretoria, South Africa in the summer of 1996 (October/November). The soil type of the experimental area is a Hutton from the Shorrocks series. Before the experiment was established, the fertility status of the soil was determined and is summarised in appendix C. The climatological data for the entire growing period is summarised in appendix B. The experimental area is located at Roodeplaat (Latitude 25° 35' 10" S, Longitude 28° 20' 45"E, Altitude 1155m above sea level).

The experimental design was a randomized block design (RBD) replicated 3 times to give a factorial experiment of 7x3x3 (to give 63 plots). Gross plot size was 1x4.5 m with data collected from a netplot of 0.5x4.5 m (2 middle rows). Plant spacing was 25x25 cm giving a total population of 160 000 plants ha^{-1}. Seedbed preparation was done by ploughing, discing followed by rotovating to give a fine tilth. The site was marked out accordingly, leaving path rows of 1 m between plots.

Seven levels of nitrogen viz; 0 kg N ha^{-1} (control), 25, 50, 75, 100, 125 and 150 kg N ha^{-1} were used. The source of nitrogen was Limestone Ammonium Nitrate (LAN 28 %). All plots received the same amount of phosphorus and potassium supplied by superphosphate (10.5 %) at 500 kg ha^{-1} and potassium chloride (50 %) at 400 kg ha^{-1} respectively. Phosphorus and potassium were incorporated prior to transplanting. Nitrogen applcation was split into two equal parts; the first portion incorporated just before transplanting and the second part (top dressing) applied three weeks after transplanting.

Seeds of the three species used (*A. hypochondriacus, A. tricolor and A. hybridus*) were obtained from the Vegetable and Ornamental Plant Institute. The seeds were sown in seedling trays from 13th September 1996 and seedlings transplanted to the seedbed on the 5th and 6th of November 1996 (growth of seedlings initially delayed by the cool temperatures of spring). Water was applied immediately by sprinkler irrigation (6 mm) to help the seedlings establish. Thereafter irrigation was applied at the rate of 15 mm per every two weeks when moisture was limiting. Weed control was done by hand. Pests were controlled when the infestation was seen to be threatening normal plant growth.

Harvesting was done six weeks after transplanting on the two middle rows (36 plants in total). During harvesting yield samples were divided into two components viz; edible portion and non-edible portion. Edible portion (leaves and tender tops/shoots) was cut 30 cm above ground level for *A. hypochondriacus* and *A. hybridus* while *A. tricolor* was cut at 10-15 cm above ground level. The difference in cutting height is due to the difference in growth of the three species; *A. tricolor* is shorter while the other species are tall. The remaining hard stem and older leaves made up the none edible portion and was cut at ground level without leaving any visible stumps. Fresh mass from all replicates were taken for both edible and nonedible portions while dry mass were only done with replications one and two because of time constraints.

Visual inspection of plants was continuously done during the growing period to monitor the condition of the plants.

The data was statistically analysed at ARC- Agrimetrics using the Genstat 5 Release 3.2. The analysis of variance was done as well as multiple comparison test using the Bonferroni test for factors showing significance difference at 5% level. The tables of analysis of variance can be found in Appendix A.

3.3 Results

The results of this preliminary experiment are shown in tables 4 to 7, figures 1 & 2 and appendix A. Nitrogen treatment showed a highly significant linear relationship at ($p<0.01$), with yield of the fresh edible portion and dry edible portion of the three species. Total fresh matter yield showed a significant quadratic relationship with nitrogen treatment for *A. hybridus*. Mean yield difference within a species according to treatment is also shown in tables 4 and 5.

There was an interaction between nitrogen and species for total fresh matter yield (Table 1.7A and Figures 1 & 2) but no significant interaction was found for the edible portion fresh matter yield only (Table 1.8A). The species/nitrogen interaction showed a linear relationship for yield. *A. hypochondriacus* and *A. tricolor* showed nitrogen to be limiting at 0, 25 and 50 kg N ha^{-1} supplementation; however, *A. hybridus* only revealed similar effect at 0 kg N ha^{-1}. *A. hypochondriacus* and *A. tricolor* produced their respective highest fresh matter yield at 125 kg N ha^{-1} application (Table 4 & Fgure 1). *A. hybridus* however showed 150 kg N ha^{-1} application to be the most favourable rate for fresh matter yield (Table 4 & Figure1). For dry matter yield, the three species showed different response curves; *A. hypochondriacus* yield is shown to be increasing with every addition of nitrogen up to the highest rate of 150 kg N ha^{-1} (Table 4 & Figure 1). Dry matter yield of *A. tricolor* increases up to nitrogen application of 50 kg N ha^{-1} and thereafter decreased at 75 kg N ha^{-1} after which there is another peak at 125 kg N ha^{-1} application. The yield decreased again at a 150 kg N ha^{-1} application (Table 4 & Figure 1). The *A. hybridus* dry matter yield response curve is slightly similar to that of *A. tricolor* as the first peak is also reached at 50 kg N ha^{-1} and then drops at 75 kg N ha^{-1} but thereafter continued to increased up to the highest application of 150 kg N ha^{-1} (Table & Figure 4). The analysis on edible portion is summarised in table 5.

Table 4. Effect of seven nitrogen levels on total fresh matter (FM) yield and dry matter (DM) yield of three vegetable amaranth species

N LEVELS (kg.ha^{-1})	YIELD (1000 kg.ha^{-1})							
	FRESH MATTER				DRY MATTER			
	A.hypochon	*A.tricolor*	*A.hybridus*	MEANS	*A.hypochon*	*A.tricolor*	*A.hybridus*	MEANS
0	18.67a	7.15a	21.86a	15.89a	2.94a	0.80a	3.02a	2.25a
25	24.73a	15.44ab	43.02b	27.73b	3.66ab	2.20ab	5.62ab	3.83b
50	32.20ab	15.79ab	54.47bc	34.15bc	4.70abc	2.37ab	6.16ab	4.41b
75	41.37bc	23.78bc	53.11bc	39.42c	5.79bc	2.32ab	5.63bc	4.91bc
100	45.97bcd	21.50bc	59.08cd	42.18c	6.00bc	3.05ab	7.05bc	5.36bc
125	57.09d	32.85c	67.33cd	52.43d	6.34bc	4.65b	7.70bc	6.23c
150	51.33cd	31.35c	71.31d	51.33d	6.75c	3.89b	8.39c	6.35c
MEANS	38.77b	21.12a	52.88c		5.17b	2.90a	6.22c	
LSD	15.03	15.03	15.03	8.68	2.72	2.72	2.72	1.57

Means in the same column followed by the same letter are not significantly different based upon the Bonferroni multiple comparison test

Test level = 0.05

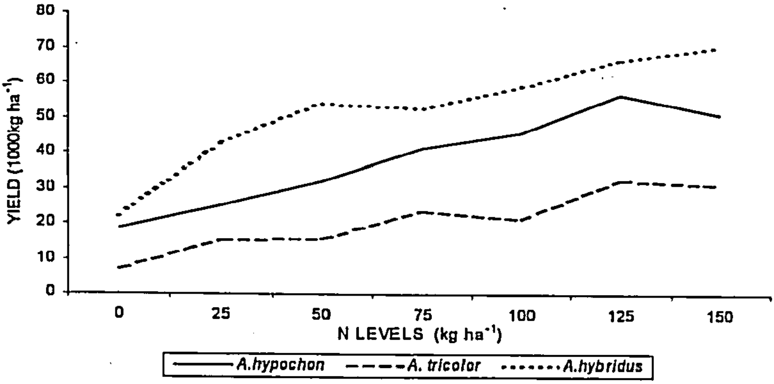

Figure 1. Effect of seven levels of nitrogen on total fresh matter (FM) yield of three vegetable amaranth species

Table 5. Effect of seven nitrogen levels on edible portion yield of three vegetable amaranth species

N LEVELS (kg N ha^{-1})	YIELD (1000 kg ha^{-1})							
	FRESH MATTER				DRY MATTER			
	A.hypochon	A.tricolor	A.hybridus	MEANS	A.hypochon	A.tricolor	A.hybridus	MEANS
0	11.46a	3.59a	13.42a	9.49a	1.77a	0.34a	1.77a	1.29a
25	14.81ab	8.31ab	25.26ab	16.13ab	2.08a	1.18ab	3.05ab	2.10ab
50	19.84abc	9.21ab	31.27bc	20.11bc	3.01a	1.49ab	3.46ab	2.65abc
75	26.90bcd	13.68ab	33.13bc	24.57bcd	3.72a	2.02ab	3.47ab	3.07bc
100	29.44cd	12.37ab	34.52bc	25.61cde	3.92a	1.92ab	4.08ab	3.31bc
125	36.54d	21.02b	42.06c	33.21e	3.62a	3.25b	4.84b	3.90c
150	32.71cd	18.80b	44.95c	32.15de	4.18a	2.64ab	5.50b	4.10c
MEANS	24.60b	12.42a	32.09c		3.18b	1.83a	3.74b	
LSD	14.71	14.71	14.71	8.50	2.57	2.57	2.57	1.48

Means in the same column followed by the same letter are not significantly different based upon the Bonferroni multiple comparison test

Test level = 0.05

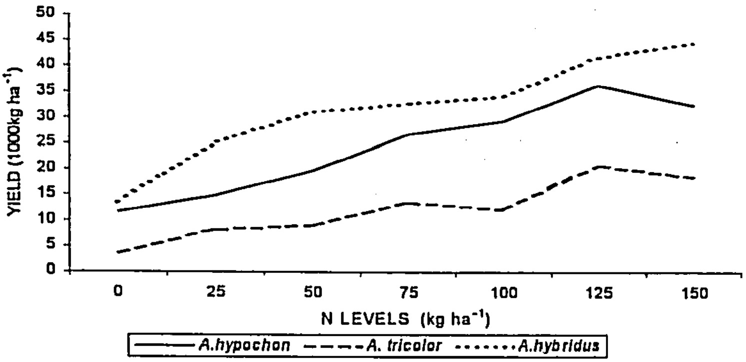

Figure 2. Effect of seven levels of nitrogen on edible fresh matter (FM) yield of three vegetable amaranth species

An important observation is that the water content (Table 6) seemed to have been affected by nitrogen treatment where 0 kg N ha^{-1} had a relatively lower water content than 150 kg N ha^{-1} for *A. hypochondriacus* and *A. hybridus* but not so for *A. tricolor*. There was a significant difference in water content between *A. hybridus* and *A. hypochondriacus* but not so between each of these species and *A. tricolor*. Harvest index (Table 7) for all the species is observed to be dependent on nitrogen application level with 150 kg N ha^{-1}application being higher than the control.

Table 6. Effect of different nitrogen application levels on water content of three vegetable amaranth species

N-LEVELS (kg ha⁻¹)	WATER CONTENT(%)		
	A.hypochondriacus	*A. tricolor*	*A. hybridus*
0	85.25	88.81	86.18
25	85.20	85.75	86.94
50	85.40	84.99	88.69
75	85.00	86.04	89.40
100	86.95	85.81	88.07
125	88.89	85.84	88.56
150	86.85	87.59	88.07
MEANS	86.43a	87.58ab	88.40b
LSD	1.47	1.47	1.47

Means followed by the same letter are not significantly different based upon the Bonferroni multiple comparison test

Test level = 0.05

Table 7. Harvest Index of three vegetable amaranth species at seven nitrogen application levels.

N LEVELS (kg ha⁻¹)	HARVEST INDEX (%)		
	A.hypochondriacus	*A. tricolor*	*A. hybridus*
0	61.38	50.12	61.39
25	59.89	53.82	58.72
50	61.61	58.33	57.41
75	65.02	57.53	62.38
100	65.13	57.53	58.43
125	64.00	63.99	62.47
150	63.72	59.97	63.03
MEANS	62.96	48.76	60.55

3.4 Discussion and Conclusions

The effect of nitrogen supplementation on the yield of vegetable amaranth cannot be over emphasized. The results of this experiment confirm findings reported by other researchers that nitrogen supplementation significantly increase the yield of vegetable amaranth. Nitrogen fertilization has been found to have a linear relationship with fresh edible yield and this is in conformity with findings that forage yield of grain amaranth increased linearly due to increased application of soil nitrogen per hectare (Elbehri *et al.*, 1993). The results of this trial also confirm that nitrogen application does affect yield of vegetable amaranth positively as reported by Makus (1986a & b), Makus (1992), Mwamba *et al.* (1992), Whitehead & Singh (1994). During the growing period visual inspection revealed plants receiving less nitrogen, particularly 0 kg N ha^{-1} to 50 kg N ha^{-1} to have some pale colour. Those receiving 0 kg N ha^{-1} and 25 kg N ha^{-1} showed stunted growth. The results affirm the statement that the requirement for nitrogen for plant development and maintenance exists throughout the plant life (Schrader, 1984).

Genotypic or variatal differences in dry matter accumulations in response to nitrogen has also been confirmed in this study. *A. hybridus* has been shown to have the highest biomass accumulation when given the same amount of fertilizer as the other species in this trial; similar response has also been reported by Makus (1992) and Elbehri *et al.* (1993). The essentiality of nitrogen to plant growth has also been confirmed in this experiment by the smaller growth rate of those plants which received the least or no nitrogen supplementation.

It has not been possible to find any negative effect of increased nitrogen fertilizer on the dry matter accumulation of the three species probably because the highest nitrogen dose was not reached. Plant water content for all nitrogen treatments for the three species fluctuated over a very narrow range.

A final conclusion was not reached as to which nitrogen level is optimal for each species because the results showed a linear relationship of yield to nitrogen up to the highest treatment used. These results have warranted an addition of two more higher nitrogen treatments viz. 175 and 200 kg N ha^{-1} for follow-up trials. It is also hoped that this wide range of treatments will give a clear turnoff point (curvature) at which one can be able to say which level of nitrogen application is optimal for yield and thus make appropriate recommendations to growers.

It was not possible to take other data such as soil residual nitrogen after harvest to determine how much nitrogen has been taken up and how much was left in the soil. Two more trials were planned during which it was hoped that the above mentioned short comings could be dealt with. A quality analysis of the product was planned for the follow-up trials as well.

It can be concluded that increased nitrogen application does have a positive influence on growth and yield of vegetable amaranth. However, it was not possible to determine which level was optimal for each species as yields continued to increase linearly.

CHAPTER 4

EFFECT OF NITROGEN FERTILIZATION ON YIELD AND QUALITY OF VEGETABLE AMARANTH

4.1 Introduction

In an effort to obtain high yields, growers apply high levels of fertilisers, particularly nitrogen fertilizer. Reviewed literature confirms the importance of nitrogen fertilization on the yield of vegetable amaranth, although it varies from one locality to another. As Deckard *et al.* (1984) stated, fertilizer N is used increasingly to supplement soil N for producing the needed quantity of food, but this is not always associated with improved quality. In some instances quality attributes are enhanced as in increased protein content and some vitamins, but there is also an adverse effect of high accumulation of harmful substances like nitrates (Deckard *et al*., 1984).

Although the preliminary experiment confirmed the previous findings in terms of yield, nothing was done regarding the quality of the product. There was also no level of nitrogen fertilizer identified beyond which no increase in the yield was realised. In other words, the seven nitrogen treatments gave a linear relationship with yield and hence an inclusion of more treatments was deemed necessary. Also recognised, was the possibility of variation of other factors such as climate, season (time of planting) and many more. Therefore, this experiment was conducted to quantify the effect of nitrogen fertilization and other environmental factors on the yield and quality of vegetable amaranth.

4.2 Materials and Methods

The experiment was conducted at the Agricultural Research Council (ARC) – Roodeplaat, Vegetable and Ornamental Plant Institute at Pretoria (VOPI), South Africa in Autumn of 1997 (February/March). The soil type of the experimental area is a Hutton from Shorrocks series. The experimental is located at Roodeplaat (Latitude 25° 35' 10" S, Longitude 28° 20' 45" E, Alitude 1155 m above sea level). The fertility status of the soil before the experiment was established at the beginning of the growing season and is summarised in appendix C. The climatological data during the entire growing period is summarised in appendix B.

The experiment was set up as a complete randomised design (CRD) replicated three times to give a factorial experiment of 9x3x3 with a total of 81 experimental units. The gross plot size was 1.25 x 5m with data collected from a netplot of 0.75 x 5.0m (three middle rows). Plant spacing was 25x25 cm giving plant density of 160 000 plants ha^{-1}. Land preparation was done by ploughing and discing the soil to a fine tilth. Plots were marked accordingly leaving path rows two metres wide since no guard rows were planted in between plots.

Nine levels of nitrogen viz., 0 kg N ha^{-1} (control), 25, 50, 75, 100, 125, 150, 175 and 200 kg N ha^{-1} were applied as Limestone Ammonium Nitrate (LAN, 28%). All plots received the same amount of phosphorus and potassium in the form of superphosphate (10.5%) at 500 kg ha^{-1} and potassium chloride (50%) at 400 kg ha^{-1} respectively. Phosphorus, and potassium were incorporated into the soil prior to transplanting while nitrogen was split applied in two equal parts. The first portion was incorporated before transplanting while the second portion was applied as a top dress three weeks later.

The three species of vegetable amaranth used were; *A. hypochondriacus*, *A. tricolor* and *A.hybridus*. The seeds were obtained from the VOPI. Seedlings were transplanted to the plots on the 27th and 28th of January 1997 and water was applied immediately by sprinkler irrigation (6 mm) to help the seedlings establish.Thereafter, irrigation was applied at the rate of 15 mm per every two weeks when moisture was limiting. Weed control was done by hand. Pests were controlled when the infestation was seen to be threatening normal plant growth.

Harvesting was done six weeks after transplanting on the middle three rows leaving two plants for nutritional analysis. During harvesting yield samples were divided into two components viz; the edible and non-edible portion. The edible portion (leaves and tender tops/shoots) was cut 30 cm above ground level for *A. hypochondriacus* and *A. hybridus* while *A. tricolor* was cut at 10-15 cm above ground level because of its short growth habit. The remaining hard stem and older leaves made up the none edible portion and was cut at ground level without leaving any visible stumps. Fresh and dry mass were determined for both edible and non edible portions. Total biomass (total fresh matter) yield was calculated from the edible and the non-edible portions and therefore comprised of only above ground matter excluding roots in determining harvest index. Quality analysis were done at the Animal Nutrition and Animal Products Institute of ARC, Department of Biochemistry of the University of Pretoria and Institute for Soil, Climate and Water of ARC for leaf nitrogen analysis. Due to high costs involved in nutritional analysis, plant leaf analysis was done on leaf material from plants with nitrogen application rates which were found to give the best yield. However, total nitrogen analysis was done in all treatments.

Visual inspection of plants was continuously done during the growing period to monitor their condition.

Data was statistically analysed at Agrimetrics Institute of the ARC using the Genstat 5 Release 3.2. The analysis of variance was done as well as multiple comparison test using the Bonferroni multiple comparison test for factors showing significant difference at 5% level.

4.3 Results

Yield

According to the analysis of variances, the nitrogen treatments differed significantly from each other ($p<0.01$) for all yield components (fresh or dry weight mass- Table 8 to 10, Figures 3 & 4 and Appendix A). All the yield components exhibited a linear tendency for nitrogen treatment except for the dry non edible portion for *A. hybridus* which showed a slight quadratic tendency with the optimum reached at 150 kg N ha^{-1} (Table 2.6A). An interaction between nitrogen and amaranth species has also been observed for all yield components (Figures 3 & 4 and Tables 2.7A & 2.8A). There is a significant linear relationship for yield. Average yields have indicated *A. hydridus* to be superior to the other two species (Tables 8 & 10 and Figures 3 & 4). However, the average yields for all species in this experiment are relatively lower than those of the preliminary experiment.

The control treatment (0 kg N ha^{-1}) has resulted in the lowest total yield of all species, however, this was not significant (Table 8 to 10 and Appendix A). Yields for *A. hypochondriacus* at application rates of 0,25, 75 and 100 kg N ha^{-1} were significantly lower than that of the 200 kg N ha^{-1} treatment; however, yields obtained from 125 to 200 kg N ha^{-1} did not differ significantly from each other. Yields obtained for *A. tricolor* at application rates of 0, 50 and 75 kg N ha^{-1} were significantly smaller than those realised with application rate of 200 kg N ha^{-1} while with *A. hybridus* 0 and 75 kg N ha^{-1} were the only rates to give fresh matter yield significantly lower than the 200 kg N ha^{-1} application. It is evident that yields continued to increase with every addition of nitrogen fertilizer up to the highest application rate of 200 kg N ha^{-1} for all the species reaffirming that the effect is still linear.

Table 8. Effect of nine nitrogen levels on total fresh matter (FM) and dry matter (DM) yield of three vegetable amaranth species.

N LEVELS (kg ha^{-1})	YIELD (1000 kg ha^{-1})							
	FRESH MATTER				DRY MATTER			
	A.hypochon	*A.tricolor*	*A.hybridus*	MEANS	*A.hypochon*	*A.tricolor*	*A.hybridus*	MEANS
0	8.67a	6.04ab	11.56a	8.76a	0.50a	0.34a	0.72a	0.52a
25	12.43ab	9.69abc	22.75abc	14.83ab	0.69ab	0.57ab	1.16ab	0.81ab
50	20.73abcd	5.90ab	23.52abc	16.72b	1.22bc	0.40ab	1.32ab	0.98bc
75	17.76abc	4.96a	20.75ab	14.49ab	1.02abc	0.32a	1.17ab	0.84ab
100	17.23abc	18.34abc	23.16abc	19.58bc	1.08abc	1.08b	1.27ab	1.15bcd
125	26.29cd	21.18c	33.87bc	27.11cd	1.53c	0.98ab	1.73b	1.41d
150	25.05bcd	19.07bc	32.30bc	25.47cd	1.35bc	0.89ab	1.64b	1.29cd
175	28.46cd	16.67abc	33.85bc	26.33cd	1.63c	0.86ab	1.69b	1.39d
200	31.79d	21.32c	35.45c	29.52d	1.68c	0.93ab	1.79b	1.45d
MEANS	20.93b	13.69a	26.31c		1.19b	0.71a	1.39c	
LSD	13.76	13.76	13.76	7.94	0.70	0.70	0.70	0.41

Means in the same column followed by the same letter are not significantly different based upon the Bonferroni multiple comparison test

Test level = 0.05

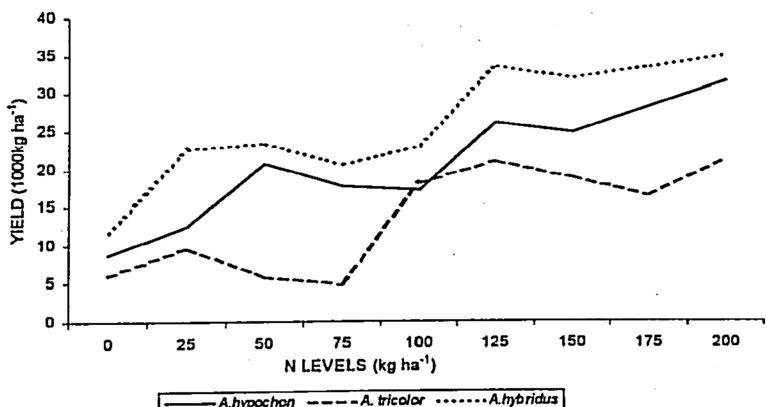

Figure 3. Effect of nine levels of nitrogen on total fresh matter (FM) yield of three vegetable amaranth species

Edible fresh matter yield accounted for more than 50% of the total fresh matter yield. In some cases the marketable yield made up more than 60% of the total yield (Table 9). The difference can be attributed to inconsistancy in the cutting height since several people were engaged in the harvesting and in some cases one might cut slightly higher or lower than others. This data was not statistically analysed but has been included to show the proportion of the marketable yield/harvest index of the crop which might be useful in further investigations.

Table 9. Harvest index of three vegetable amaranth species at nine nitrogen application levels.

N-LEVELS (kg ha^{-1})	Harvest Index %		
	A. hypochondriacus	*A. tricolor*	*A. hybridus*
0	64.13	51.16	60.29
25	54.06	57.79	61.49
50	59.62	60.00	52.38
75	51.63	61.69	67.08
100	67.09	69.63	54.75
125	59.64	64.07	58.67
150	57.92	57.37	54.09
175	54.15	57.17	57.28
200	64.20	63.37	68.91
MEANS	59.16	60.25	59.44

Table 10. Effect of nine levels of nitrogen application on edible portion yields (Fresl matter (FM) and Dry matter (DM)) of three vegetable amaranth species.

N LEVELS (kg ha^{-1})	YIELD (1000 kg ha^{-1})							
	FRESH MATTER				DRY MATTER			
	A.hypochon	*A.tricolor*	*A.hybridus*	MEANS	*A.hypochon*	*A.tricolor*	*A.hybridus*	MEAI
0	5.56a	3.09ab	6.97a	5.21a	0.33a	0.19a	0.44a	0.32a
25	6.72a	5.60a	13.99ab	8.77abc	0.38ab	0.32a	0.69abc	0.46a
50	12.36ab	3.54abc	12.32ab	9.41abc	0.70abc	0.23a	0.70abc	0.55a
75	9.17a	3.06a	13.92ab	8.72ab	0.52abc	0.19a	0.76abc	0.49a
100	11.56ab	12.77abc	12.68ab	12.33bcd	0.71abc	0.66a	0.66ab	0.67b
125	15.68ab	13.57c	19.87bc	16.37de	0.88bc	0.58a	0.98bc	0.82c
150	14.51ab	10.75abc	17.47bc	14.24bcde	0.76abc	0.49a	0.83abc	0.70b
175	15.41ab	9.53abc	19.39bc	14.78cde	0.86bc	0.47a	0.94abc	0.76b
200	20.41b	13.51bc	24.43c	19.45e	1.04c	0.58a	1.20c	0.94d
MEAN	12.38b	8.38a	15.67c		0.69b	0.41a	0.80b	
LSD	10.43	10.43	10.43	6.02	0.53	0.53	0.53	0.31

Means in the same column followed by the same letter are not significantly different based upon the Bonferroni multiple comparison test

Test level = 0.05

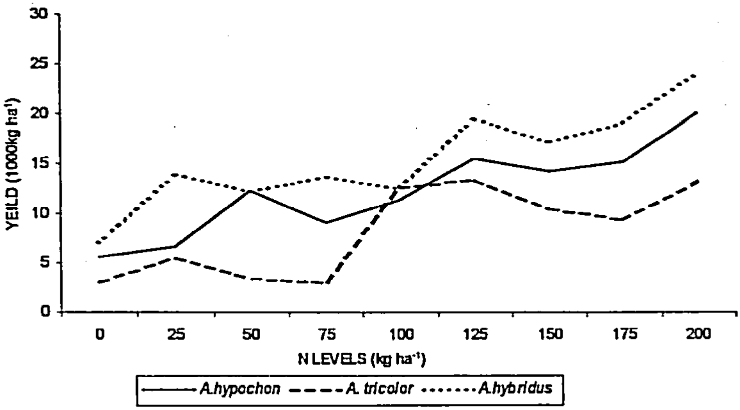

Figure 4. Effect of nine levels of nitrogen on edible fresh matter (FM) yield of three vegetable amaranth species

Quality

Since the analysis for quality components on all treatments was not done due to high costs, only data from treatment levels that were found to be representive of optimal nitrogen application rates has been presented in table 11. This table reveals that the crop is rich in numerous nutrients essential to humans although lower when compared to what Allemann *et al.* (1996) found in the same species particularly in such substances as protein and vitamin A.

Table 11. Nutritional quality of three vegetable amaranth species at an application rate of 125 kg N ha^{-1}.

SUBSTANCE	NUTRITIONAL COMPOSITION		
	A. hypochon	*A. tricolor*	*A. hybridus*
Protein (%)	14.26	21.24	16.72
Fat (%)	4.75	3.73	5.19
Fibre (%)	12.18	11.28	10.74
Sugars (%)	45.81	38.33	44.89
Vit. A (mg $100g^{-1}$)	0.75	0.35	0.49
Vit B_1 (mg $100g^{-1}$)	0.06	NA	0.02
Vit B_2 (mg $100g^{-1}$)	0.22	0.15	0.22
Vit B_3 (mg $100g^{-1}$)	0.17	NA	0.06
Vit C (mg $100g^{-1}$)	25.93	26.44	26.89
Arginine (mg $100g^{-1}$)	940.00	1290.00	900.00
Histidine (mg $100g^{-1}$)	60.00	140.00	90.00
Isoleucine (mg $100g^{-1}$)	330.00	720.00	600.00
Leucine (mg $100g^{-1}$)	740.00	1290.00	1360.00
Lysine (mg $100g^{-1}$)	580.00	1150.00	1020
Methionine (mg $100g^{-1}$)	120.00	160.00	210.00
Phenylalanine (mg $100g^{-1}$)	620.00	900.00	760.00
Threonine (mg $100g^{-1}$)	490.00	870.00	580.00
Valine (mg $100g^{-1}$)	370.00	820.00	560.00
Ash (%)	16.18	17.53	16.61

*NA- Not Available

More than 90% of the vegetable product is water. Effect of increased nitrogen fertiliization levels on the plant water content has not been clearly revealed (Table 12). The lowest water content for *A. hypochondriacus*, *A. tricolor* and *A. hybridus* were 93.73, 93.22 and 93,77% respectively, while the highest water content were 94.61, 95.64 and 95.01% respectively. The differences between these figures is quite small which represent less significant differences amongst treatments as revealed by the Bonferroni multiple comparison test. Only the nitrogen application level of 200 kg ha^{-1} for *A.tricolor* differed from other treatments while the same treatment showed a significant difference only with 0 kg N ha^{-1} application level for *A hybridus*. No significant difference amongst treatments was revealed for *A. hypochondriacus*.

Table 12. Effect of nine nitrogen application levels on water content of three vegetable amaranth species (expressed as percentage (%) of total fresh matter yield).

N-LEVELS (kg ha^{-1})	Water Content (%)			
	A.hypochon.	*A.tricolor*	*A. hybridus*	MEANS
0	94.23a	94.37abc	93.77a	93.94a
25	94.45a	94.12ab	94.90ab	94.38abc
50	94.11a	93.22a	94.39ab	93.88a
75	94.26a	93.55a	94.36ab	94.02ab
100	93.73a	94.11ab	94.52ab	94..08ab
125	94.18a	95.37cd	94.89ab	94.79cd
150	94.61a	95.33cd	94.92b	94.93cd
175	94.27a	94.84bcd	95.01b	94.71bcd
200	94.27a	95.64d	94.95b	95.10d
MEANS	94.23a	94.45ab	94.59b	
LSD	1.20	1.20	1.20	0.69

Means in the same column followed by the same letter are not significantly different based on the Bonferroni multiple comparison test

Test level = 0.05%

The nitrogen content for the nine nitrogen application levels has been determined in the dry matter for the three species and the results are summarized under table 13. Although not statistically analyzed, the nitrogen content seem to be related to the highest fertilizer rate (200 kg N ha^{-1}) leading to higher nitrogen accumalation than the rest of the treatments for all the species. *A. tricolor* accumulated significantly more nitrate than both other species averaged over all the levels of N application. Leaf nitrate accumulation averaged over all the treatment were 3.60%, 3.98% and 3.62% for *A. hypochondriacus*, *A. tricolor* and *A. hybridus* respectively.

Table 13. Total nitrogen content (% of dry matter yield) in leaf material of three vegetable amaranth species after applying nine levels of nitrogen fertilizer.

N-LEVELS (kg ha^{-1})	Nitrogen Content(%)			
	A. hypochon.	*A. tricolor*	*A. hybridus*	MEANS
0	3.43	3.88	3.08	3.46a
25	3.06	NA*	3.32	3.31a
50	3.79	3.81	3.12	3.57ab
75	3.26	3.62	NA*	3.38a
100	3.3	4.15	3.66	3.70ab
125	3.69	4.01	3.97	3.89ab
150	3.76	4.39	4.08	4.71ab
175	3.84	4.00	3.93	3.92ab
200	4.27	4.40	4.16	4.28b
MEANS	3.60a	3.98b	3.62a	

Means followed by the same letter are not significantly different based on the Bonferroni multiple comparison test

Test level = 0.05%

*NA means not available

4.4 Discussion and Conclusions

Yield

Nitrogen fertilizer played an invaluable role in the yield of vegetable amaranth. Observations made in the preliminary experiment about the influence of nitrogen on the yield has been confirmed in this experiment. The results are consistent with those of the preliminary experiment and the significant linear relationship between yield and nitrogen fertilization continued indicating that the optimal level of N fertilizer was still not reached at application of 200 kg N ha^{-1}. These results are also in agreement with data from several other researchers who found leafy vegetables as well as forage crops receiving high doses of nitrogen improve their biological yield (Makus, 1987; Markovic *et al.*, 1989; Vavrina & Obreza, 1993; Foy & Campbell, 1994; Whitehead & Singh, 1994; Thompson & Doerge, 1995). Plants receiving a low nitrogen treatment particularly 0 kg N ha^{-1} had a stunted growth with some yellowish color particularly in the lower leaves characteristic of nitrogen deficiency. Leaf size and number, although not measured were observed to increase with increase in N fertilization with plants receiving less fertilizer having relatively lower vegetative volume and narrow and smaller leaves. Yield increases following fertilizer application from 0 to 200 kg N ha^{-1} were 71.73%, 72,65% and 67.39% for *A. hypochondriacus, A. tricolor* and *A. hybridus* respectively. Vavrina & Obreza (1993) recorded a 14.2% increase in head fresh weight of Chinese cabbage when nitrogen application was raised from 67 to 112 kg N ha^{-1}. There was however no significant difference between the yield of the three species treated with 125 kg N ha^{-1} and that treated with 200 kg N ha^{-1} which might confirm the possibility of an excessive level beyond which no benefit will be realized from continued addition of more fertilizer. However this cannot be an outright conclusion since the results indicated a linear relationship which calls for further investigation particularly with higher doses of nitrogen to determine a point where yield no longer increases. In view of this observation it was not possible to say which level was optimal.

Quality

Quality analyses were carried out on a selected number of plants due to the prohibitively high cost of analyses. However, nutritional composition of the three species determined in this study compare favourably to those recorded by Gopalan *et al.* (1971) in Salunkhe (1984). Water content is relatively higher than reported in table 1; however no conclusion can be reached as to whether this could have been due to any factor or condition prevailing during any of the experiments from which these data were collected. Total nitrogen content was measured for all the treatments and showed a tendency towards increased application of nitrogen fertlizer. This is consistent with many findings which establish total nitrogen content of leafy vegetables to be nitrogen fertilization dependent (Cantliffe,1973; Rose & Guillarmod, 1974; Maynard *et al.*,, 1976; Ryder, 1979; Breimer, 1982; Eze, 1986; Makus, 1989; Cserin & Prohászka, 1987; Mengel & Kirkby, 1987; Walters *et al.*, 1988). The total nitrogen content for the highest nitrogen treatment for all the species is well over critical values for table beet (leaves & roots) and spinach leaves as determined by Cantliffe (1973) to be values at which NO_3 will correspondingly start to accumulate. Therefore, according to these values, *A. tricolor* had started accumulating NO_3 even at 0 kg N ha^{-1} while *A. hypochondriacus* and *A. hybridus* started at 125 kg N ha^{-1} and 100 kg N ha^{-1} respectively. Whether, the amount accumulated posed any human health hazard is a case for further investigation.

The results revealed no optimal nitrogen application level because the plants continued to accumulate more nitrogen with every increase in nitrogen levels. No conclusion can also be drawn for the nutritional quality attributes as the analyses has not been carried on all the treatments; however, vegetable amaranth compares favourably with other leafy vegetables investigated by other reseachers.

CHAPTER 5

EFFECT OF NITROGEN ON THE YIELD AND QUALITY OF VEGETABLE AMARANTH (AUTUMN PLANTING).

5.1 Introduction

The results of the previous two experiments were not conclusive and also varied from each other. This experiment was therefore conducted to substantiate and compare the results of these previous experiments with an autumn planting. It will also enable a comparison of the effects of such factors as temperature, light intensity and precipitation on nitrogen utilization by plants. Vegetable amaranth is a fast growing crop, and because of its superior nutritional quality, it might be necessary for resource poor farmers to plant several crops during different times of the year when the climate allows production.

5.2 Materials and Methods

The experiment was conducted at the Agricultural Research Council (ARC)-Roodeplaat Vegetable and Ornamental Plant Institute at Pretoria, South Africa in Autumn of 1997 (March/April/May). Since the experimental area is adjacent to the first two, they have the same soil type of Hutton from Shorrocks series. The experimental area is located at Roodeplaat (Latitude 25° 35' 10"S, Longitude 28° 20' 45"E, altitude 1 155m above sea level). The fertility status of the soil before the experiment was established and is summarized in appendix C. The climatological data during the season is summarized in appendix B.

The experiment used the three species of vegetable amaranth used in the first experiments (*A. hypochondriacus, A. tricolor* and *A. hybridus*) and the seeds were obtained from the Vegetable and Ornamental Plant Institute (VOPI). Nine levels of nitrogen application viz; 0 kg ha^{-1} (control), 25, 50, 75, 100, 125, 150, 175 and 200 kg N ha^{-1} were used and the source was limestone Ammonium Nitrate (LAN

28%). All plants received 500 kg ha^{-1} of superphosphate (10.5%) and 400 kg ha^{-1} of potassium chloride (50%).

The experiment was laid out as a complete randomized design (CRD) with three replications for each treatment. These gave a factorial experiment of 9x3x3 (nine N levels x three species x three replications). Plot size was 1.25 x 5.0 m with data collected from a subplot of 0.75 x 5.0 m (three middle rows). Plant spacing was 25 x 25 cm giving a total plant population of 160 000 plants ha^{-1}.

Seedbed preparation was done by ploughing, discing and rotovating to give a fine tilth. Plots were marked accordingly, leaving path rows of two metres between plots since no guard rows were planted to take off any treatment overlaps. Nitrogen application was split in two equal parts with the first portion incorporated together with phosphorus and potassium prior to transplanting. The second portion was applied as a top dress three weeks after transplanting. The seedlings were transplanted on 19th and 20th of March 1997. Irrigation was applied immediately at about 6 mm to help the seedlings establish and thereafter applied at a rate of 15 mm every two weeks when moisture was limiting (this was based on the rainfall, conditions of the plants as well as visual soil moisture estimation where the soil was not allowed to dry to a point where it will not hold together when pressed between fingers). Weed control was done by hand.

As with previous experiments plants were grown for six weeks and thereafter harvested by cutting at 20-30 cm above ground for *A. hypochondriacus*, and *A.hybridus* and 10-15 cm for *A. tricolor* because of the difference in growth habit, where some plants were taller than others. Data was collected in the three middle rows leaving two plants per plot for leaf analysis. Yield samples were divided into two components viz; edible (marketable) and a nonedible portion (the remaining stems after cutting). Plant mass was taken for both dry and fresh matter yield and total yields calculated accordingly from which harvest index was also determined.

Plant leaf analysis for nutritional composition was done on leaf material from plants at nitrogen application rates which were found to give the best yield. Total nitrogen analysis was however done for all treatments with the first leaf analyses done three weeks after transplanting prior to top dressing and the other analysis done at harvesting.

Plants were inspected continuously during the growing period for any abnormality in their growth.

Data was statistically analyzed for analysis of variance using the Genstat 5 Release 3.2. The analysis of variance was done as well as multiple comparison test using the Bonferroni multiple comparison test for factors showing significant difference at 5% level.

5.3 Results

The results of this experiment reiterate findings by other researchers and also observations made in the previous experiments. These results are summarized in tables 14, 15, 16, 17, 18 & 19, figures 5 & 6 and Appendix A.

Yield

On average, the yields of *A.hypochondriacus* and *A.hybridus* were significantly higher than that of *A.tricolor*. Neither fresh matter nor dry matter yield of *A.tricolor* increased signficantly when nitrogen application level was raised from 0 kg N ha^{-1} to 200 kg N ha^{-1} (Tables 14 & 16). Statistical analysis have, however, found nitrogen to have a significant effect on all yield components for *A. hypochondriacus* and *A. hybridus* (Tables 14 & 16). Significant differences were observed between the yields obtained at 0 kg N ha^{-1} and 200 kg N ha^{-1} for both species. The analysis of variance has shown a highly significant linear relationship for all the species towards increased nitrogen application levels. Interaction between species and nitrogen application was also significant for all yield componets (Tables3.7A & 3.8A and Figures 5 & 6).

Genotypic variation in response to nitrogen utilization has also been reaffirmed in this experiment when *A. hypochondriacus* and *A.hybridus* gave higher average yields compared to *A. tricolor* under similar conditions of the experiment. *A. hypochondriacus* and *A.hybridus* did not differ significantly from one another (Table 14 & 16).

Table 14. Effect of nine nitrogen levels on total fresh matter (FM) and dry matter (DM) yield of three vegetable amaranth species.

N LEVELS (kg ha^{-1})	YIELD (1000 kg ha^{-1})							
	FRESH MATTER				DRY MATTER			
	A.hypochon	*A.tricolor*	*A.hybridus*	MEANS	*A.hypochon*	*A.tricolor*	*A.hybridus*	MEANS
0	3.92a	0.23a	3.46a	2.53a	0.27a	0.02a	0.24a	0.18a
25	4.76ab	1.01a	7.18ab	4.32ab	0.33a	0.07a	0.47ab	0.29ab
50	11.62bc	1.49a	10.86abc	7.99bc	0.71b	0.10a	0.63bc	0.48bc
75	12.70c	1.62a	18.30cd	10.87cde	0.78b	0.11a	0.98cd	0.63cde
100	12.82c	1.56a	13.46bc	9.28cd	0.82bc	0.10a	0.77bc	0.56cd
125	15.35cd	2.21a	16.86cd	11.47cde	0.92bc	0.15a	0.93cd	0.67cde
150	18.43cd	1.97a	22.75de	14.39ef	1.04bcd	0.13a	1.18de	0.79ef
175	20.42d	1.57a	15.00c	12.33de	1.15cd	0.10a	0.86cd	0.70de
200	22.75d	2.12a	26.20e	17.02f	1.31d	0.15a	1.39e	0.95f
MEANS	13.64b	1.53a	14.90b		0.82b	0.10a	0.83b	
LSD	7.50	7.50	7.50	4.33	0.37	0.37	0.37	0.21

Means followed by the same letter are not significantly different based on the Bonferroni multiple comparison test

Test level = 0.05%

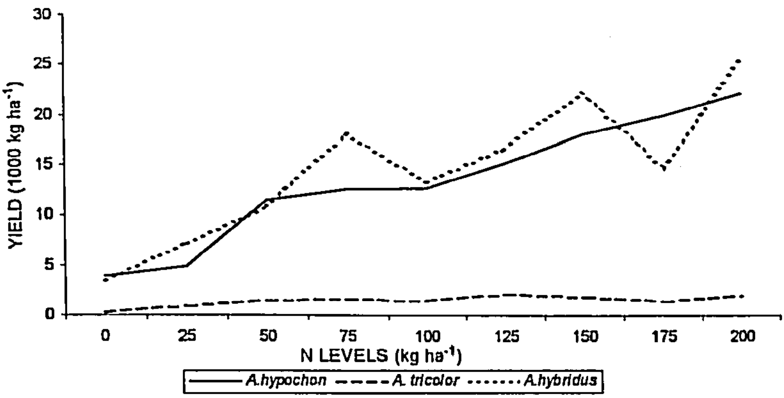

Figure 5. Effect of nine levels of nitrogen on total fresh matter (FM) yield of three vegetable amaranth species

Plant growth in terms of plant height, leaf size and general vegetative volume was generally poor for plants receiving less nitrogen fertilisation as shown by the low biological yield (Table 14). Fresh edible yield accounted for close to 70% of the total fresh matter yield (above ground or biological yield) for both *A. hypochondriacus* and *A. hybridus* while it accounted for less than 65% for *A. tricolor* (Table 15). No statistical explanation can be given because of the inconsistancy that is sometimes experienced with cutting height at harvesting (because of human error as different people were used to assist with the harvesting). However, the difference found in the harvest index between the species is consistant with vegetative growth volume which was observed to be relatively high for *A. hypochondriacus* and *A. hybridus* while lower for *A. tricolor*. Average edible potion yields (Table16) for *A. hypochondriacus* and *A. hybridus* were not significantly different from each other while it was different from *A. tricolor*. The same trend has been observed for total biomass yield (Table 14).

Table 15. Harvest index of three vegetable amaranth species at nine nitrogen application levels.

N levels kg ha^{-1}	Harvest Index (%)		
	A. hypochondriacus	*A. tricolor*	*A. hybridus*
0	68.37	56.52	74.57
25	73.74	65.35	70.61
50	66.70	66.44	66.85
75	69.92	59.86	59.49
100	74.02	61.54	64.93
125	68.86	62.44	71.95
150	69.23	68.02	70.55
175	63.61	72.61	64.40
200	68.04	66.98	78.38
MEANS	69.17	64.42	69.08

Table 16. Effect of nine nitrogen levels on edible portion yields, (Fresh Matter (FM) and Dry Matter (DM)) of three vegetable amaranth species.

N LEVELS (kg ha^{-1})	YIELD (1000 kg ha^{-1})							
	FRESH MATTER				DRY MATTER			
	A.hypochon	*A.tricolor*	*A.hybridus*	MEANS	*A.hypochon*	*A.tricolor*	*A.hybridus*	MEANS
0	2.68a	0.13a	2.58a	1.80a	0.19a	0.01a	0.18a	0.13a
25	3.51ab	0.66a	5.07ab	3.08ab	0.24ab	0.05a	0.33ab	0.21ab
50	7.75bc	0.99a	7.26abc	5.33bc	0.46bc	0.07a	0.42bc	0.32bc
75	8.88cd	0.97a	11.22cd	7.02c	0.53cd	0.07a	0.59cde	0.40cd
100	9.49cd	0.96a	8.74bcd	6.39c	0.60cd	0.07a	0.49bcd	0.39cd
125	10.57cd	1.38a	12.13de	8.03cd	0.64cd	0.10a	0.66de	0.47de
150	12.76de	1.34a	16.05e	10.05de	0.72de	0.10a	0.81ef	0.54ef
175	12.99de	1.14a	9.66bcd	7.93cd	0.73de	0.08a	0.55bcd	0.45de
200	15.48e	1.42a	16.68e	11.19e	0.90e	0.11a	0.89f	0.63f
MEAN	9.35b	1.00a	9.93b		0.56b	0.07a	0.55b	
LSD	4.70	4.70	4.70	2.71	0.23	0.23	0.23	0.13

Means in the same column followed by the same letter are not significantly different based upon the Bonferroni multiple comparison test

Test level = 0.05

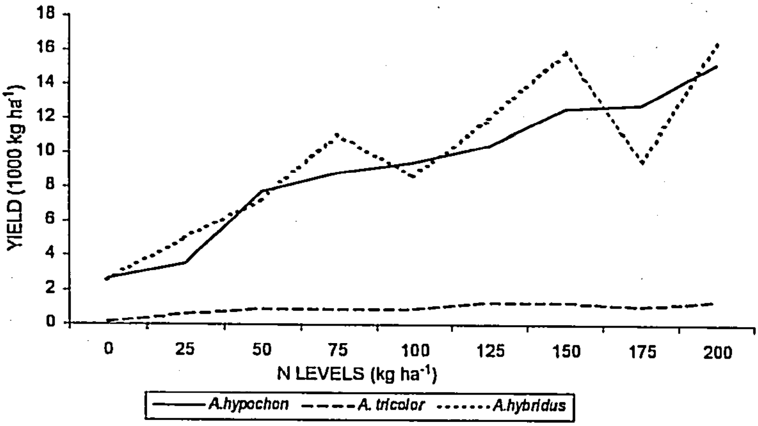

Figure 6. Effect of nine levels of nitrogen on edible fresh matter (FM) yield of three vegetable amaranth species

Quality

Quality analysis, as in the previous experiment has been restricted to cost effective components only. However, the most expensive analyses were done on one treatment only which was arbitrarily chosen as the most optimal, simply to give an indication of nutritional values of the vegetable amaranth under specific conditions at that time of the season. The results are summarized in tables 17, 18 and 19 . Protein was once again found to be lower than that showed in table 3 by Allemann *et al.* (1996) and the fat content was found to be almost twice as high as that revealed in table 3. However, the results compared favourably to those of vegetables shown in tables 1and 2.

Table 17. Nutritional Quality of three vegetable amaranth species at a nitrogen application level of 150 kg N ha^{-1}

SUBSTANCE	NUTRITIONAL CONTENT		
	A. hypochon.	*A. tricolor*	*A. hybridus*
Protein (%)	20.65	25.45	24.93
Fat (%)	4.90	4.07	4.43
Fibre (%)	NA*	NA	NA
Sugars (%)	NA	NA	NA
Ash (%)	20.37	19.47	16.66
Vit. A ($mg.100g^{-1}$)	11.24	7.83	10.15
Vit. B_1 ($mg.100g^{-1}$)	0.01	0	0
Vit. B_2 ($mg.100g^{-1}$)	0.11	0.10	0.09
Vit. B_3 ($mg.100g^{-1}$)	0.66	0.78	0.77
Vit. C ($mg.100g^{-1}$)	1.42	2.92	4.67
Arginine ($mg.100g^{-1}$)	900.00	1 270.00	940.00
Isoleucine ($mg.100g^{-1}$)	720.00	1 060.00	760.00
Leucine ($mg.100g^{-1}$)	1 310.00	1 900.00	1 370.00
Lysine ($mg.100g^{-1}$)	950.00	1 430.00	1 000.00
Methionine ($mg.100g^{-1}$)	290.00	390.00	300.00
Phenylalanine ($mg.100g^{-1}$)	830.00	1 170.00	900.00
Threonine ($mg.100g^{-1}$)	740.00	1 010.00	780.00
Valine ($mg.100g^{-1}$)	830.00	1 280.00	860.00

NA means not available

Water content as affected by nitrogen level was statistically analysed, and the data as summarised in table 18 reveals an increase in water content with higher nitrogen treatments particularly for *A. hypochondriacus* and *A. hybridus* where there is a significant difference between application rate of 0 kg N ha^{-1} and 200 kg N ha^{-1}. The analysis of variance also indicated a linear relationship between water content and nitrogen application levels. However, the difference between the lowest and highest content does not exceed 2.5% for all the species. All the treatments yielded over 90% water for all three species. *A. hypochondriacus* and *A. hybridus* tend to be more succulent than *A. tricolor* (Table 18). Mean differences do comfirm that highest nitrogen treatments were giving a relatively more succulent product.

Table 18. Effect of nine nitrogen application levels in the water content of three vegetable amaranth species.

N levels kg ha^{-1}	WATER CONTENT(%)			
	A. hypochndriacus	*A. tricolor*	*A. hybridus*	MEANS
0	93.11a	91.30a	93.06a	93.21a
25	93.07a	93.07a	93.45ab	93.24a
50	93.89ab	93.29a	94.20bc	93.86ab
75	93.86ab	93.21a	94.80c	93.93b
100	93.60ab	93.59a	94.28bc	93.83ab
125	94.01ab	93.21a	94.48bc	93.85ab
150	94.36b	93.40a	94.81c	94.17b
175	94.37b	93.63a	94.27bc	94.03b
200	94.24b	92.92a	94.64c	93.98b
MEANS	93.79b	93.43a	94.15c	
LSD	1.15	1.15	1.15	0.66

Means followed by the same letter are not significanly different based upon the Bonferroni multiple comparison test
Test Level = 0.05

Table 19 shows that *A. hypochondriacus* and *A. hybridus* accumulated more nitrogen at younger age than at older age and the amount accumulated did not seem to be fertilizer dependent particularly at the early age. On contrary, accumulation of nitrogen did not differ with age for *A. tricolor* but there was a tendency towards increased fertilizer application levels. Statistical analysis on nitrogen content amongst species indicated no significant difference amongst the species at three week stage. No significant difference was found between *A. hypochondriacus* and *A. hybridus* at six week stage; however, *A. tricolor* accumulated more nitrogen when analysed over all levels of N fertilizer at the six week growth stage than the other two species.

Table 19. Total nitrogen content (%) in leaf material of three vegetable amaranth species after nine levels of nitrogen fertilization at different growth stages

N levels in kg.ha⁻¹	Nitrogen Content (%)							
	A. hypochon.		*A. tricolor*		*A. hybridus*			
	3 week	6 week	3 week	6 week	3 week	6 week	3 week	6 week
0	4.27	3.33	4.57	4.57	3.89	3.07	4.24ab	3.66a
25	4.16	3.29	3.87	4.55	4.06	3.19	4.03a	3.68a
50	4.31	3.67	4.86	4.88	4.01	3.21	4.39ab	3.92ab
75	5.02	3.88	5.05	4.29	4.23	3.94	4.77ab	4.04ab
100	4.09	3.77	4.59	5.23	4.50	3.52	4.39ab	4.17ab
125	4.74	3.77	4.43	4.41	4.89	3.63	4.69ab	3.94ab
150	4.48	3.96	5.03	5.05	4.52	3.87	4.68ab	4.29ab
175	4.37	3.93	5.40	5.33	4.68	3.67	4.82ab	4.31ab
200	4.87	4.16	5.05	5.35	5.12	4.03	5.01b	4.51b
MEAN LSD	4.48c	3.75a	4.76c	4.85b	4.43c	3.57a		

Means in the same column and same row followed by the same letter are not significanly different based on the Bonferroni multiple comparison test

Test Level = 0.05

5.4 Discussion and Conclusions

Yield

The difference in yield between *A. hypochondriacus* and *A. hybridus* was less conspicuous in this experiment but more so for *A. tricolor.* The yield was lower in this experiment for all three species than in the two previous experiments with *A. tricolor* showing a severely reduced yield. This outcome could be due to a variety of reasons, such as light intensity and temperature which have a serious bearing on nitrogen assimilation and utilisation. Average temperature was lower during this experiment than in the previous experiments (Appendix B) which might have had an effect on the availability of nitrogen. Nitrogen availability in the soil involves several factors and processes some of which are physico-chemical, and others biological which are controlled by various environmental conditions. Some of those processes such as ammonification and nitrification are controlled by microbial activity and have been reported to be lower under 26 °C and 50 °C temperatures respectivily (Beck, 1983 in Mengel & Kirkby, 1987). Nitrification is biological oxidation of ammonia to nitrate (the main form of nitrogen taken up by plants) and it is possible that during this experiment the process was retarded by low temperatures resulting in some ammonia portion of the fertilizer being unavailable to plants. The continued increase in the yield of the three species of vegetable amaranth due to increased dose of nitrogen fertilizer despite difference in season or time of planting confirmed the importance of nitrogen fertilizer in producing high yields of leafy vegetables and forage crops. Such necessity has been proven by several researchers in the field of plant nitrogen nutrition (; Markovic *et al.*,1987; Makus, 1989; Elberhi *et al.*, 1993; Whitehead & Singh 1994; Thompson & Doerge 1995).

All three species continued to show genotypic variation in nitrogen utilization efficiency with a more pronounced variation in *A. tricolor* than the other two species. The variation in this experiment was, however, less than in the previous experiment. This corroborated reports that optimal levels of N supply differs among cultivars and species (Chevalier & Schrader, 1977; Cox *et al.*, 1985; Markovic *et al.*, 1987; Makus 1992; Elberhi *et al.*, 1993). The genotypic difference in yield was, however, not so evident between *A. hypochondriacus* and *A. hybridus*. This could possibly be attributed to seasonal adaptation with *A. hypochondriacus* not severely affected by late planting because it is better adapted to the conditions.

Reduced plant growth (plant height, leaf size etc.) for all species as observed at lower rates of nitrogen fertilizer is consistent with what many scientists call the essentiality of N for plant growth. Glass (1989) states that nitrogen is one the elements that participate directly as an indispensable requirement for the plant life cycle. Schrader (1984) attributes its importance to the fact that it is required throughout the development of a plant because it is a constituent of both structural and non-structural components of the cell. Its deficiency or inadequacy would definitely affect normal plant growth.

Quality

Results of this experiment on nutritional composition confirm the potential of vegetable amaranth as an alternative food crop. These results compare favourably with those cited in the literature review (Tables 1, 2 & 3). Once again the water content for all treatments is significantly higher than that shown in table 1 and this could be due to possible difference in growing conditions. *A. tricolor* accumulated more nitrogen than the other species at all the growth stages and this confirms varietal difference in N utilisation observed in yield as well. Therefore, age of the plants did not seem to have any effect on the amount of nitrogen accumulated for *A. tricolor.* However, *A. hypochondriacus* and *A. hybridus* accumulated more nitrogen at three weeks than at six weeks indicating that age has an influence on total nitrogen accumulated in these two species. It would therefore be advisable to harvest these two species at a later stage as the leaves contain less nitrogen, a precursor of nitrate and nitrite compounds known to be hazardous to humans. Addition of nitrogen had an influence on total nitrogen accumulated but this trend is not clear with *A. tricolor.* This finding is consistent with previous findings (Cantliffe, 1973; Rose & Guillarmod, 1974; Maynard *et al.*, 1976; Eze, 1986; Makus, 1986; Cserin & Prohászka, 1987; Mengel & Kirkby, 1987; Walters *et al.*, 1988)

CHAPTER 6

GENERAL DISCUSSION AND CONCLUSIONS

6.1 Yield

There is no doubt that nitrogen has a significant influence on the yield and quality of vegetable amaranth. The increase in levels of applied nitrogen fertilizer resulted in a significant increase in the yield of vegetable amaranth for all three species at the three different planting times. However, the average yields and quality attributes differed between the various planting dates.

Yield has been shown to increase as nitrogen doses increased, an outcome consistent with previous findings (Makus, 1986b; Markovic *et al.*,1987; Elberhi *et al.*, 1993; Vavrina & Obreza, 1993; Foy & Campbell, 1994; Whitehead & Singh, 1994; Thompson & Doerge, 1995). Decreasing nitrogen dose to levels as low as 0 kg N ha^{-1} adversely affected both plant growth and yield (fresh and dry matter) as opposed to high doses which promoted heavy vegetative volume and high yields. Mengel & Kirkby (1987), stated that the nitrogen nutrition of the plant controls the growth rate of the plant to a large extent during the vegetative growth stage. Beside reduced or stunted growth, those plants receiving less nitrogen were pale in colour, a sign characteristic of nitrogen deficiency. It is therefore important to supply plants with adequate nitrogen to cater for this stage of active growth for formation of leaves, stems and roots.

Good vegetative growth would ensure a good economic yield, particularly of the fresh matter which is required of leafy vegetables. This expectation has been confirmed in these experiments, particularly during the spring planting where yield (total fresh yield) was exceptionally high. However the other two planting times also showed a good yield response to increased application of nitrogen. The total fresh yield for *A. hypochondriacus* and *A. hybridus* continued to show a significant linear relationship to nitrogen fertilization for all planting dates. *A. tricolor* however showed no significant relationship with nitrogen treatment during the autumn experiment. Generally the results of these three planting times are consistent with previous findings as outlined in literature review.

Although the influence of nitrogen fertilization has been confirmed at the three planting times, average yields between the experiments were clearly different. The spring planting out performed the other two experiments with the autumn planting producing the lowest yield. Factors such as soil texture, soil pH, salinity and sodicity, other nutrients, sources of nitrogen, organic matter and genotype and plant density were equal for the three experiments. The difference in yield can therefore only be attributed to difference in season which comes as a result of the climatic conditions prevalent in a particular season. Rainfall, temperature and light vary from season to season. Climatic data registered at Roodeplaat during the course of the experiment is summarised under appendix B. The spring season gave the highest yields, indicating it to be the most favourable time to plant vegetable amaranth. This is consistent with the findings of Breimer (1982) that temperature (particularly soil temperature), day length and light intensity increase during the development of the crop and so favour both dry matter accumulation and nitrate reduction. On the contrary, the autumn season is characterised by declining temperatures, low light intensity and low rainfall; conditions which are generally unfavourable for crops such as vegetable amaranth. This investigation has also shown that autumn is a less suitable season to plant vegetable amaranth. Average sunlight hours during most of the month that the autumn crop was in the field (i.e March) were very low at 3.9 hours (Appendix B). Glass (1989) has indicated that the dependence of plant ion uptake on light in photosynthetic cells has been documented as far back as 1926. It is possible, that during the autumn season, ion uptake by roots might have been disrupted or disturbed by lack of or insufficient supply of photosynthates (carbobydrates) from the photosynthetic organs for the energy required. Temperature is another factor to which plant growth is very sensitive. Salisbury & Ross (1986) stated that every species of plant have minimum and maximum temperatures beyond which there will be no growth and an optimum at which growth is at a maximum. Plants are also said to require more nitrogen fertilizer under cool conditions than is required under warm conditions because of reduced root tissue activity at lower temperatures (Glass, 1989). These temperature conditions have also been shown not to be prevalent during the autumn season as compared to spring. Appendix B also shows that the average maximum temperatures were 27.7, 30.4 and 24.9°C for spring, summer and autumn months respectively. Low temperature (particularly low soil temperatures) have been shown to significantly reduce the dry weight of soybean (Duke *et al.*, 1979; Mederski, 1983) and high temperature have been indicated to lead to nitrogen losses due to denitrification and ammonia volatilization (Amberger, 1983). Relatively high temperature (30.4°C) and low temperature (24.9°C) conditions existed during the summer and autumn season of the vegetable amaranth trial and the resulting yield was relatively low for those two seasons. This outcome can also be used to indicate why the spring season is the most suitable time to grow vegetable amaranth.

Soil moisture and plant nutrition, especially nitrogen deficiency, affect crop production in arid regions (Pier & Doerge, 1995; Thompson & Doerge, 1996). Excessive water affects crop yields adversely by water logging and leaching of essential nutrients such as nitrogen. Water stress on the other hand results in poor plant ion uptake. Average rainfall was the highest and lowest during the months of March and February respectively (Appendix B); these are the months during which the two lowest yielding experiments (summer and autumn experiments) were actively growing. Rainfall was lowest (at 47mm) in February and this is the time during which the summer planting was actively growing. Although, all the trials were irrigated, total precipitation (i.e rainfall plus irrigation water) was lower in the summer trial than in the other trials. This resulted in the difference in total moisture available to the plants. Water is a solvent of many substances such as inorganic fertilizers and the amount of nutrients reaching the root is dependent on the rate of water flow or the water consumption of the plant and the average nutrient concentration of the water (Mengel & Kirkby, 1987). This means without water, plant utilization of nutrients, supplied to it by the soil, will be significantly reduced. It is possible that because the summer crop received relatively less water (total from irrigation and rainfall) this might have resulted in low yield due to reduced plant uptake of nitrogen even though this cannot be argued entirely since no soil analysis was done after harvesting. Reduced moisture had a greater adverse effect on leaf area than leaf number (Singh & Whitehead, 1992); during the summer trial plant vegetative volume was relatively reduced and so was the resulting yield. During the time (March) when most of the autumn planting was in the field, average rainfall was the highest at 207mm; average yields were also the lowest for the whole study. Excessive irrigation has been blamed for lower yields, low nitrogen uptake and higher unutilized fertilizer nitrogen (Thompson & Doerge, 1995). Nitrogen lost from the soil in the form of nitrate through leaching depends on the amount of water that moves through the soil (Pratt, 1984). Due to the amount of rain that fell during the time of the autumn experiment it is most probable that besides other factors such as low temperature and reduced amount of sunlight, inadequate soil nitrogen due to leaching below the active root zone, might have contributed to the low yields obtained. Therefore, excessive rainfall during March could have lead to loss of N out of the root zone, resulting in lower yields recorded for the autumn trial. Although no soil analysis was conducted to determine residual soil nitrogen, the low yield achieved in the autumn experiment is consistent with above findings. The need for greater amounts of nitrogen under excessive moisture conditions in order to reach optimal yields of lettuce have been documented by Thompson & Doerge (1995). The source of nitrogen used in this experiment was limestone ammonium nitrate (LAN) which contains approximately equal parts of both ammonium and nitrate, and the latter form, as stated by Braun & Roy (1983), has a poor performance under flooded paddy soils due to losses by leaching and nitrification. It is therefore, highly likely that this could have contributed to the low yields recorded. However, LAN is by far the best source of nitrogen since it combines the quick action of nitrate of soda with the more sustained action of sulphate of ammonia. It also contains sufficient calcium to counteract the acidifying effect of the ammonium nitrogen and hence no effect on the soil reaction (Hadfield, 1995). This means that under conditions of excessive soil moisture, particularly under heavy rainfall as recorded during the course of the autumn planting, additional nitrogen fertilization is one of the best solutions available to a grower. It is particularly true for a fast growing crop like vegetable amaranth since the so called slow release fertilizer would not release sufficient N within the short period of time during which the crop was growing.

The three species showed varietal differences in the yield during all three plantings with *A. hybridus* outperforming both *A. tricolor* and *A. hypochondriacus*. *Amaranthus hypochondriacus* as well as *A. hybridus* performed well in the autumn experiment. *Amaranthus tricolor* performed badly to such an extent that no significant differences occured amongst all the nitrogen treatments. This result was observed over all three plantings confirming the genotypic difference in dry matter accumulation in response to the application of various nitrogen fertilizer levels as previously reported (Chevalier & Schrader, 1977; Cox *et al.*, 1985; Markovic *et al.*, 1987; Makus, 1992; Elberhi *et al.*, 1993). The result of the autumn trial has shown that *A. hypochondriacus* is better adapted to a cool climate than the other two species while *A. tricolor* is the most unsuitable for autumn planting. It would therefore be uneconomical for any grower to plant *A. tricolor* in the cooler season while *A. hybridus* can be considered a crop of all seasons.

The results of these three experiments are not conclusive in terms of the objective of the study as the yield of the three vegetable amaranth species still showed a linear relationship with nitrogen application. This means that higher yields may be obtained with addition of more nitrogen, particularly under favourable conditions such as those that existed during the spring trial. More experiments using additional treatments are recommended.

6.2 Quality

Nutritional analysis were done on a very limited scale because of the costs involved, particularly for essential nutritional substances such as protein, vitamins and amino acids. However, the nutritional composition of vegetable amaranth in these experimenst is consistent with previous reports that the vegetable is nutritionally superior to most crops (Fafuso & Bassiri, 1976 in Feine *et al.*, 1979; Allemann *et al.*,1996).

Accumulation of NO_3-N estimated by the total nitrogen due to the nitrogen supply to plants is in line with previous observations (Cantliffe, 1973; Rose & Guillarmod, 1974; Maynard *et al.*, 1976; Eze, 1986; Makus, 1986(a); Cserin & Prohászka, 1987; Mengel & Kirkby, 1987; Walters *et al.*, 1988). During the summer and autumn experiments, the total nitrogen content in the leaves increased as levels of nitrogen application were raised. The magnitude of influence or response, however, differed from season to season and amongst species. Whether the amount of NO_3 in the product is detrimental to humans is open for further investigation. If critical values for spinach as identified by Cantliffe (1973) are anything to go by, then one might conclude that in the summer planting, the 100 kg N ha^{-1} application on *A. hypochondriacus* and *A. hybridus* should be the highest rate to use, while for *A. tricolor* 75 kg N ha^{-1} might be taken to be the highest. The data also showed all three species to accumulate exceptionally high levels of total N even at the lowest fertilizer application levels for autumn planting which might indicate the need for limited use of fertilizer in late season crop. The above observation is in agreement with results reported on spinach that spring conditions characterised by high light intensity and temperature favour lower NO_3 accumalation than autumn conditions (Cantliffe, 1973; Breimer, 1982; Mengel & Kirkby, 1987). The outlook on NO_3 accumulation as influenced by season for *A. tricolor* is even more alarming with this species accumulating high amounts, even in unfertilized plots.

Leaf nitrogen content has also been confirmed to depend on plant age. Plant leaf analysis done at three weeks of age showed the plants to contain more nitrogen than those analysed at six weeks of age (during harvesting). Rose & Guillarmod (1974) and Walters *et al.* (1988) observed NO_3-N to be prominent in immature plants. It is therefore advisable to harvest not earlier than three weeks and in the late crop it might even be worthwhile to extend the growing period a little longer than six weeks.

CHAPTER 7

SUMMARY AND CONCLUSIONS

e importance or potential of vegetable amaranth as an alternative food crop has en long recognised, but low vegetative yield normally obtained from local species der the current production practices has hindered the realisation of this potential. e effect of nitrogen fertilizer on the yield and quality of three vegetable amaranth ecies viz. *A.hypochondriacus, A.triolar* and *A.hybridus* was investigated under ld conditions over three different planting times during the 1996/97 planting ason. Various levels of nitrogen application were tried starting from 0 kg N ha^{-1} west) to 200 kg N ha^{-1} (highest).

ising nitrogen application levels from the lowest to the highest resulted in nificant increase in yields (total fresh matter and harvest index) during all the anting dates for *A.hypochondriacus* and *A.hybridus* while *A.tricolor* showed no nificant difference amongst treatments in the last trial (Autumn planting). mparison of yield amongst planting times, revealed that spring season is the st time to plant vegetable amaranth due to its relatively high average yields. The tumn planting was the least favourable. *A.hypochondriacus* performed as good *A.hyridus* during the summer trial. However, good yields were obtained even e in the planting season which indicated that with improved management actices (such as good fertilizer use, planting of the right cultivar or species) oduction of vegetable amaranth is possible for a good part of the growing season. conclusion was reached regarding recommendation of any fertilizer application vel because no optimal level was identified, since the yields showed a linear lationship with fertilizer application levels even with increased number of eatments. This calls for further investigation with more additional application vels to try to identify the highest level at which there will be no increase in yields.

utritional analysis have indicated that vegetable amaranth compares favourably ith other leafy vegetables. No conclusion has been drawn regarding the effect of nitrogen on essential nutritional substances such as protein, vitamins and amino acids because the scale of their analyses was limited by the high costs involved. A separate investigation with limited number of treatments (particularly those indicating to be optimal for yield) is recommended for future undertaking.

Accumulation of nitrogen in the plant matter has been shown to increase with levels of nitrogen for the two analysed trials (summer and autumn plantings). Nitrogen accumulation increased with delay in planting. Amongst the three species, *A. tricolar* had the highest nitrogen accumulation. Young plants were also shown to accumulate more nitrogen than the older plants.

Genotypic or varietal differences in nitrogen utilisation and nitrogen accumulation have also been confirmed in this study.

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APPENDIX A

SUMMARISED ANALYSIS OF VARIANCE

1. PRELIMINARY (SPRING) EXPERIMENT

Table 1.1A. Summarised analysis of variance for total fresh matter yield at seven levels of nitrogen application for three vegetable amaranth species.

Source		*A.hypochon*		*A.tricolor*		*A.hybridus*	
		df	F	df	F	df	F
Replicate (Reps)		2		2		2	
Nitrogen (N) Levels		6	<.001***	6	<.001***	6	<.001***
Lin		1	<.001***	1	<.001***	1	<.001***
Quad		1	0.170ns	1	0.522ns	1	0.013*
Cub		1	0.167ns	1	0.860ns	1	0.025*
Deviations		3	0.643ns	3	0.099ns	3	0.370ns
Residual		12		12		12	
Total		20		20		20	
C.V. (%)	Reps	5.0		17.9		4.7	
	Reps x N Levels	16.7		19.7		10.7	
SE	Reps	1.93		3.78		2.47	
	Reps x N Levels	6.48		4.17		5.68	

Table 1.2A. Summarised analysis of variance for fresh edible (marketable) yield at seven levels of nitrogen application for three vegetable amaranth species.

Source		*A.hypochon*		*A.tricolor*		*A.hybridus*	
		df	F	df	F	df	F
Replicate (Reps)		2		2		2	
Nitrogen Levels		6	0.003**	6	<.001***	6	<.001***
Lin		1	<.001***	1	<.001***	1	<.001***
Quad		1	0.299ns	1	0.621ns	1	0.225ns
Cub		1	0.257ns	1	0.870ns	1	0.175ns
Deviations		3	0.899ns	3	0.067ns	3	0.781ns
Residual		12		12		12	
Total		20		20		20	
C.V. (%)	Reps	10.9		8.8		17.3	
	Reps x N Levels	25.6		22.4		17.5	
SE	Reps	2.68		1.10		5.56	
	Reps x N Levels	6.29		2.78		5.63	

Table 1.3A. Summarised analysis of variance for fresh non-edible yield at seven levels of nitrogen application for three vegetable amaranth species.

Source		*A.hypochon*		*A.tricolor*		*A.hybridus*	
		df	F	df	F	df	F
Replicate (Reps)		2		2		2	
Nitrogen Levels		6	<.001***	6	<.001***	6	<.001***
Lin		1	<.001***	1	<.001***	1	<.001***
Quad		1	0.180ns	1	0.466ns	1	0.002**
Cub		1	0.291ns	1	0.505ns	1	0.017*
Deviations		3	0.263ns	3	0.247ns	3	0.083ns
Residual		12		12		12	
Total		20		20		20	
C.V. (%)	Reps	15.0		31.8		25.5	
	Reps x N Levels	13.1		20.4		11.2	
SE	Reps	2.13		2.77		5.31	
	Reps x N Levels	1.85		1.78		2.32	

Table 1.4A. Summarised analysis of variance for total dry matter yield at seven levels of nitrogen application for three vegetable amaranth species.

Source		*A.hypochon*		*A.tricolor*		*A.hybridus*	
		df	F	df	F	df	F
Replicate (Reps)		1		1		1	
Nitrogen Levels		6	<.001***	6	<.001***	6	<.001***
Lin		1	<.001***	1	<.001***	1	<.001***
Quad		1	0.194ns	1	0.140ns	1	0.369ns
Cub		1	0.899ns	1	0.976ns	1	0.137ns
Deviations		3	0.880ns	3	0.166ns	3	0.356ns
Residual		6		6		6	
Total		13		13		13	
C.V. (%)	Reps	10.2		15.3		3.7	
	Reps x N Levels	13.8		19.1		13.0	
SE	Reps	0.53		0.44		0.23	
	Reps x N Levels	0.71		0.55		0.81	

Table 1.5A. Summarised analysis of variance for dry edible (marketable) yield at seven levels of nitrogen application for three vegetable amaranth species.

Source		A.hypochon		A.tricolor		A.hybridus	
		df	F	df	F	df	F
Replicate (Reps)		1		1		1	
Nitrogen Levels		6	0.110ns	6	0.005**	6	0.032*
Lin		1	0.008**	1	<.001***	1	0.002**
Quad		1	0.283ns	1	0.238ns	1	0.977ns
Cub		1	0.978ns	1	0.783ns	1	0.349ns
Deviations		3	0.767ns	3	0.151ns	3	0.887ns
Residual		6		6		6	
Total		13		13		13	
C.V. (%)	Reps	17.6		11.4		16.0	
	Reps x N Levels	24.4		22.1		20.2	
SE	Reps	0.56		0.21		0.60	
	Reps x N Levels	0.78		0.41		0.76	

Table 1.6A. Summarised analysis of variance for dry non-edible yield at seven of nitrogen application for three vegetable amaranth species.

Source		A.hypochon		A.tricolor		A.hybridus	
		df	F	df	F	df	F
Replicate (Reps)		1		1		1	
Nitrogen Levels		6	<.001***	6	0.040*	6	0.023*
Lin		1	<.001***	1	0.005**	1	0.005**
Quad		1	0.463ns	1	0.096ns	1	0.072ns
Cub		1	0.672	1	0.648ns	1	0.125ns
Deviations		3	0.118ns	3	0.271ns	3	0.114ns
Residual		6		6		6	
Total		13		13		13	
C.V. (%)	Reps	1.7		22.1		15.0	
	Reps x N Levels	8.2		19.5		14.0	
SE	Reps	0.03		0.24		0.37	
	Reps x N Levels	0.16		0.21		0.35	

Table 1.7A. Summarised analysis of variance on the interaction of seven nitrogen levels and three vegetable amaranth species on fresh matter yield components.

Source		Total Fresh		Edible Fresh		Non Edible Fresh	
		df	f	df	f	df	f
Reps		2		2		2	
Species		2	<.001***	2	<.001***	2	<.001***
Nitrogen Levels		6	<.001***	6	<.001***	6	<.001***
Lin		1	<.001***	1	<.001***	1	<.001***
Quad		1	0.006**	1	0.117ns	1	0.004**
Cub		1	0.562ns	1	0.987ns	1	0.201ns
Deviations		3	0.099ns	3	0.312ns	3	0.277ns
Species x N Levels		12	0.018*	12	0.517ns	12	0.018*
Lin		2	0.003**	2	0.057ns	2	0.019*
Quad		2	0.243ns	2	0.715ns	2	0.062ns
Cub		2	0.017*	2	0.151ns	2	0.064ns
Deviations		6	0.778*	6	0.988ns	6	0.237ns
Residual		40		40		40	
Total		62		62		62	
CV %	Reps	5.0		10.8		22.8	
	Reps x Species x N Levels	15.1		24.1		17.0	
SE	Reps	1.89		2.50		3.32	
	Reps x Species x N Levels	5.67		5.55		2.45	

Table 1.8A. Summarised analysis of variance on interaction of seven nitrogen levels and three vegetable amaranth species on dry matter yield components.

Source		Total Dry		Edible Dry		Non Edible Dry	
		df	f	df	f	df	f
Reps		1		1		1	
Species		2	<.001***	2	<.001***	2	<.001***
Nitrogen Levels		6	<.001***	6	<.001***	6	<.001***
Lin		1	<.001***	1	<.001***	1	<.001***
Quad		1	0.055ns	1	0.265ns	1	0.014*
Cub		1	0.357ns	1	0.629ns	1	0.194ns
Deviations		3	0.583ns	3	0.940ns	3	0.081ns
Species x N Levels		12	0.553ns	12	0.838ns	12	0.080ns
Lin		2	0.339ns	2	0.500ns	2	0.077ns
Quad		2	0.973ns	2	0.697ns	2	0.294ns
Cub		2	0.340ns	2	0.655ns	2	0.211ns
Deviations		6	0.422ns	6	0.696ns	6	0.105ns
Residual		20		20		20	
Total		41		41		41	
CV %	Reps	2.2		10.9		11.6	
	Reps x Species x N Levels	16.4		25.3		15.1	
SE	Reps	0.1.0		0.32		0.21	
	Reps x Species x N Levels	0.78		0.74		0.28	

2. SUMMER TRIAL

Table 2.1A. Summarised analysis of variance for total fresh matter yield at different levels of nitrogen application for three vegetable amaranth species.

Source	*A.hypochon*		*A.tricolor*		*A.hybridus*	
	df	F	df	F	df	F
Nitrogen Levels	8	<.001***	8	<.001***	8	0.001**
Lin	1	<.001***	1	<.001***	1	<.001***
Quad	1	0.775ns	1	0.655ns	1	0.482ns
Cub	1	0.361ns	1	0.072ns	1	0.840ns
Deviations	5	0.315ns	5	0.031*	5	0.285ns
Residual	18		18		18	
Total	26		26		26	
C.V. (%)	22.0		32.0		22.3	
SE	4.60		4.38		5.88	

Table 2.2A. Summarised analysis of variance for fresh edible (marketable) yield at nine levels of nitrogen application for three vegetable amaranth species.

Source	*A.hypochon*		*A.tricolor*		*A.hybridus*	
	df	F	df	F	df	F
Nitrogen Levels	8	0.006**	8	<.001***	8	0.005**
Lin	1	<.001***	1	<.001***	1	<.001***
Quad	1	0.914ns	1	0.357ns	1	0.727ns
Cub	1	0.422ns	1	0.193ns	1	0.286ns
Deviations	5	0.603ns	5	0.010*	5	0.452ns
Residual	18		18		18	
Total	26		26		26	
C.V. (%)	32.8		34.0		27.5	
SE	4.06		2.85		4.31	

Table 2.3A. Summarised analysis of variance for fresh non-edible yield at nine levels of nitrogen application for three vegetable amaranth species.

Source	*A.hypochon*		*A.tricolor*		*A.hybridus*	
	df	F	df	F	df	F
Nitrogen Levels	8	0.002**	8	0.008**	8	0.010*
Lin	1	<.001***	1	<.001***	1	<.001***
Quad	1	0.473ns	1	0.757ns	1	0.086ns
Cub	1	0.690ns	1	0.056ns	1	0.279ns
Deviations	5	0.155ns	5	0.407ns	5	0.192ns
Residual	18		18		18	
Total	26		26		26	
C.V. (%)	28.4		41.7		29.8	
SE	2.43		2.22		3.17	

Table 2.4A. Summarised analysis of variance for total dry matter yield at nine levels of nitrogen application for three vegetable amaranth species.

Source	*A.hypochon*		*A.tricolor*		*A.hybridus*	
	df	F	df	F	df	F
Nitrogen Levels	8	<.001***	8	0.001**	8	0.006**
Lin	1	<.001***	1	<.001***	1	<.001***
Quad	1	0.277ns	1	0.215ns	1	0.374ns
Cub	1	0.407ns	1	0.138ns	1	0.721ns
Deviations	5	0.209ns	5	0.031*	5	0.488ns
Residual	18		18		18	
Total	26		26		26	
C.V. (%)	20.2		31.0		21.5	
SE	0.24		0.22		0.30	

Table 2.5A. Summarised analysis of variance for dry edible (marketable) yield at nine levels of nitrogen application for three vegetable amaranth species.

Source	*A.hypochon*		*A.tricolor*		*A.hybridus*	
	df	F	df	F	df	F
Nitrogen Levels	8	0.008**	8	0.003**	8	0.022*
Lin	1	<.001***	1	<.001***	1	<.001***
Quad	1	0.672ns	1	0.263ns	1	0.731ns
Cub	1	0.494ns	1	0.355ns	1	0.200
Deviations	5	0.534ns	5	0.036*	5	0.633ns
Residual	18		18		18	
Total	26		26		26	
C.V. (%)	30.3		35.1		27.1	
SE	0.21		0.15		0.22	

Table 2.6A. Summarised analysis of variance for dry non-edible yield at nine levels of nitrogen application for three vegetable amaranth species.

Source	*A.hypochon*		*A.tricolor*		*A.hybridus*	
	df	F	df	F	df	F
Nitrogen Levels	8	0.003**	8	0.003**	8	0.010*
Lin	1	<.001***	1	<.001***	1	<.001***
Quad	1	0.252ns	1	0.249ns	1	0.038*
Cub	1	0.705ns	1	0.050ns	1	0.261ns
Deviations	5	0.206ns	5	0.091ns	5	0.240ns
Residual	18		18		18	
Total	26		26		26	
C.V. (%)	30.2		32.8		26.5	
SE	0.15		0.10		0.16	

Table 2.7A. Summarised analysis of variance on the interaction of nine nitrogen levels and three vegetable amaranth species on fresh matter yield components.

Source		Total Fresh		Edible Fresh		Non Edible Fresh	
		df	f	df	f	df	f
Species		2	<.001***	2	<.001***	2	<.001***
Nitrogen Levels		8	<.001***	8	<.001***	8	<.001***
Lin		1	<.001***	1	<.001***	1	<.001***
Quad		1	0.387ns	1	0.914ns	1	0.140ns
Cub		1	0.743ns	1	0.523ns	1	0.127ns
Deviations		5	0.025*	5	0.054ns	5	0.045*
Species x N Levels		16	0.341ns	16	0.499ns	16	0.363ns
Lin		2	0.454ns	2	0.588ns	2	0.629ns
Quad		2	0.912ns	2	0.718ns	2	0.228ns
Cub		2	0.183ns	2	0.238ns	2	0.297ns
Deviations		10	0.253ns	10	0.389ns	10	0.349ns
Residual		54		54		54	
Total		80		80		80	
CV %	Reps x Species x N Levels	24.6		31.2		32.3	
SE	Reps x Species x N Levels	5.00		3.79		2.64	

Table 2.8A. Summarised analysis of variance on the interaction of nine nitrogen levels and three vegetable amaranth species on dry matter yield components.

Source		Total Dry		Edible Dry		Non Edible Dry	
		df	f	df	f	df	f
Species		2	<.001***	2	<.001***	2	<.001***
Nitrogen Levels		8	<.001***	8	<.001***	8	<.001***
Lin		1	<.001***	1	<.001***	1	<.001***
Quad		1	0.068ns	1	0.591ns	1	0009**
Cub		1	0.950ns	1	0.377ns	1	0.177ns
Deviations		5	0.069ns	5	0.160ns	5	0.088ns
Species x N Levels		16	0.202ns	16	0.508ns	16	0.181ns
Lin		2	0.104ns	2	0.310ns	2	0.178ns
Quad		2	0.999ns	2	0.664ns	2	0.468ns
Cub		2	0.282ns	2	0.290ns	2	0.336ns
Deviations		10	0.192ns	10	0.484ns	10	0.168ns
Residual		54		54		54	
Total		80		80		80	
CV %	Reps x Species x N Levels	23.3		30.4		29.8	
SE	Reps x Species x N Levels	0.26		0.19		0.14	

Table 2.9A. Summarised analysis of variance for water content at nine nitrogen levels for vegetable amaranth species.

Source		*A. hypochondriacus*		*A. tricolor*		*A. hybridus*	
		df	f	df	f	df	f
Nitrogen Levels		8	1.19ns	8	13.61***	8	3.60**
Lin		1	2.32ns	1	62.05***	1	18.51***
Quad		1	1.12ns	1	10.07***	1	0.82ns
Cub		1	0.39ns	1	16.22***	1	0.34ns
Deviations		5	1.18ns	5	4.10**	5	1.83ns
Residual		18		18		18	
Total		26		26		26	
CV %	Reps x N Levels	0.5		0.4		0.4	
SE	Reps x N Levels	0.50		0.41		0.39	

Table 2.10A. Summarised analysis of variance on the interaction of nine nitrogen levels and three vegetable amaranth species on water content (%).

Source		Water content (%)	
		df	f
Species		2	0.014*
Nitrogen Levels		8	<.001***
Lin		1	<.001***
Quad		1	0.056ns
Cub		1	0.148ns
Deviations		5	0.004**
Species x N Levels		16	<.001***
Lin		2	<.001***
Quad		2	0.034*
Cub		2	0.003**
Deviations		10	0.237ns
Residual		54	
Total		80	
CV %	Reps x Species x N Levels	0.5	
SE	Reps x Species x N Levels	0.44	

3. AUTUMN TRIAL

Table 3.1A. Summarised analysis of variance for total fresh matter yield at nine levels of nitrogen application for three vegetable amaranth species.

Source	*A.hypochon*		*A.tricolor*		*A.hybridus*	
	df	F	df	F	df	F
Nitrogen Levels	8	0.001***	8	0.014*	8	0.001***
Lin	1	0.001***	1	0.001***	1	0.001***
Quad	1	0.572ns	1	0.032*	1	0.197ns
Cub	1	0.438ns	1	0.303ns	1	0.085ns
Deviations	5	0.566ns	5	0.690ns	5	0.022*
Residual	18		18		18	
Total	26		26		26	
C.V. (%)	21.2		37.1		24.7	
SE	2.89		0.57		3.68	

Table 3.2A. Summarised analysis of variance for fresh edible (marketable) yield at nine levels of nitrogen application for three vegetable amaranth species.

Source	*A.hypochon*		*A.tricolor*		*A.hybridus*	
	df	F	df	F	df	F
Nitrogen Levels	8	0.001***	8	0.003**	8	0.001***
Lin	1	0.001***	1	0.001***	1	0.001***
Quad	1	0.294ns	1	0.042*	1	0.113ns
Cub	1	0.343ns	1	0.290ns	1	0.316ns
Deviations	5	0.638ns	5	0.605ns	5	0.009**
Residual	18		18		18	
Total	26		26		26	
C.V. (%)	19.7		32.3		23.1	
SE	1.84		0.32		2.29	

Table 3.3A. Summarised analysis of variance for fresh non-edible yield at nine levels of nitrogen application for three vegetable amaranth species.

Source	*A.hypochon*		*A.tricolor*		*A.hybridus*	
	df	F	df	F	df	F
Nitrogen Levels	8	0.003**	8	0.123ns	8	0.002**
Lin	1	0.001***	1	0.021*	1	0.001***
Quad	1	0.858ns	1	0.037*	1	0.590ns
Cub	1	0.780ns	1	0.373ns	1	0.048*
Deviations	5	0.659ns	5	0.712ns	5	0.266ns
Residual	18		18		18	
Total	26		26		26	
C.V. (%)	41.2		51.6		41.3	
SE	1.77		0.27		2.05	

Table 3.4A. Summarised analysis of variance for total dry matter yield at nine levels of nitrogen application for three vegetable amaranth species.

Source	*A.hypochon*		*A.tricolor*		*A.hybridus*	
	df	F	df	F	df	F
Nitrogen Levels	8	0.001***	8	0.016*	8	0.001***
Lin	1	0.001***	1	0.001***	1	0.001***
Quad	1	0.330ns	1	0.061ns	1	0.169ns
Cub	1	0.257ns	1	0.287ns	1	0.045*
Deviations	5	0.616ns	5	0.603ns	5	0.028*
Residual	18		18		18	
Total	26		26		26	
C.V. (%)	18.6		39.0		20.4	
SE	0.15		0.04		0.17	

Table 3.5A. Summarised analysis of variance for dry edible (marketable) yield at nine levels of nitrogen application for three vegetable amaranth species.

Source	*A.hypochon*		*A.tricolor*		*A.hybridus*	
	df	F	df	F	df	F
Nitrogen Levels	8	0.001***	8	0.004**	8	0.004**
Lin	1	0.001***	1	<.001***	1	<.001***
Quad	1	0.177ns	1	0.071ns	1	0.071ns
Cub	1	0.240ns	1	0.260ns	1	0.260ns
Deviations	5	0.614ns	5	0.525ns	5	0.525ns
Residual	18		18		18	
Total	26		26		26	
C.V. (%)	17.8		33.7		18.7	
SE	0.10		0.02		0.10	

Table 3.6A. Summarised analysis of variance for dry non-edible yield at nine levels of nitrogen application for three vegetable amaranth species

Source	*A.hypochon*		*A.tricolor*		*A.hybridus*	
	df	F	df	F	df	F
Nitrogen Levels	8	0.002**	8	0.209ns	8	0.001**
Lin	1	0.001***	1	0.030*	1	<.001***
Quad	1	0.896ns	1	0.090ns	1	0.365
Cub	1	0.554ns	1	0.407ns	1	0.044*
Deviations	5	0.586ns	5	0.711ns	5	0.256ns
Residual	18		18		18	
Total	26		26		26	
C.V. (%)	36.7		60.0		35.3	
SE	0.10		0.02		0.10	

Table 3.7A. Summarised analysis of variance on the interaction of nine nitrogen levels and three vegetable amaranth species on fresh matter yield components.

Source		Total Fresh		Edible Fresh		Non Edible Fresh	
		df	f	df	f	df	f
Species		2	<.001***	2	<.001***	2	<.001***
Nitrogen Levels		8	<.001***	8	<.001***	8	<.001***
Lin		1	<.001***	1	<.001***	1	<.001***
Quad		1	0.099ns	1	0.032*	1	0.605ns
Cub		1	0.046*	1	0.133ns	1	0.066ns
Deviations		5	0.020*	5	0.004**	5	0.409ns
Species x N Levels		16	<.001***	16	<.001***	16	0.004**
Lin		2	<.001***	2	<.001***	2	<.001***
Quad		2	0.588ns	2	0.439ns	2	0.805ns
Cub		2	0.269ns	2	0.693ns	2	0.127ns
Deviations		10	0.033*	10	0.020*	10	0.369ns
Residual		54		54		54	
Total		80		80		80	
CV %	Reps x Species x N Levels	27.2		25.2		48.2	
SE	Reps x Species x N Levels	2.72		1.71		1.57	

Table 3.8A. Summarised analysis of variance on the interaction of nine nitrogen levels and three vegetable amaranth species on dry matter yield components.

Source		Total Dry		Edible Dry		Non Edible Dry	
		df	f	df	f	df	f
Species		2	<.001***	2	<.001***	2	<.001***
Nitrogen Levels		8	<.001***	8	<.001***	8	<.001***
Lin		1	<.001***	1	<.001***	1	<.001***
Quad		1	0.045*	1	0.024*	1	0.322ns
Cub		1	0.014*	1	0.044*	1	0.042*
Deviations		5	0.037*	5	0.008**	5	0.414ns
Species x N Levels		16	<.001***	16	<.001***	16	0.004**
Lin		2	<.001***	2	<.001***	2	<.001***
Quad		2	0.688ns	2	0.626ns	2	0.766ns
Cub		2	0.239ns	2	0.563ns	2	0.186ns
Deviations		10	0.073ns	10	0.060ns	10	0.339ns
Residual		54		54		54	
Total		80		80		80	
CV %	Reps x Species x N Levels	22.9		21.3		42.1	
SE	Reps x Species x N Levels	0.13		0.08		0.08	

Table 3.9A. Summarised analysis of variance for water content (%) at nine nitrogen levels for vegetable amaranth species.

Source		*A. hypochondriacus*		*A. tricolor*		*A. hybridus*	
		df	f	df	f	df	f
Nitrogen Levels		8	7.46***	8	0.50ns	8	8.55***
Lin		1	28.38***	1	1.47ns	1	41.07***
Quad		1	1.21ns	1	0.05ns	1	15.98***
Cub		1	0.02ns	1	0.71ns	1	4.63ns
Deviations		5	1.23ns	5	0.35ns	5	1.11ns
Residual		18		18		18	
Total		26		26		26	
CV %	Reps x N Levels	0.3		0.6		0.4	
SE	Reps x N Levels	0.32		0.52		0.38	

Table 3.10A. Summarised analysis of variance on the interaction of nine nitrogen levels and three vegetable amaranth species on water content (%).

Source		Water content (%)	
		df	f
Species		2	<.001***
Nitrogen Levels		8	<.001***
Lin		1	<.001***
Quad		1	0.006**
Cub		1	0.666ns
Deviations		5	0.181ns
Species x N Levels		16	<.001***
Lin		2	<.001***
Quad		2	0.050ns
Cub		2	0.101ns
Deviations		10	0.758ns
Residual		54	
Total		80	
CV %	Reps x Species x N Levels	0.4	
SE	Reps x Species x N Levels	0.42	

APPENDIX B

CLIMATOLOGICAL DATA REGISTERED AT ROODEPLAAT DURING THE COURSE OF 1996/97 *AMARANTHUS* GROWING SEASON

Month	Temperature (°C)						Relative Humidity (%)						Precipitation Rainfall (mm)		Sunlight hours
	1996/97			Long-term average			1996/97			Long-term average			1996/97	Annual Average	
	Avg Max	Avg Min	Daily Avg	Avg Max	Avg Min	Daily Avg	Avg Max	Avg Min	Daily Avg	Avg Max	Avg Min	Daily Avg			
September	27.4	7.9	17.6	26.8	8.9	17.8	74	23	48	58	27	42	0	18	9.0
October	29.5	13.7	21.6	28.3	12.9	20.6	76	27	51	58	33	45	128	65	8.3
November	27.7	15.0	21.3	28.0	14.7	21.3	85	36	60	66	43	54	54	117	7.4
December	28.4	16.7	22.5	28.6	15.8	22.2	88	36	62	69	47	58	149	108	7.6
January	28.8	18.0	23.4	29.2	16.6	22.9	86	36	61	71	47	59	118	132	7.2
February	30.4	17.3	23.8	28.8	16.4	22.6	87	31	59	73	47	60	47	85	7.8
March	24.9	17.0	20.9	27.8	14.6	21.2	88	41	64	75	46	60	207	64	3.9
April	23.8	9.8	16.8	25.1	10.9	18.1	88	37	62	77	44	60	34	59	8.1
May				22.6	5.9	14.3				76	36	56		23	
June				20.1	2.6	11.3				73	33	53		7	
July				20.6	2.4	11.5				71	29	50		4	

APPENDIX C

FERTILITY STATUS OF EXPERIMENTAL PLOT PRIOR TO INITIATING THE TRIALS

SOIL LEVEL	P mg/kg	K mg/kg	Ca mg/kg	Mg mg/kg	Na mg/kg	Titr.Acid me/100g	pH	R ohms	Carbon %	CEC me/100g	Clay %	Silt %	Sand %	Total N %
Top soil	22.8	205	642	250	38	0	6.67	2000	0.57	7.02	23.0	11.2	66.0	0.050
Sub soil	3.7	157	696	373	46	0	7.16	2000	0.42	7.65	33.0	14.5	52.5	0.045