CHAPTER 1

LITERATURE REVIEW

1.1 Introduction

Plants were once a primary source of all the medicines in the world and they still continue to provide mankind with new remedies. Natural products and their derivatives represent more than 50% of all drugs in clinical use in the world (Kinghorn & Balandrin, 1993).

Wild ginger is scientifically known as *Siphonochilus aethiopicus* (Schweif.) B.L. Burt and commonly known as Natal ginger or isiphephetho. It belongs to the *Zingiberaceae* family and the same family with true ginger (*Zingiberaceae officinale*). Wild ginger is a rare African plant in the ginger family and is regarded as Africa's natural anti-inflammatory which is reputed to have a number of spice plants such as turmeric and cardamom. The generic name *Siphonochilus* is derived from Greek siphono meaning tube, and *chilus* meaning lip in reference to the shape of the flower and the specific name *aethiopicus* means from southern Africa (Hankey & Reynolds, 2002).

Wild ginger is a deciduous plant with large, hairless leaves developing annually from a small, distinctive, cone-shaped rhizome and they may reach the height of up to 400 mm. Leaves are light green, lance shaped and borne at the end of stem-like leaf bases (Van Wyk *et al.*, 2000). It has very attractive flowers, which are borne at the ground level and are very short lived and appear in early summer, from the end of October to early December (Hankey & Reynolds, 2002). Flowers are broadly funnel-shaped, pink and white in colour with a small yellow blotch in the middle. Most of the flowers in the plants are bisexual, and they are usually more female flowers in plants than the male counterparts (Smith *et al*, 1997). The small, berry-like fruits are borne below or above the ground and the leaves and rhizomes have a smell similar to that of real ginger, *Zingiber officinale* (Van Wyk *et al.*, 2000).

Rhizomes of wild ginger are used for colds, coughs, influenza and hysteria and to clear nasal passages and they may also be taken for pain. Several other traditional and cultural uses include the treatment of asthma and dysmennorhoea (Pujol, 1993; Crouch, 1996; Hutchings, 1996).

Wild ginger contains volatile oil with α-terpineol which are generally used for their decongestant, antiseptic and diuretic effects and various other monoterpenoids, but the main compound is a highly characteristic sesquiterpenoid in the oil used for colds and influenza (Merck, 1989). However, the similarity between wild ginger and true ginger appears to be superficial only, as none of the terpenoids of ginger oil are present in the essential oil of *Siphonochilus*. The highly aromatic roots have a variety of medicinal and traditional purposes and they are used by Zulu people as a protection against lightning and to ward off snakes (Hankey & Reynolds, 2002).

The conical rhizome and roots contain a high percentage of a characteristic sesquiterpenoid, which is a key phytochemical active ingredient. Extracts of the rhizome have been demonstrated to be anti-inflammatory (prostaglandin-synthetase inhibition), bronchodilatory, smooth muscle relaxant, mildly sedative, and anti-candidal. The presence of antiseptic monoterpenoids contributes to the bioactivity (Hankey & Reynolds, 2002).

The plant is easily cultivated in the warm parts of South Africa and attempts have been made for the large-scale production of rhizomes through tissue culture in order to reduce the pressure of wild populations (Van Wyk *et al.*, 2000). Wild ginger is easy to propagate provided it is given a well-drained, compost rich soil and warm, but shady position in containers or in the garden. Watering should be reduced to a minimum during winter months while the plant is dormant and may be resumed with the onset of spring. During the growing season plants respond very well to high levels of feeding with organic matter (Hankey & Reynolds, 2002).

Fertilizer usage played a major role in the universal need to increase food production to meet the demand of the growing world population. Fertilizer application resulted in crop yield increases, which for most crops was more than 100 %. The extent to which fertilizers are used still differ considerably between various regions of the world (Stanford & Legg, 1984).

Nitrogen is a major essential nutrient element and required by plants in substantial quantities. It is the constituent of proteins and many metabolic intermediates involved in synthesis and energy transfer of nucleic acids (Goh & Haynes, 1986; Mengel & Kirkby, 1987). Olson & Kurtz (1982) reported that when the supplies of soil water is adequate, it is the most limiting factor for crop production. On average, considerably more nitrogen than any other element is supplied to crops as fertilizer and is removed from agricultural lands in harvested crops.

It is commonly the most limiting plant nutrient for crop production in the majority of the world's agricultural areas and the only plant nutrient which can be added to the soil by biological nitrogen fixation (BNF). Therefore, adoption of good N management strategies often results in large economic benefits to farmers (Novoa & Loomis, 1981). It must be viewed as the control element because of its role in substances such as protein and nucleic acids that form the living material.

There was no literature available on the effect of nitrogen nutrition, fertigation frequency and growing medium on wild ginger as well as little is available on true ginger (*Zingiberaceae officinale Roscoe*). However, the literature in this study will be mainly of a potato crop. A potato crop was chosen on the basis that it is a tuberous crop and produces tubers underground similar to wild ginger. It is believed that a potato crop will respond to nitrogen levels, fertigation frequency and growing medium in a similar manner to wild ginger.

1.1.1 Effect of nitrogen on potato plant growth and yield

The most critical way in promoting extremely high yields, is supplying nutrients especially nitrogen, in sequence with crop demand without creating toxic conditions and affecting the quality of harvested products (Oagile, 1998).

The application of mineral fertilizer has to a large extent been responsible for increasing crop yields on a worldwide scale (Mengel, 1991). The author pointed out that of all plant nutrients, particularly nitrogen is applied at highest rates and has the greatest impact on crop yield. Under the economic conditions of the developed countries the price cost ratio is such that for most crops highest profit is obtained at the maximum yield. In numerous cases it is also only by the application of nitrogen fertilizer that a profit can be obtained (Mengel, 1991).

Nutrient content and assimilation by plants are the results of total plant growth and nutrient availability. Relatively high N applications can delay potato tuber growth 7 to 10 days, particularly for indeterminate potato varieties (Westermann, Kleinkopf & Porter, 1985). They showed that N has a major role in the production and maintenance of an optimum plant canopy for continued tuber growth through long growing seasons. Therefore, during periods of high tuber growth rates, the demand for nutrients may exceed uptake rates and cause depletion of mobile nutrients from the tops to the tubers (Westermann *et al.*, 1985). If the depletion starts too early in the growing season, it may cause premature canopy senescence and reduce final tuber yields.

ABA/GA ratio controls tuber setting, a high ratio favouring and a low ratio restricting tuber initiation. Hence, ABA/GA ratios respond sensitively and rapidly to nitrogen nutrition (Mengel & Kirkby, 1987). They reported that a continuos N supply result in a relatively low ABA/GA ratio with 'regrowth' of tuber occurring. However, interrupting nitrogen supply increased ABA content dramatically and gave rise to tuber initiation. In practice this reversible cessation of tuber growth by a high level of nitrogen nutrition often occurred at late stages of tuber growth. In addition, nitrogen nutrition is important for root crops unlike cereals in that, enhanced nitrogen nutrition after flowering can stimulate vegetative growth and initiation of new leaves (Mengel & Kirkby, 1987).

During early stages the developing tuberous crops should be well supplied with nitrogen in order to develop the vegetative plant organs needed for photosynthesis. After flowering nitrogen supply to tuberous crops should decline, because continuous nitrogen supply affects quality of tubers, since later stages are characterized primarily by the synthesis of carbohydrates and their translocation to the tubers. Increasing the level of nitrogen nutrition may lead to excess of soluble amino acids, which cannot be used for growth processes (Mengel & Kirkby, 1987).

Crozier, Creamer & Cubeta (2000) stated that, although numerous studies document yield response to nitrogen application, yield and tuber quality could be reduced by excess fertilizer application. They reported that high nitrogen rate delay tuber initiation, which may be critical since the potato growing season is typically curtailed by high summer temperatures. However, the influence of residual nitrogen is important when evaluating crop response to N fertilization.

The increased crop yield resulting from the application of N fertilizer to N-deficient soils and increased protein percentage resulting from excessive N fertilizer applications have long been recognized (Deckard, Tsai & Tucker, 1984). The tuber protein percentage increased most rapidly in response to N supply after the yield response leveled off. The response of yield and protein to N supply was strongly influenced by environmental conditions, especially the quantity and timing of water available to the crop (Westermann & Tindall, 1998).

Under low water availability conditions, a positive yield response to added N leveled off at low soil N level and an increased protein response was shown more readily (Deckard *et al.*, Tsai & Tucker, 1984). The relationship between yield and protein percentage across N level can vary from negative to positive, depending on the environmental conditions. They pointed out that the positive relationship occurred when both yield and protein percentage increased whereas negative relationships were less common and generally resulted from increasing low soil N levels at high available water or when soil N levels resulted in lodging of the crop.

Leaf area duration (LAD) is an important determinant of potato yield (Vos, 1995a). Nitrogen nutrition affects tuber yield of potato crops mainly by its effect on leaf area duration (Biemond & Vos, 1992;Vos & Biemond, 1992). Vos and Biemond (1992) observed that leaf are index (LAI) at a particular point in time, and its change in time were determined by the dynamics of leaf growth and branching. In a potato field experiment carried out by Vos (1995a), it was shown that stem density was variable and that modified response to nitrogen for a given rate of N supply per unit area and the amount of N that was available per stem was lower in dense population than in open stands. Similarly, Vos and van der Putten (1998) showed that N supply affected leaf expansion rate and size in potato and also the total number of leaves that emerge on the plant. It was found that the effect of N on leaf size and number of leaves per plant was affected by the seasonal pattern of light interception and crop production (Vos, 1995b).

Application of N fertilizer to potato affected leaf growth, onset and duration of tuber growth and the composition of the progeny tuber (O`brien & Allen, 1986). Variations in onset of tuber growth affected the chronological age of the tuber, which has been reported to influence its productivity. Many authors showed that in potato production, N is applied more frequently and in greater amounts than any other nutrient. It is also the nutrient that most often limits yield. Without added nitrogen, growing plants often shows N deficiency characterized by yellow leaves, stunted growth, and lower yields (Bowen, Cabrera, Barrera & Baigorria, 1998). Similarly, Baritelle, Hyde & Thornton (2000) stated that N is an important nutrient in potato production. Hence, tuber yields were greatly increased by increased N fertilizer treatments.

Westermann *et al.* (1985) found that increasing N fertilizer increased total tuber yield and reduced the yield of undersized tubers.

Marshall & Vos (1991) showed that N influenced the productivity of potatoes by influencing the size of leaves, maximum leaf area index, and leaf area duration, whereas the light conversion coefficient into dry mass was little affected by nitrogen. In a pot experiment with potato they observed a direct relation between photosynthetic capacity and the concentration of N in leaf dry matter, changes in both variables being associated with leaf aging. In the field, the N content of a leaf at a given level on the plant will depend on N supply. However, this dependency may be either direct, with a low rate of N supply resulting in an overall low concentration of N in the plant.

Millard & Marshall (1986) pointed out that as the amount of N applied to the potato crop is increased, a decreasing proportion was taken up, while the concentration of N in the dry matter in the plant tissues increased. Numerous studies showed that N in the canopy accumulates as both nitrate and reduced N. Thus, the rate of N uptake by the crop decreases towards the end of the season. In addition, accumulation of N in the canopy allowed redistribution of N between leaves to support new leaf growth late in the season (Millard & MacKerron, 1986). Hence, accumulation of N by the crop increased leaf dry matter production, LAI and LAD (Millard & Marshall, 1986).

1.1.2 **Nitrogen use efficiency**

Efficient use of N in plant production is an essential goal in crop management (Novoa & Loomis, 1981). They stated that a realistic approach to diminishing the environmental hazard of N fertilizers is to make a better use of N fertilizers or in other words to increase their efficiency of utilization and that crops take up less than 50% of N applied to soils.

Supplying the needed nitrogen just prior to the crop's greatest demand can maximize nitrogen efficiency. Vitosh (1990) reported for potatoes that this occurs during rapid growth and dry matter accumulation. Similarly, Waddell, Gupta, Moncrief, Rosen & Steele (1999) showed that a management option to increase N use efficiency is to split N applications over the growing season. Westermann *et al.* (1985) showed that post-hilling N application increased yield by potentially limiting N leaching beyond the root zone.

Because of the high cost on nitrogen fertilizer, improving N efficiency of cultivars is an important goal. An important variation of N efficiency among genotypes has been reported in many commercial crops (Broadbent, Goh & Haynes, 1987). A higher efficiency would permit reducing N rate without reducing yield and profit and therefore, lead to a small proportion of N susceptible of being carried to surface and ground water (Clark, 1983). Similarly, Sinclair & Horrie (1989) stated efficient use of N is also important for minimizing environmental contamination.

The rate and kind of fertilizer used and the method of application, influence the recovery of N. The recovery could be improved when the fertilizer is concentrated in the root zone in band rather than broadcast on the surface. Improved efficiency of nitrogen use at the field and farm scale, both increased crop yield and quality and reduced losses was dependent upon dynamic optimization to match the N supply and the N requirements of the crop at a field scale. This optimization required measurement and prediction of soil N supply and their variability (Vos & Marshall, 1994).

1.1.3 Nitrogen fertilizer application and crop production

MacKerron, Young & Davies (1993) showed that requirements for N fertilizer differ greatly from field to field in ways that are difficult to predict. In a study by Neetson & Wadman (1987) they found economic optimum level of N application of potato to range between 0 and 450 kg ha^{-1}. In addition, they showed the best estimator of the available N from the soil to be the amount of mineral N in the top 60 cm of soil in spring. Traditionally, recommended fertilizer rates have been based on empirically derived relations between application rates and yield (MacKerron, Young & Davies, 1987).

The response curves of potato to applied N present an extending plateau over which commercial yields do not decline at higher applications. They affirmed that applications of N fertilizer should be adequate to ensure the potential growth of the crop, but low enough to minimize losses through leaching. They showed that relationships could be derived between the rate of N uptake in plant tissues and final N level at the end of the growing season. Thus, suggesting that it might be possible to estimate the rate of uptake of N at an early stage in the season and comparing it with the required total uptake for anticipated yield.

1.1.4 Response of nitrogen application in crop production

Although crops usually respond to nitrogen fertilizer, this is not always the case. Response to nitrogen depends on soil conditions, the particular crop species and the plant nutrient supply (Mengel & Kirkby, 1987). They observed that when the soil N content is higher, the N response is poorer and in the absence of a response, residual N and/or the rate of N release by microbial decomposition of soil organic matter is probably adequate to meet the demand of a crop. Goh & Haynes (1986) outlined that yield response of plants to applied N fertilizer addition may occur as dry matter and protein yield and quality improvement or other plant features.
Molle & Jessen (1968), cited by Goh & Haynes (1986), considered the relationship between nitrogen fertilizer response and soil organic matter in their experiments. The authors found that on sandy soils under humid climatic condition, N application rates of 90 – 135 $kg{\cdot}ha^{-1}$ for many crops resulted in optimum economic return and again on peat soils rich in organic nitrogen. Crops that are harvested before maturity such as forage grasses require high amounts of nitrogen (25 to 30 $kg{\cdot}ha^{-1}$ of dry matter) (Stanford & Legg, 1984) in contrast to mature crops.

Responses to nitrogen application is limited when water availability is restricted (Vitosh, 1990). The response of nitrogen also depends on how well the crop is supplied with other nutrients. Mengel & Kirkby (1987) observed that without phosphorus (P) and potassium (K) application, the yield response to increasing nitrogen levels was smaller than when adequate amounts of P and K were applied. The efficiency of nitrogen fertilizer usage is much dependent on factors such as water supply and the presence of other nutrients in the soil. Similarly, Lopez-Bellido & Lopez-Bellido (2000) pointed out that crop response to N is not influenced only by available water and N fertilizer management but also by factors such as soil type and tillage methods, crop sequence and N supply. Subsequently, increasing N fertilizer rates prompt to increase yield up to a point, beyond which there is no additional response, thus it prompts greater N loss.

In a study by Goh & Haynes (1986), they pointed out that the simple response of plants to applied N, is when N is the major growth-limiting factor, and that dry matter yield increase with increasing rates of N up to a maximum and either stayed constant or declined with further rates of nitrogen. Hence, total N uptake by the crop increased up to the maximum yield so that maximum fertilizer uptake efficiency can be achieved at the same fertilizer rate as was required for maximum yield.

Fertilizer uptake efficiency is normally relatively constant with increasing rates of N up to a level at which maximum yield is first obtained and further fertilizer addition decrease uptake efficiency. The potential of excess NO_3^- in soil profile rises sharply above the fertilizer rate required for giving maximum yield. Several authors showed that the magnitude of the positive response to applied N is likely to be primarily dependent on the size of available and potentially available pool of N in the soil and the demand for N by crops as determined by its potential dry matter production (Greenwood, Cleaver, Turner, Hunt, Niedorg & Loquens, 1980; Olson & Kurtz, 1982).

1.1.4.1 **Time and rate of uptake**

Numerous researchers showed that N uptake by field crops involve a period of very slow accumulation followed by a rapid linear rate of accumulation that coincides with rapid plant growth (Neetson & Wadman, 1987). They found that for field crops, the rate of uptake can be extremely rapid (3-5 $kg{\cdot}ha^{-1}$ N day^{-1}) during the rapid growth phase. A linear rate of uptake does not necessarily mean that N concentration in the plant is constant but in fact, N concentration in a young plant is initially high and characteristically decline as the plant age and accumulate dry matter.

1.1.4.2 **Effect of nitrogen fertilizer application rates**

The level of nitrogen that should be applied to a crop depends largely on the particular crop species and on the prevalent soil conditions (Mengel & Kirkby, 1987). Generally, the quantity of nitrogen taken up by a good crop over the growing period serves as a guideline in assessing the appropriate rate of nitrogen application. When the rate of inorganic N release from soil organic matter is high, lower application rates need to be applied and for poor soils low in nitrogen, application rate should be in excess of the total amount of N uptake (Mengel & Kirkby, 1987).

The distribution of N between component plant parts, such as leaves, stems, storage organs and harvest index, are relatively constant irrespective of the average N concentration of the plant (Biemond & Vos, 1992). Vos (1995a) stated that the pattern of N uptake in potato crop can be dramatically influenced by the dose and timing of split application. For most crops such as wild ginger (*Siphonochilus aethiopicus*), there is little information about which developmental stage N applications will continue to influence crop growth and quality of harvested components and in what form of N should be applied to achieve maximal effect.

Lee & Asher (1981) reported that substantial amount of nitrogen fertilizer are used to obtain higher yield in ginger (*Zingiber roscoe officinale*) (up to 830 kg·ha^{-1}) but little information is available concerning optimum rates and times of application or the most suitable form of nitrogen fertilizer. It was also reported that substantial leaching losses of N were likely because growers apply 50% of their total N at planting and a further 25% in the first sixteen weeks, a period during which only about 11% of the total growth of the crop occurs. In addition, higher yield of ginger was obtained with relatively low rates of N (less than 300 kg·ha^{-1}) in an experiment in which the total fertilizer N was divided into 10 applications.

Hegney & McPharlin (2000) pointed out that potato crops produced in the coastal plains used ranges from 356 to 1510 kg·ha^{-1} N. However, these rates are high compared to the measured N requirement of potatoes grown on sandy soil elsewhere. They showed increased agronomic N efficiency in potatoes (i.e. tuber yield per unit N applied) to be achieved by reducing pre-plant application and frequently applying small amounts during the growing season. For example, yield of Russet Burbank potatoes was increased from 61.8 to 77.5 t·ha^{-1} and rate of maximum yield decreased from 448 kg·ha^{-1} (when all was applied pre-plant) to 336 kg·ha^{-1} (when two-thirds of the N was applied post-planting). Similarly, Kolbe & Zhang (1995) reported that different rates of N fertilization lead to differences in tuber yield and chemical composition at harvest and affected the behaviour of stored tubers.

1.1.5 **Crop nitrogen demand**

Knowledge of the factors governing nitrogen demand is essential to predict the need of crops under a wide range of field conditions, so that growers can be given more reliable fertilizer recommendations (Greenwood, 1982; van Keulen, Goudriana & Seligman, 1989). Addiscot, Whitmore & Powlson (1991) agreed with the statement by stating that this is important, not just for economic reasons, but because of the risk to the environment that can arise from over-application of nitrogen fertilizer, in particular the problem of nitrate leaching. They defined the nitrogen demand of plants as the N uptake over a set of period which would allow maximum (dry matter) growth rate under the given environmental conditions, i.e. when N supply just ceases to be a limiting factor for growth.

Several authors affirmed that there is good evidence that the growth of the shoot is the main determinant of the N demand and hence the potential of N uptake (Grindlay, Sylvestser-Bradley & Scott, 1993). Van Keulen *et al.* (1989) reported that N uptake by the plant will be less than the N demand if there is insufficient mineral N available for uptake by the roots, in this case N supply determine the amount of nitrogen taken up.

Numerous researchers concluded that the most widespread approach to N nutrition has been to express nitrogen content on a mass basis, usually as a percentage N in the dry matter (Greenwood, 1982; Grindlay, 1997). Grindlay (1997) suggested that the instantaneous rate on N uptake can be calculated by multiplying the concentration of nitrogen (which needs to be determined by chemical analysis), and is complicated by the fact that nitrogen content on a dry matter basis varies with N supply and the age of the plant.

Grindlay (1997) defined the crop N demand on the basis of concentrations of total N on a dry matter basis, but these values vary with the plant age and the N supply. In agreement with the above statement Stanford & Legg (1984) outlined that crop N demand is the product of expected yield and internal N requirement, which can be thought of as the minimum amount of plant N associated with maximum yield. According to Bowen *et al.* (1998), although a growing crop may take up more than minimum N needed, extra N (luxury consumption) does not usually result in any yield benefit. Therefore, to optimize N management and avoid its inefficient use, it is important to know the expected maximum yield and its associated internal N requirement (Stanford & Legg, 1984)

When N is non-limiting for growth, plants may restrict their N uptake to meet their immediate requirement for maximum dry matter growth rate (Greenwood *et al.*, 1980). According to Millard (1998) some species have or showed a tendency of luxury consumption, the accumulation of NO^{-}_3 and/or reduced form of nitrogen. According to Haremink, Johnston, O'Sullivan & Poloma (2000) different rates of N fertilizer are used to derive functions for crop N demand, expansion of the green crop area and dry matter accumulation. Therefore, such functions can be used in simple crop growth models or for defining crop N demand in precision farming.

1.1.6 Nitrogen nutrition and crop phenology

Phenology refers to the changes in life stages of a biological material. Thies, Singleton & Bohlool (1995) defined phenology as the study of the timing of biological events and causes of timing with regard to biotic and abiotic factors. The information among phases of the same or different species e.g. the timing of a heading of a potato crop is a biological event, which depends on the temperature and photoperiod under which the crop is grown (i.e. the abiotic forces). They outlined the purpose of phenological studies as (i) to indicate whether a crop could be grown commercially in an area; (ii) to serve as a guide in developing varieties for a specific environment; (iii) to grow plants with varying maturity dates to facilitate harvesting at intervals suitable to commercial canning operation; (iv) in hybrid seed production involving inbreds of different maturity rating, adjusting planting dates so that inbreds will be at the appropriate stage of development for crossing; and (v) to facilitate planning of operations, such as irrigation, fertilization, and herbicides application, when such operations are made at the best stage of a crop development.

Vegetative growth mainly consists of growth and formation of new leaves, stems, roots and meristematic tissues responsible for these organs that have a very active protein metabolism. Hence, photosynthates transported to these sites are used predominately during the vegetative growth stage in the synthesis of nucleic acids and proteins. It is for this reason that during the vegetative stage, the N nutrition of the plant controls the growth rate of the plant to a larger extent (Mengel & Kirkby, 1987). They showed that the concentration of N in the leaves might also determine the efficiency with which intercepted light is converted to dry matter accumulated. Numerous authors documented that the concentration declines as the plant develops (Greenwood *et al.*, 1980). Attempts have been made to relate the decline in total plant N concentration to either crop development using thermal time or to crop biomass (Greenwood, Lemaire, Gosse, Cruz, Draycott & Neetson, 1990)

Novoa & Loomis (1981) reported that leaves play an important role in N metabolism in crops because large amount of N is required for leaf growth. Finck (1982) also reported that three-quarters of total reduced N in the leaf might be connected with photosynthesis. He reported that tissues must have a certain N concentration and that decrease in N supply would limit the amount of tissue that can be produced. In agreement with this, Grindlay *et al.* (1993) found that there is a relationship between the amount of N in the shoot and dry matter. Vigorous leaf growth during early growth stage of a crop and the development of leaf area per plant is essential for voluminous roots. The more quickly in the growth period the leaves are able to form a complete canopy over the soil, the better are the chances of good yield. Leaf growth depends very much on a higher level of N nutrition during early stages of plant development. N translocation is an important process in plant life. However, young leaves are supplied with amino acids until they have reached maturity (Mengel & Kirkby, 1987).

1.1.7 **Soil and plant nitrogen dynamics for optimum crop yields**

Research on soil – plant nitrogen dynamics have been carried out from the very beginning of agricultural investigations. Soil – plant N dynamics lie at the heart of some questions being asked of researchers by farmers, environmentalists and policy markers. However, farmers seek to apply economic optimum rates of fertilizer, considering the costs of application and the effect on crop quality as well as yield (Neetson & Wadman, 1987; Vos, 1995b).

1.1.7.1 **Soil N supply**

Recently emphasis had been placed on the measurement of inorganic N (usually nitrate) in the soil before planting or at a specific time during the crop growing season to asses soil N supply (the Nmin approach). The required soil N supply for any period depend not only on crop N demand, but also on the crop uptake efficiency. A measure of that efficiency is the apparent N fertilizer recovery, which is defined by (N uptake of a fertilized crop – N uptake of unfertilized crop) X fertilizer applied (Neetson & Wadman, 1987). According to Stockdale, Ganut & Seligman (1997) apparent N recovery usually range from 0.4 – 0.7 with 0.8 as the upper limit. These recoveries are low where conditions favour losses of nitrate from the soil by denitrification or leaching and where carbon is available for net microbial immobilization will occur at least temporarily. However, to minimize the effect of spatial variability in the N supply from the soil, the distribution of fertilizer N applied would have to be negatively correlated with the soil.

N fertilizer is an expensive input and in many trials less than 60% of the applied N is recovered in the crop and soil with the remainder being lost. Numerous studies showed that increasing the amount of N applied at sowing does not increase the amount of N available to the potato crop because the fertilizer N is lost before the crop can assimilate it (Vos & Marshall, 1994). They reported that a minimum of six weeks is required before the crop has the capacity or potential to accumulate much of the N applied at sowing. Between 50 and 70% of the post sowing, N applications were recovered in the crops compared to less than 40% when N was applied at sowing (Vos & Biemond, 1992). Similarly, Biemond & Vos (1992) reported that the fertilizer N is used more efficiently when the supply of available N in the soil is matched with the demand for N by the crop.

Nitrogen supplied by soil comes mostly from two sources (1) mineralization of soil organic N during the growing season and (2) mineral N initially present in the soil profile at planting. Dahnke & Johnson (1990) pointed out that both sources should be considered when estimating the amount of supplemented N needed by a growing crop. Hence, the importance of initial mineral N needs an environment where significant leaching can occur.

The amount of mineral N present in the soil profile at planting often have a substantial impact on the need for supplemental N, particularly in less humid environments (Dahnke & Johnson, 1990). Initial mineral N usually varied across sites and years, with the amount largely determined by management and growth of the previous crop and the residual N left from earlier applications (Dahnke & Johnson, 1990). In addition, if rainfall is not excessive, much of the initial mineral N can remain available to a crop throughout the growing season.

1.1.7.2 **Crop N uptake**

Relationship between N uptake rate and growth rate is described by physiological efficiency of N use for a crop (Harper, 1994). Ingestad & Agren (1992) observed that during exponential growth, the relative growth rate is proportional to the relative N uptake rate of a crop when constant. The authors found that N concentration in the plant is then stable and controlled by the relationship between the relative uptake and relative growth rate. This approach allowed the determination of physiological plant response to N application at a constant relative 'addition rate'. Although such approach is important for increasing understanding of the control of plant growth, it is difficult to apply in the field due to the fact that linear rather exponential growth occurs following canopy closure.

According to Greenwood *et al.* (1990) the crop critical N can be derived from the relationship between crop N uptake and dry matter production. Thus, a widely used relationship of critical crop N and crop dry mass for potato have been derived by Greenwood *et al.* (1990) and for the vegetative stage. For annual cultivated crops, the N uptake efficiency is less than 50% despite following good management practices (Gillian, Logan & Broadbent, 1985). Wang & Alva (1996) showed that in sandy soils receiving 100-120 mm annual rainfall, the efficiency of N uptake may exceed 20 to 30%. Therefore, the portion of the applied N which was not taken by a crop is either adsorbed by soil components, incorporated into organic matter, volatilized, denitrified, or leached below the effective root zone of a crop.

1.1.8 **Nitrogen availability for optimum crop production**

Nitrogen availability is the factor limiting primary production in most natural terrestrial ecosystem (Ohlson, Nordin & Nasholm, 1995). In boreal forests the availability of N determines species composition as well as the production and changes in the availability. Therefore, N can be predicted to have a great impact on the structure and function of these ecosystems. These limitations of N availability were not expected to integrate the numerous inter-related soil, plant environment and management factors which control N release and plant growth, but supply to provide extra information for assessment of soil N supply (Ohlson *et al.*, 1995). They stressed that, today chemical and biological indices are not thought to provide only a relative indication of N availability among soils differing in management, but used with other indicators to asses soil quality.

1.1.8.1. Factors affecting nitrogen availability

1.1.8.1.1 Nitrogen losses in farming systems

Intensive agriculture entails the risk of excessive fertilization. The magnitude of this excess can be measured as the difference between the amount of plant nutrients applied and those exported in the harvested crops (Kucke & Kleeberg, 1997). They showed that such fertilization surpluses have steadily increased the soil nutrient status, soil fertility and the nitrogen pools, which participate in the N turnover, and subsequently the leaching potentials.

It is widely argued that N leaching losses and ground water pollution can only be limited if the fertilization is reduced to an extent that the fertilization balance (= N fertilization – N removal by harvested crops) is nearly zero. Gransdedt (2000) concluded from the results of a long term field experiment that reduction of N fertilization will decrease yield and yield potentials (soil fertility), but may have little or even an adverse effect on nitrate leaching in a short period.

Environmental concerns are focused on nitrogen losses from soils, which may pollute the environment. Leaching is the major route by which nitrate enters ground and surface waters, while denitrification and nitrification are significant sources of nitrite, an important greenhouse gas (O'enema, Boert, van Eerdt, Frakers, van der Meer, Roest, Schreder & Willems, 1998).

The main rate limiting process controlling the availability and loss of the mobile nitrate ion might be nitrification, rather than mineralization. Despite a reasonable knowledge of ecology of the bacteria, nitrification remains a poorly defined process in many soils. In temperate tilled agricultural soils, nitrification rates are usually limited by mineralisation. However, in grassland soils significant quantities of ammonium may accumulate where swards are grazed or farm wastes are applied (Kucke & Kleeberg, 1997).

The balance between mineralisation and nitrification is changed under environmental conditions and management. According to Vos (1992), leaching loss of N seems inevitable, however efficiently N is taken up by the crop, as plant processes have higher threshold temperatures for activity than mineralisation processes occurring in the soil. He pointed out that inefficient use of N fertilizer appear to be responsible for increased NO^{-}_{3} levels in ground waters. The increase incidence of NO^-_3 contamination of ground water was related to increased use of N fertilizer in intensive agricultural production (Wall & Magner, 1988). Leaching of N from soils has been demonstrated in several experiments carried out in areas with varying climate, soil type and cropping systems (O'enema *et al.*, 1998).

Agriculture contributed substantially to an increase in nutrient leaching (Granstdedt, 2000). Leaching of applied fertilizer N resulted in reduced uptake efficiency of applied N by a target crop and is an agricultural and an environmental problem (Wang & Alva, 1996). It is commonly perceived that increased reliance on industrial fertilizer has been the main cause of increased nitrate contamination of water resources. Based on this argument the reduction in sales of N fertilizers is important for improved water quality (Addiscott *et al.*, 1991). They showed that conservation tillage, particularly no-till can result in greater losses of fertilizer N by leaching following spring rains. Wall & Magner (1988) pointed out that the balance of N on the farm depended on the output, including losses to the environment, either in gaseous form by ammonium volatilization and denitrification or through leaching. For such systems a simplified N balance can be constructed. Additionally, any excess of N inputs over output of N in agricultural produce then represent a potential loss to the environment through leaching or in gaseous form.

1.1.9 **Environmental factors affecting nitrogen availability**

1.1.9.1 **Temperature**

O'brien & Allen (1986) pointed out that temperature influence microbial activity and the rate of mineralization, which is in general higher at higher temperatures. On the other hand higher temperatures may lead to greater losses of mineralised N by increased denitrification (a microbial process or by favouring volitilization or ammoniacal compounds.

1.1.9.2 **Precipitation**

Rainfall may have various effects on the N balance, it supplies N to the soil from atmospheric sources and through its effect on the moisture balance in the soil. It also influences the rate and duration of mineralisation as well as the magnitude of losses through denitrification and leaching. Mineralization of organic N is the most important biological process that is involved in the availability of soil N under submerged conditions (O'brien & Allen, 1986).

1.2 Effect of nitrogen on potato quality

Fertilizer nitrogen has been and is still used increasingly to supplement soil N for producing the needed quantity of food, feed and fibre for increasing world population, but unfortunately this is not always associated with improved quality (Deckard *et al.*, 1984). The level of nutrient supply in the soil played a major role in determining product quality. It is important as it forms an integral part of numerous plant compounds such as amino acids, proteins, nucleic acids and chlorophyll (Fink, 1982; Locascio, Wiltbank, Gull, & Maynard, 1984).

The increasing world population is confronted by a major shortage of plant products and there is a worldwide need to produce higher yielding quality crops (Mengel & Kirkby, 1987). Quality requirements are all influenced by plant nutrition. Therefore, fertilization should not only ensure high yield 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. Chemical composition controls the nutritional quality or value and important sensory attributes such as taste and texture of the product. Increased concentration of nitrogen in plants generally increase compounds such as amino acids, proteins and chlorophyll in some plants (Oagile, 1998).

Tuber dry matter percentage (TDM%) is an important component of tuber quality in potatoes (*Solanum tuberosum* L.) required for processing. Jenkins & Nelson (1992) reported that many factors are known to influence final TDM% and variation in N fertilizer showed significant effects.

1.2.1 Factors influencing quality on potato

1.2.1.1 Nitrogen source

Both nitrate (NO^-_3) and ammonium (NH_4^+) are dissolved in the soil solution from which they can be taken up by plant roots (Mengel, 1991). Several authors observed that NO^-_3 may be transported to the roots by mass flow and /or diffusion (Novoa & Loomis, 1981; Stanford &

Legg, 1984; Neetson & Wadman, 1987), NH_4^+ mainly by diffusion (Mengel, 1991). They stated that since NO^-_3 is virtually not absorbed to soil colloids, the total NO^-_3 present in the rooting depth of a crop is in available form. Mengel (1991) reported that in most soil types NH_4^+ is negligible but in those soils in which illite and vermiculite make up the clay fraction, NH_4^+ bound at interlayer sites may amount to several thousand kg·ha^{-1} N at a soil depth of one meter. Therefore, this NH_4^+ is only partially available to crops.

Most studies showed that the concentration of NH_4^+ under a crop stand decreased during the period of highest N uptake (Vos & Marshall, 1994; Biemond & Vos, 1992). From these observations it may be concluded that plants are supplied from interlayer NH_4^+ (Mengel, 1991). This example showed that in soils with 'available' interlayer NH_4^+ this source may be more important for crop nutrition than NO^-_3.

1.2.1.2 **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. However, NH_4^+ is absorbed more readily than NO^-_3 when the ions are supplied together at the same concentration especially at a low temperature (Oagile, 1998). Any factor which increased the total N concentration of the tissue resulted in a corresponding increment in the N concentration of that tissue. When N fertilizer was applied, the increased in the total N due to light reduction was less than the increase in NO^-_3 -N. This phenomenon attributed to the possible existence of critical total N levels above which any increase in total N showed up as predominately NO^-_3.N, and below which NO^-_3-N did not account regardless of the external factors applied (Oagile, 1998).

Several variations in nitrate contents are connected with temperature and especially with daylength and light intensity, which increase in spring during the development of a crop, but decrease in autumn (Oagile, 1998). Spring conditions are characterized by lower soil temperature than summer and together with above conditions are more favourable for both dry matter accumulation and nitrate reduction.

Water stress is one of the major factors limiting potato quality throughout the world (Mengel & Kirkby, 1987). It has been shown to inhibit incorporation of amino acids into proteins which in turn have 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 (Oagile, 1998). CO_2 assimilation rate and reduction in the translocation rate of photosynthesis from leaves to other plant parts were also observed. Breimer (1982) have shown that water stress increased nitrate content in plants. They also attributed this phenomenon to a decrease in nitrate reductase activity prior to the moment at which uptake started to decline.

Crop production is not only dependent on light interception, but also on radiation use efficiency (RUE), the ration between the amount of radiation intercepted and gain in total plant dry mass during particular time intervals (Vos & van der Putten, 1998). RUE, the photosynthetic properties of leaves and the aerial N concentration, N_a (gm^{-2}) are interrelated (Sinclair & Horie, 1989; Hammer & Wright, 1994). However, N can affect RUE by an effect on average N_a in the canopy or on the pattern of decline of N_a with depth in the canopy.

1.2.1.3 **Plant genotype and age**

Published reports on the effects of physiological age are mainly restricted to tuberous crops in which large effects on tuber yield have been observed (O`brien, Jones, Allen, & Raouf, 1986). They found that increasing the age to reduce number of tubers has important implications for seed production where lower and upper size limit apply and changes in number of tubers may affect seed yield, where little or no effect on total yield can be detected. As physiological age of the seed tubers affect the timing of tuber initiation it may also affect the duration of dormancy of the progeny tuber (O`brein *et al.*, 1986). Possibilities exist that such effect may be cumulative over successive multiplication and thereby create changes in the growth pattern of a variety. However, the age of the seed tuber may affect both yield and physiological quality of the seed produced.

1.3 **Effect of drip fertigation on potato growth, quality and yield**

Although fertilization by irrigation, or "fertigation" as it is commonly known, is a relatively new concept to South Africa, it has been applied in various forms elsewhere since the beginning of the 20th century (FSSA, 2003)

Most researchers stressed that the combined application of irrigation and nitrogen through fertigation is now becoming a common practice in modern agriculture because of its advantages over conventional methods (Asadi, Clemente, Gupta, Loof & Hansen, 2002). They reported that some of these advantages include timely nitrogen application, excellent uniformity of nitrogen application, reduced environmental contamination, adequate movement of applied N into the rooting zone by irrigation water and reduced soil compaction and mechanical damage of the crop.

Irrigation and fertilization are the most important management factors through which farmers control plant development, crop yields and quality. Most studies showed that the introduction of simultaneous microirrigation and fertilization (fertigation) opened up new possibilities for controlling water and nutrient supplies to crops and maintaining the desired concentration and distribution of ions and water in the soil (Dasberg & Bresler, 1985).

In a study of Darwish & Nimah (1997) with potato where they had three levels of N fertilizers (73.3, 110, and 146.6 ppm), they found that the middle treatment of 110 ppm which was equivalent to 360 kg. ha^{-1} N gave the highest yield. In comparison with conventional treatment, fertigation significantly increased the marketable tuber, although the yield was not significantly higher. Bar Yosef (1999) affirmed that fertigation management is aimed at maximizing grower income and minimizing environmental pollution. Some studies indicated that drip fertigation reduced fertilizer application cost by improving nutrient efficiencies by applying them close to where plants need them (Follett, 2002).

Mmolawa & Dani (2000) reported that drip irrigation has gained widespread popularity as an efficient and economically viable method for fertigation because of its highly localized application and the flexibility in scheduling irrigation. However, this method ensured that applied soluble plant nutrients become available to a substantial fraction of plant root system. They pointed out that drip irrigation has the potential to improve nutrient management and increase farm profit. Where management was not practiced properly, fertigation with drippers compounded salinity problems which affect crop growth, quality and yield because salts leached beyond the rooting zone and pollute the underlying ground water resources.

In most instances drip fertigation uses brackish water or recycled water of which is low quality water for irrigation. However, Mmolawa & Dani (2000) observed that in such cases fertigation with drippers using brackish or recycled water increased the amount of total dissolved solutes leading to salinization of the soil. Salinization induced unfavorable osmotic stresses and at high levels became toxic to plants. In addition, they emphasized that fertigation methods used to introduce salts and nutrients into the soil and salinity level of both the irrigation water and the resident soil water solution had some profound effect on root zone solute dynamics. Thus, fertigation had an impact on plant growth and development as well as quality (Mmolawa & Dani, 2000).

Several workers showed that drip irrigation is an effective method of supplying water and soluble nutrients to plants (Cooke, 1982). However, drip irrigation maximize profits through optimizing plant growth, resulting in higher yield and better quality by delivering precise amount of water in a uniform fashion directly to the root zone without runoff, wind drift, leaching below the rootzone or wetting the canopy. Furthermore, the dripperline apply water only to a portion of the surface thus maintaining high moisture within the root zone without water logging due to dry surroundings.

In a study of Marschner & Krauss with potato (1995), they reported that improperly managed fertigation led to the leaching of nitrate from the rootzone hence, tubers stopped growing when nitrate concentration was about 100 $g \cdot m^{-3}$ N. High nitrate concentration encouraged vegetative growth thereby delaying tuber initiation. This was due to the competition on carbohydrate consumption between the top and the underground storage organs in favour of the leaves at high N levels in the rootzone

In an experiment carried out by Steyn, Du Plessis, Fourie & Roos (1999) with potato, they found that the total yield of low frequency irrigation was higher than high irrigation frequency and this was attributed to the fact that the total amount of water applied to the pulse method (high irrigation frequency) was less than that applied to the non-pulse method (low frequency irrigation). They found no statistical significant relationships in frying chip colour. Significant differences were observed in the specific gravity between different irrigation frequencies, where the low frequency irrigation was significantly higher than that of the higher frequency irrigation.