AN ASSESSMENT OF THE NITROGEN FERTILIZER REQUIREMENTS OF WINTER CABBAGES (*Brassica oleracea* var. *capitata* L.)

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ABSTRACT

The increasing costs of N fertilizers and the danger of creating environmental pollution due to excessive N fertilisation practices create a need for more efficient N fertilisation of vegetable crops. This present study was conducted with the main objective of assessing the N fertilizer requirements of winter cabbages on a coarse loamy mixed mesic Dystric Eutrochrept soil and consequently developing a model which would assist in predicting N fertilizer requirements over a wider area.

Glasshouse and field experiments were conducted to assess the utility of soil and plant (sap) tests for assisting in determining the N fertilizer requirements of winter cabbages. The concentrations of NO_3-N and NH_4-N in either the xylem or petiole sap of cabbages were found to be influenced by several factors such as leaf position, time of day, sample storage time, plant age and form of fertilizer N.

A large field trial indicated that at 4 sampling dates (50, 60, 80 and 90 days after transplanting; DAT) and prior to sidedressing, xylem (R^2 = 0.73**) and petiole (R^2 = 0.86**) sap were strongly correlated to extractable NO_3-N and NH_4-N in the soil to a depth of 30 cm. Nitrate-N levels in xylem sap at 60 and 80 DAT and petiole sap at 50, 60 and 80 DAT were good predictors of harvestable fresh head yield. Maximum marketable fresh head yield (55 t/ha) was achieved with an initial N application of 300 kg N/ha over a growing period of 150 days in which 448 mm of drainage was estimated. At heading, on the 300 kg N ha^{-1}, soil mineral N levels were 75 kg N ha^{-1}, xylem sap concentration was 333 μg NO_3-N ml^{-1} and 1651 μg NO_3-N ml^{-1} in the petiole sap. This critical value for petiole sap is higher than that reported in the literature for cabbages. At petiole sap levels below the critical value, sidedressing with 100 kg N/ha as urea was required to achieve a similar yield as found with an initial application of 300 kg N ha^{-1} as calcium ammonium nitrate.

In a small scale field experiment, plant recovery (62-65%) of sidedressed

^{15}N labelled urea N did not differ between sidedressing rates (100 and 200 kg N). Total recovery of ^{15}N in the plant and soil was considered high (114 $\pm$ 0.9% and 90 $\pm$ 1.1%) for the respective rates.

Using the data obtained from the field trials, a simple model termed a "sidedressing model" was developed. The model specifically determines the amount of N fertilizer needed to be applied as a sidedressing at a critical time (heading) to obtain maximum yield. The model was validated, using the data from another N fertilizer field trial conducted in the following year. The model successfully predicted whether N sidedressing is required or not but only a limited validation could be made of the prediction rates.

The limitation of the sidedressing model of being site and season specific can be reduced by using simple submodels to predict the measured component which assessed N in cabbages at heading (N_h). One submodel used (the heat unit model) was modified by including data from 2-year trial results, to predict N_h and also provided a prediction of N uptake at maturity (N_y). Although not able to be validated in this study, the model shows potential for use by environmental administrators in predicting the likely effects of various growers practices in relation to identifying problems associated with NO_3-N in drinking water and in edible cabbage heads.

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TABLE OF CONTENTS

CHAPTER 3

METHODS OF MEASURING SAP NITRATE CONCENTRATIONS IN CABBAGES

CHAPTER 4

FACTORS AFFECTING SAP NUTRIENT CONCENTRATIONS IN CABBAGES

CHAPTER 5

INFLUENCE OF FERTILIZER FORMS ON SAP NUTRIENT CONCENTRATIONS AND YIELD OF WINTER CABBAGES

CHAPTER 7

EFFICIENCY OF ^{15}N LABELLED UREA FERTILIZER APPLIED AS A SIDEDRESSING TO WINTER CABBAGES

CHAPTER 8

MODELLING THE NITROGEN FERTILIZER REQUIREMENTS OF WINTER CABBAGES

CHAPTER 9

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

Fertilization is one of the most important factors which influence the yield and quality of leafy vegetable crops. Quality, as expressed by succulence in leafy vegetable crops is related to high water content. In order to ensure succulence, and therefore quality, vegetable growth should be rapid and uninterrupted (Maynard, 1979). Consequently, high rates of fertilization are used in vegetable production to promote vigorous growth and crop quality. Of all the essential plant nutrients, nitrogen (N) is usually the element which most limits field productivity of leafy vegetable crops.

From an economic standpoint, vegetables are grown intensively with generally high production costs and a high crop value. The cost of fertilizers represents only a small fraction of the total production inputs. Thus, commercial vegetable growers often apply N in excess of the required for maximum growth and yield. However, the continuing increase of fertilizer costs and the fear of excessive N fertilisation resulting in unduly high nitrate levels in both produce and in domestic water supplies, which may detrimentally affect human health, point to a need for more efficient N fertilization of vegetables.

Nitrogen requirements of vegetable crops have not been studied extensively in New Zealand (Goh and Vityakon, 1983). The main reason for this is the great diversity of vegetable crops and soils on which they are grown making it quite impossible to carry out fertilizer trials on each crop and soil. Over the years, a number of N rate type field trials have been conducted in NZ (Wilson, 1975) from which N response curves are derived. The results from such trials (published in Aglinks by the Ministry of Agriculture and Fisheries) have been the basis of current N recommendations by the Ministry of Agriculture and Fisheries (MAF) Advisory Service. In 1986, MAF published a bulletin "Fertilizer

Recommendations for Horticultural Crops" pooling together all available information on fertilizer requirements of horticultural crops including vegetables commonly grown in NZ. The bulletin was written primarily for advisers and growers with the aim of answering the question; what types and rates of fertilizers are needed to maximise crop production. The authors of the bulletin, however, have recognised the fact that for some crops there are still large gaps in the knowledge about their nutrient requirements. In these cases, the recommendations given in the bulletin are considered very tentative and may prove to be unsatisfactory. It appears, therefore, that in NZ there is still a need to conduct further studies to develop more definite N fertilizer recommendations for horticultural crops, including vegetables, so that growers can utilise N fertilizers more efficiently but continue to meet production objectives.

The general objective of this study was to determine the N fertilizer requirements of winter cabbages. More specific objectives were to:

1. Assess the use of soil and plant (sap) tests for determining the N fertilizer requirements of winter cabbages;

2. Study factors affecting sap tests, particularly for nitrogen, in winter cabbages;

3. Determine the efficiency of ^{15}N labelled urea applied as a sidedressing to a winter cabbage crop;

4. Develop and validate a simple model designed to predict the N fertilizer requirements of winter cabbages.

CHAPTER 2

REVIEW OF LITERATURE

2.1 NITROGEN FERTILIZER REQUIREMENTS OF CROPS, PARTICULARLY VEGETABLE CROPS

The nitrogen (N) fertilizer requirements of a crop usually relates to the amount of N fertilizer required by the crop for maximum yield. In a broader sense, N fertilizer requirements of crops (Allison, 1966; Parr, 1973) depend not only on the amount of N application but also the form, time, and method of N fertilizer application.

Until recently, knowledge about the N fertilizer requirements of vegetable crops has been limited. This is mainly attributed to the diverse nature of vegetable crops and the wide variety of conditions under which they are grown (Greenwood, 1979). In the UK, the tremendous diversity of vegetable cropping makes it impractical to carry out numerous fertilizer trials to cover the entire range of soil conditions and cultural practices. Similarly, research activity on fertilizer requirements of vegetable crops in NZ is complicated by the wide range of crops, the number of different soil types on which they are grown, and likely variations in response due to time of sowing or planting (Wilson, 1975).

In the case of cabbages (*Brassica oleracea* var. *capitata* L.), the major fresh green vegetable consumed in NZ (MAF, 1984), the recommended N rates for maximum growth and yield vary from 300 to 500 kg N ha^{-1}. It is also recommended that the application of N should be split between a base dressing (just before planting) and later sidedressings. Such statements are, however, very general and do not cater for differences in locations and soils.

Climatic. factors (rainfall, temperature, light intensity) which vary as to location modify the rate of growth of plant species and, at the same time,

the utilisation of nutrients by the plant. In effect, there is still a need to conduct further studies to develop more definitive N fertiliser recommendations for vegetable crops in NZ so that growers utilise N fertiliser more efficiently but continue to meet production objectives without creating the potential for environmental contamination.

2.2 DIAGNOSTIC TESTS FOR DETERMINING N FERTILIZER REQUIREMENTS OF CROPS

To make recommendations for N fertilizer requirements of crops, an assessment of the N status of a site must be made. The two main methods available for assessment of N status are soil testing and plant analysis.

2.2.1 Soil Testing

Numerous attempts have been made to relate various features of N response or N requirement to a single measure of N status of the soil (Greenwood, 1986). The amount of inorganic N in the profile at the start of the growing season was closely related to the yield of field grown spring barley (Soper et al., 1971) in Canada, corn and sugarbeets (Spencer et al., 1966; Giles et al., 1975) in the Western United States and N uptake by spring barley (Soper and Huang, 1963). More than 53% ($r = 0.73^{**}$) of the variance in yield or N uptake on unfertilized plots was removed by regression against soil inorganic N. In humid regions, however, soil mineral N content has been reported to be too variable to be a good indicator of N availability to crops (Fox and Piekielek, 1978). The poor calibration of soil NO_3-N under humid conditions is attributed to the movement of NO_3-N out of the root zone during crop growth. Although this leaching loss, like rainfall, cannot be predicted in advance, the effect of leaching can be measured (Mohammed et al., 1987b) and its effect on soil NO_3-N calculated.

Apart from the residual mineral N at planting, the N mineralised from soil organic matter during plant growth is also an important factor in determining the N fertilizer requirements of crops (Parr, 1973). A number of incubation tests (aerobic and anaerobic) have been developed for measuring N mineralisation rates to give a measure of the available soil N. Interpretation of the tests, in terms of fertilizer needs, was dependent on empirical relations between amount of soil N mineralised under controlled conditions (constant temperature and soil water level) and the crop yield response to applied N (Stanford, 1982). The results from incubation tests, therefore, are difficult to relate to those from field and pot tests because in the former, the soils are brought to optimum conditions, a condition which nature does not continually provide (Vlassak, 1970).

The limitation of the above incubation analyses may be a reflection of the manner in which they have been used to determine N fertilizer requirements of crops. Scaife and Turner (1987) using information from a soil incubation experiment, as only one of the inputs a multi-component static model to determine N sidedressing requirements of brussels sprouts, found a successful relationship. The amounts and rates of mineralisation of organic N in soils are expected to vary depending on temperature, soil water content, pH, and the type and form of soil organic matter (Greenwood, 1983). Using 24 different soils with a wide range of total N contents (0.09-0.32%), Vlassak (1970) showed that mineralisation of soil N is roughly proportional to soil total N(%) in excess of 0.09%. In NZ, the estimated N mineralisation rates are found to vary for different cropping soils. In the Manawatu district, Elliott and Gregg (1979) using field data experiments for corn calculated net mineralisation in the top 300 mm to be in the range of 0.5 to 1.0 kg N ha^{-1} d^{-1}, over the growing season. These values were found to be lower than the predicted mineralisation rates by a laboratory incubation test at 3 of the 4 sites. For a Canterbury soil (Quin and Drewitt, 1979) and for two Waikato soils (Ross et al., 1982) the potential mineralisation rate of the soils was about 1 kg N ha^{-1} d^{-1} based on laboratory incubation experiments. For some Canterbury cropping soils, Ludecke and Tham (1971) and Hart et al., (1979) reported higher value of about 1.5 kg N ha^{-1} d^{-1} for the amount of

N mineralised over a growing season in the top 150 mm depth.

The literature review indicates that under NZ conditions, there appears to be no published information of mineralisation rates in field soils growing vegetable crops compared with that found with agricultural crops. It might be expected that in general the rate of mineralisation with vegetable crops would be lower because of the low level of native organic matter under vegetable growing conditions and also less root exploration.

Applications of fertilizer N have been reported to stimulate, depress, or have no effect on the mineralisation rate of soil N (Westerman and Kurtz, 1973). Stimulation of mineralisation of soil N by the addition of fertilizer N has been referred to as the "priming effect" (Jenkinson et al., 1985). Plants given N fertilizer would take up more unlabelled N from soil than plants receiving no fertilizer N. Field studies with ^{15}N labelled fertilizers on winter wheat, at the Rothamsted Experimental Station in England, have shown large positive priming effects in soils. There was an increase in uptake of unlabelled soil N as labelled fertilizer application increased. More than twice as much soil N was taken up by the winter wheat receiving 182 kg labelled fertilizer N compared with the wheat receiving none. It was explained that plots receiving inorganic N annually contain more biomass than plots receiving no N, and therefore presumably mineralise more N each year.

2.2.2 Plant Analysis

Plant analysis has been used to evaluate the nutritional status of many crops for diagnostic and corrective purposes (Gardner and Roth, 1989). As a method of assisting in the determination of fertiliser requirements of crops, it is based on the fact that within certain limits, increasing the content of a nutrient in soil results in an increase of its concentration in the plant and also a rise in yield (Jungk and Wehrmann, 1978). The nutrient concentration in the plant at any one time is thus correlated with final yield. If this correlation is quantitatively known, the nutrient

concentration of a plant can be used to indicate whether or not the application of more fertiliser at the time of sampling will result in a higher yield.

Plant analysis has distinct advantages over soil analysis as a diagnostic aid for horticultural plants (MAF, 1986). The nutrient elements present in the plant at the time of sampling do not only present what have been available in the soil but they also reflect the current nutrient availability from the entire root zone. In addition, plant composition integrates both seasonal and site effects (Russell, 1968).

Plant analysis should be used in two important ways: (1) as a diagnostic aid for identifying possible causes of poor plant growth and to confirm visible leaf symptoms of suspected nutritional disorders; and (2) as a monitoring aid for current plant N status (Jones, 1985). However, many factors can affect the calibration of plant analysis tests for a specific combination of crop species and mineral nutrient (Lee et al., 1981). Important among these are plant age at the time of sampling, plant part selected for analysis, and type of analysis performed (Bates, 1971).

2.2.2.1 *Total N*

The N status of a plant has been primarily based on its total N content (Mills and Jones, 1979). Total N content in plants have been widely used and successfully correlated with yields of vegetable crops including cabbages (Geraldson et al., 1973). The application of the simple relationship between crop yield and N content of the plant, is however, restricted by the fact that optimum values differ markedly within and between plant species (Jungk and Wehrmann, 1978). In analysing a particular plant part for total N, e.g., leaves, the problem that often arises is the total N concentration increases markedly from older to younger tissues. This effect is independent of N nutrition so that the total N content is unsuitable for evaluating the N status of the crop, unless leaves of the same age are used. Between plant species, there is a

need to calibrate all varieties which is time consuming and with new varieties continually entering the market it is difficult to justify the use of total N. Essentially, total N provides a picture of the plant's N history up to the time of sampling but it fails to clearly indicate the N status at the time of sampling.

2.2.2.2 *Extractable N*

Extractable N from plants involves the direct assessment of the unassimilated, soluble N contents of sap from fresh tissue or the elemental N content determined by an acid extraction of either fresh or dried plant tissue (Jones, 1985). In essence, the constituents that are measured are en route from the point of entry to the site of utilisation within the plant (Aldrich, 1973).

The levels of N compounds; e.g., nitrate; rather than total N, have been used to assess the N nutritional status of crops (Jungk and Wehrmann, 1978). The main reason is that nitrate rather than total N reflects current N supply. In the suboptimal range of N nutrition, an increase in N supply is registered much more sensitively by an increase in nitrate content in the plant than by an increase in total N. Nitrate may therefore be used preferably to total N in the N deficient range to indicate the current N status of the plant. The work of Lorenz and Tyler, (1978); Woodson and Bordley, (1983); Prasad and Spiers (1984a) support this viewpoint.

The feasibility of using petiole concentration of NO_3-N, on a dry weight basis, as an aid in the efficient production of crops has been successfully demonstrated by several workers. Nitrate-N content in cotton petioles was found to be related to the rate of N application and total yield (Mackenzie et al., 1963; Amer and Abuamin, 1969; Lutrick et al., 1986). Grain yield of wheat was closely related to NO_3-N concentration during early growth stages (Papastylianou and Pukridge, 1981) but not later growth stages. There was also a marked positive correlation between final yield and NO_3-N levels in tissues of corn from the fifth to the seventh week and

sugarbeet from the seventh to the eight week (Chamberland and Doison, 1973).

University of California (1978) recommended a plant tissue testing procedure for horticultural crops including vegetables i.e., the use of 2% acetic acid to extract NO_3-N in plant tissues (acetic acid soluble NO_3-N) to evaluate their N status. The method eliminates the destruction of organic matter as required in total N analysis, thus, acetic acid extraction is more rapid and less tedious.

2.2.2.3 *Sap nitrate testing*

The concept of testing plants for NO_3 status is based on the fact that under cropping situations, N is extracted by plants from soils mainly as NO_3^-, and in most plant species NO_3^- is moved in this form to the leaves where it is reduced to ammonia and then combined with carbohydrates to form amino acids, amines and thence proteins. Apparently, nitrate testing is not applicable for crop species that exhibit nitrate reducing capacities in their roots (Lewis, 1986). This situation exists in legumes using N fixed from the soil atmosphere by root nodule bacteria which reduce N rather than oxidize it and *Rosaceae* species.

Rather than extracting nitrate chemically in the laboratory, sap extracts have been used to give a rapid field assessment of plant N status (Withers, 1982; Scaife et al., 1983; Prasad and Spiers, 1984a; Scaife and Turner, 1984; 1987). Scaife et al., (1983) have demonstrated a way of determining whether N fertilizer applications are required as a sidedressing to vegetable crops through sap nitrate testing at a critical stage of growth. The strategy is to apply a modest amount of N at planting, such as it is sufficient to meet the N requirement of its initial exponential growth phase (a low N requirement situation) and then sidedress N fertilizer just before the most rapid period of growth (a maximum N requirement situation) based on the result of a sap nitrate test.

The use of sap tests to determine the N status of crops is not new

(Williams, 1969). The early methods, however, involved the use of hazardous chemicals e.g., H_2SO_4 so they were not widely used by growers. The commercial availability of strips for testing the nitrate content of water samples has meant that widespread testing of plant sap for a range of agricultural and horticultural crops is now possible (Withers, 1982).

A semi-quantitative field testing kit for the measurement of nitrate in plant sap has been commercially marketed by E. Merck, Darmstadt, F.R. Germany. The "Merck test" are thin plastic strips 75 mm x 5 mm, to which are attached two squares of white filter paper, impregnated with an aromatic amine and N-(1 naphthyl) ethylene diamine. Both squares turn violet when wetted with a nitrite solution, and one of them contains a reducing agent and hence turns violet with nitrate. The latter reaction involves diazotisation and coupling, to produce an azo dye. Colour standards representing 0, 10, 30, 60, 100, 250 and 500 (ppm) NO_3^- are printed on the tube containing the strips (Scaife and Bray, 1977).

Using the Merck test strips, the NO_3^- concentration in the sap is determined by crushing a drop of sap from a leaf-stalk (petiole), stem or midrib on the test strip which records the concentration of nitrate in the sap from turning white to various shades of purple. The colour reached after two minutes is compared with standards in the tube containing the strips (Scaife and Stevens, 1977). The figures on the scale on the container are in ppm NO_3^- and should be divided by 4.4 to get ppm NO_3-N. When the concentrations are higher than 500 ppm NO_3^-; the range is extended by timing from wetting the strip to when the darkest colour in the scale is reached.

Several workers have found good correlation between petiole sap NO_3^- by the Merck test strips and the standard laboratory methods of measuring nitrate in plant tissues or sap. Scaife and Stevens (1983) using field grown cabbages have found good correlation between petiole sap nitrate levels measured by Merck test strip and by specific ion electrode on fresh ($r = 0.790^{**}$; 94 df) or dry ($r = 0.895^{**}$; 94 df) petiole basis. They, however, found that the Merck test strip had the general tendency to give sap

concentrations substantially lower than those by the electrode method on fresh tissue basis at concentrations below 100 μg NO_3-N ml^{-1}.

Prasad and Spiers (1984b) have also found good relationships between sap nitrate determined by Merck strip and acetic acid soluble nitrate using the autoanalyser for a range of vegetable crops such as carrot, celery, potato, sweet corn and tomato.

Coltman (1987) using tomatoes growing in nutrient solution reported a good correlation between Merck test strip nitrate levels in petiole sap of recently matured leaves and levels of nitrate determined in the laboratory by the phenodisulfonic acid (PDS) method. The relationship was described by the equation $NO_3\text{-}N_{(Merck)} = 168 + 0.1059\ (NO_3\text{-}N)_{PDS}$ ($R^2 = 0.69^{**}$; n=25). In a follow up field study using tomatoes, Coltman (1988) found a good linear relationship between Merck test strip and tissue nitrate concentrations by PDS conducted in the laboratory ($R^2 = 0.80^{**}$).

Lyons and Barnes (1987) measured the petiole sap nitrate levels of field grown tomatoes by the Merck test strip and compared the results with the nitrate levels measured by the autoanalyser method (AA). They found a reproducible relationship between the two methods in the form $Y = b_1X$ where $b_1 = 1.159 + 0.056$ ($P = 0.05$); Y = Merck test strip value and X = AA value ($R^2 = 0.995^{**}$).

Methods of extracting petiole sap (roll and press) for nitrate analysis by Merck test strip were compared by Coltman (1987). In the roll method, the sap was extracted from the basal one cm of the petiole by pressing and rolling a thick pen barrel toward the cut end of the petiole as it overlay the test strip. The press method involved crushing an adjacent one cm segment of petiole in a garlic press. He found out that sap extracted with the garlic press was turbid and green, whereas sap extracted by the roll method was nearly clear and colourless. Nevertheless, there were no differences between kind of sap sample or sap extraction method on the nitrate levels in the sap at any given sampling time.

Based from the results of the above mentioned workers, there is strong evidence that the Merck test strip is a suitable method of measuring nitrate levels in the petiole sap of some vegetable crops. The sap nitrate test is considered to have many advantages over the conventional plant analysis techniques (Prasad and Spiers, 1984b). Sap nitrate tests using the Merck test strips are safe, convenient, simple to use and gives immediate readings. The conventional methods (total N and acetic acid extraction) are time consuming, costly and require laboratory facilities.

Prasad and Spiers (1984b); Scaife and Turner (1984) and Coltman (1987) further concluded that sap nitrate analysis using the strip method gives a good indication of the current N nutrition of vegetable crops (brussels sprouts, carrot, celery, leek, lettuce, onion, potato, spinach, sweet corn and tomato) but cabbages were not included in the evaluation.

The Merck strips have also been tried and found useful for other crops such as pot (ornamental) plants (Prasad and Spiers, 1982) and kiwifruit (Prasad and Ravenwood, 1986; Prasad et al., 1987).

Past studies involving sap testing as a diagnostic test of N status of crops mainly emphasized the measurement of nitrate levels in petiole sap. Although, attempts have been made to use the composition of bleeding sap in stem (xylem) as a guide to the nutritional status of crops (Bollard, 1960), there has been no published data to indicate the utility of xylem sap nitrate levels as indices of the nutritional status of vegetable crops. Measurement of xylem nitrate concentration would appear to be more related to external N supply than petiole sap. Xylem is a pathway through which substances are transported from the roots to the upper parts of the plants (Goto, 1987). Thus, the nutrient concentration in the xylem sap is more directly influenced by factors affecting nutrient absorption by roots from external medium. On the otherhand, petiole sap nutrient level is always in a dynamic state since it represents the difference between the rates of absorption and assimilation within the plant (Maynard et al., 1976). Thus, nitrate concentration in petiole sap is influenced by any factor affecting one or all of the processes of absorption, assimilation and

translocation. Theoretically, xylem sap measurements may offer a better test in determining N status of plants where an assessment of external N supply is required.

Darby et al., (1986) have successfully correlated the concentration of NO_3-N in the xylem sap of winter wheat (determined colorimetrically by a rapid nitrate test; Williams, 1969) with NO_3-N in the soil to a depth of 90 cm; concentrations remained high until most of the soil NO_3-N had been removed by the crop. The time at which stem sap NO_3-N concentrations declined therefore acted as an index of soil N supply, and the data showed that fertilizer-N was needed when the NO_3-N concentration in the xylem sap fell below a 200 $\mu g\ ml^{-1}$ threshold. Wheat grain yields benefited from the N applied in early spring i.e., before the main topdressing was given in April (late spring); only when stem sap NO_3-N concentration fell below this threshold level. On the other hand, Scaife and Turner (1987) found sap test results in brussels sprouts showed only a slight correlation ($r = 0.53^*$) with soil NO_3 concentration (0-30 cm) at one sampling time (sidedressing) in different sites.

In another study, Clark et al., (1986) suggested the use of xylem sap analysis as a pre-season indicator of the micronutrient status of kiwifruit. Sap was collected from excised one-year-old extension shoots on individual vines over a 2-hr period following the method of Ferguson (1980) i.e., by cutting the shoot with secateurs and stripping back the bark for about 3 cm. The shoot was quickly wiped with an absorbent tissue and the first few drops of exudate were discarded. Sap was then collected into plastic bag held over the debarked wood with rubber bands. They found that abnormalities in Mn nutrition were clearly indicated by the Mn concentration in xylem sap. Xylem sap analysis, however, was not appropriate for Zn due to the formation of metal-organic ligand complexes between malate complexes and Zn which provided interferences during analysis.

As stated earlier, previous workers using plant sap analyses have mainly measured nitrate levels in petiole sap of some vegetable crops. The

possibility of using nitrate levels in xylem sap of vegetable crops (e.g., cabbages) as indicators of their N status as well as soil N availability requires examination.

2.2.3 Factors Affecting Nitrate Concentrations in Plants

There is at present a growing concern in European countries about high levels of nitrate in food (chiefly vegetables) and water because of possible link with medical health problems (Richardson, 1987). In 1982, the Dutch government laid down maximum permissible levels for nitrate in endive, spinach and outdoor lettuce as 4000 mg NO_3 (909 mg NO_3-N) per kg fresh produce (Roorda van Eysinga, 1984). Thus, every reasonable measure to control excessive accumulation of NO_3-N in the environment is essential.

Accumulation of nitrate in plants is genetically controlled and is modified by environment, fertilizer management and crop production practices (Maynard et al., 1976). The relationships of these factors and nitrate levels in plants are important considerations in the interpretation and comparison of test results taken from different sites and times (Scaife and Stevens, 1983). These factors also affect the production of chemical constituents and physical properties of plant material relevant to quality (Mengel, 1979). The following review will briefly consider some of these factors.

2.2.3.1 *Genetic control*

Between plant species, small but consistent differences have been noted among cultivars in their tendency to accumulate nitrate-N (Maynard and Barker, 1972). A savoyed leaf spinach cultivar for example may accumulate more nitrate-N to higher levels than the smooth-leaf cultivars indicating that the accumulation of nitrate-N is genetically controlled.

Using different varieties of wheat and barley from breeding plots in

advanced yield trials, Papastylianou (1987) concluded that varietal differences in NO_3 concentration among varieties are not a critical consideration for the interpretation of prognostic standards for crop genotypes which have been developed for certain environmental condition. Other factors like soil fertility and different growing conditions in the different years accounted for differences in plant NO_3-N concentrations. This result was in contradiction to the earlier findings of Huffaker and Rains (1978) and Crawford et al., (1961) who found consistent differences between wheat and oat varieties, respectively. The variations of plant ability to acquire nitrate due to differing root development and morphology affecting the efficiency of N uptake mechanism explained the differences in plant NO_3-N concentrations among wheat varieties (Huffaker and Rains, 1978).

Within a plant, nitrate concentrations may vary among its parts, and with growth and development (Maynard et al., 1976). Generally, the highest nitrate levels in a plant are found in the petioles of recently mature leaves, with lower levels in the petioles of very young and old leaves (Scaife, 1979). Mason and Wilcox (1982) found that the NO_3-N content of tomato petioles was about 3 times higher than of the whole leaf for all sampling dates and application rates. Maynard et al., (1976) found that nitrate concentrations in older celery petioles were about 2.8 times higher than in the younger petioles, and older lettuce leaves had 2.6 times higher nitrate concentrations than younger lettuce leaves. This is in contradiction to the findings of Scaife and Stevens (1983) using field grown summer cabbages who found that nitrate concentration in the middle (young mature) were the highest, followed by those of the upper leaf (youngest) and those of the lower leaf (oldest). Whether this above finding applies to winter cabbages (different growing conditions) or not needs to be assessed to standardise plant leaf position for nitrate analysis.

2.2.3.2 *Light and temperature*

Environmental factors particularly light and temperature have been found

to affect the pattern of diurnal fluctuation in the nitrate concentration of young field grown beets (Minotti and Stankey, 1973). Maximum concentration of nitrate in the plant tissues was measured at 4:00 am and 8:00 am and minimum concentration at 4:00 pm. The high nitrate concentration measured at early morning, during the 52-hr sampling period, was enhanced by low light intensity which inactivates nitrate reductase activity, and the low temperature which decelerates assimilation process than absorption favouring net accumulation of nitrate.

The above findings are in contradiction to the results of Scaife and Stevens (1983) who found the effect of time of day, on petiole sap nitrate concentration in summer cabbages, of no significance. However, the pattern of sap NO_3-N concentration consisted of peaks at 10:00 am and 2:00 pm and a minimum at 6:00 pm.

This finding was also supported by Coltman (1987) who found an insignificant effect of time of day on petiole sap nitrate levels in tomatoes. The pattern indicated sap nitrate levels to be higher at 11:30 am than at 8:30 am or 2:30 pm. Although higher light intensities were recorded during the 2:30 pm sampling than in the other two sampling times, this factor did not result in higher sap nitrate levels as found in beets.

2.2.3.3 *Rate and amount of nitrate supply*

Nitrate uptake by plants increases sharply with increases in the external supply of nitrate, and when the supply is high, nitrates will be absorbed in excess of the needs of plants and will accumulate internally (Barker and Mills, 1980). The external supply of nitrate is probably the most important factor controlling the accumulation of nitrates in plants (Wright and Davidson, 1964; Maynard et al, 1976; Maynard, 1979).

Greenwood and Hunt (1986) found nitrate concentrations in foliage vegetable crops (lettuce, spinach, summer cabbages and winter cabbages) at

final harvest in 14 experiments grown with a range of N fertilizer levels to increase in a "diminishing returns" way with increasing levels of N fertilizer. For winter cabbages, the levels of NO_3-N ($\mu g\ g^{-1}$ dry matter) was 1815 with 0 kg N ha^{-1}; 3074 with 241 kg N ha^{-1} (optimum level) and 3550 with 785 kg N ha^{-1} (maximum level). Average concentrations of NO_3-N for all the vegetable crops were 1280 $\mu g\ g^{-1}$ in plots receiving no fertilizer; 3498 $\mu g\ g^{-1}$ in plots receiving the optimum levels of N fertilizer and 5540 $\mu g\ g^{-1}$ in plots receiving the maximum levels. It could be inferred that the application of N higher than the recommended rate could lead to accumulation of excessive levels of nitrate in cabbages posing hazard to humans.

2.2.3.4 *Form of fertilizer N*

In a glasshouse study, Scaife et al., (1986) found higher petiole sap NO_3-N concentration in lettuce where ammonium nitrate and calcium nitrate was used as the N fertiliser sources compared with ammonium sulphate + nitrification inhibitor (nitropyrin). Satisfactory growth of lettuce was achieved by the use of ammmonium sulphate and nitrification inhibitor which incidentally was accompanied by very low sap nitrate levels. In actual commercial practice, however, nitrification inhibitors are not commonly used, hence, N supplied as NH_4^+ is rapidly nitrified and taken up by crops in the form of NO_3^-.

Using nutrient solution, cultured tomatoes applied with various NO_3:NH_4 ratios, Hartman et al., (1986) have found the nitrate content of leaves, stems and roots to decrease with each increment of NH_4 in the N ratio at all harvest dates. Highest NO_3 content in each of the plant parts was obtained with 100% NO_3 treatment.

A contrasting result was found by Shelp (1987b), in which the composition of the phloem sap supplying the inflorescence of broccoli plants grown under glasshouse conditions was relatively unaffected by the various concentrations and forms of N (NH_4^+, NO_3^- or NH_4NO_3) supplied in the

nutrient medium. However, the composition of the nitrogenous solute in the xylem sap (root bleeding sap) was dependent on N source. When NO_3 was supplied exclusively or in equimolar amounts with NH_4^+, NO_3^- was the predominant N solute in the xylem with a smaller but significant (up to 48% of N) proportion of amino acids, suggesting that while NO_3^- reduction occurred in the roots, there was a significant transport of NO_3^- which was reduced in the shoot. When the source of fertilizer N was NH_4^+, the predominant form of xylem-borne N was amino compounds, indicating, as is virtually the case with all plants, that NH_4^+ was incorporated into organic-N in the roots. The differences in the relative composition of N solutes in the xylem sap as caused by the form of N supplied, probably reflect differential degrees of uptake and/or metabolism of NH_4^+ and NO_3^- and the relative importance of their site of assimilation.

Under field conditions, the effect of N form on NO_3-N concentration in plant tissues may be related to the timing of N fertilizer application. Due to the rapid conversion of urea and ammoniacal-N to NO_3^-, the ammoniacal form of N, when applied before planting, has no significant effect on plant NO_3-N concentrations as has been found in spinach leaves (Barker et al., 1971). However, when N fertilizers were sidedressed at about one week before the spinach reached marketable-size, NO_3-N concentrations in the leaves were 0.40, 0.27, and 0.22% for KNO_3, NH_4NO_3, and urea, respectively. A similar result was found by Peck et al., (1971) in table beets. Therefore, due to rapid conversion of urea and ammoniacal forms of N (from NH_4^+ to NO_3^-) under cropping conditions, the form of N fertiliser may not have a significant effect on plant NO_3-N concentrations.

2.2.3.5 *Time and method of N application*

Irrespective of rate of N application (100-450 kg N ha^{-1}), Barker et al., (1971) found that broadcasting N fertilizer as NH_4NO_3 at planting has a greater effect on NO_3-N concentration in spinach leaves (composite sample) than sidedressing N fertilizer one week before spinach reached

marketable size. Due to limited time for plant to extract soil NO_3^- from sidedressed fertilizers, NO_3-N concentrations were lower at harvest if N fertilizer was sidedressed than if broadcast at an equivalent rate before planting.

Welch et al., (1985) have found a contradictory result in cauliflower. At equal rates of N, split application of N fertilizer as $(NH_4)_2SO_4$ resulted in higher midrib NO_3-N concentration (3888 ppm) than a single application (2490 ppm) measured at 1/3 curd formation. He concluded that N applied in one application was more subject to leaching or denitrification loss than that applied in split application.

2.2.3.6 *Other macronutrients*

Studies involving the effects of several other essential elements, other than N, indicated no marked effects of these elements on nitrate accumulation in vegetables (Wright and Davison, 1964). It was concluded that the only nutritional factor having a marked effect on nitrate-N accumulation is N. Some studies (Steineck, 1974; Loue, 1978; Steineck and Haeder, 1978;), however, reported the stimulating effect of abundant supply of K in the soils on NO_3^- absorption by plants. Both of these ions undergo luxury consumption by plants, are often applied together and one may be absorbed after the accumulation of the other to preserve electrical neutrality in the plant.

2.2.3.7 *Nitrification inhibitors*

In response to environmental concern, the use of nitrification inhibitors has been proposed as one possible means of reducing the nitrate content in vegetables.

Vaughan (1985) found that by adding nitrification inhibitor (dicyandiamide) to urea (414 kg N ha^{-1}), nitrate concentration in glasshouse grown winter

lettuce was significantly reduced to about 15% of the total NO_3-N but this was accompanied by an unacceptable loss in yield and quality thought to be due to phytotoxic effects of the high level of residual ammonium. The inhibitor had no effect on nitrate concentrations at the lower rate of applied N (138 kg N ha^{-1}). The work of Roorda Van Eysinga (1984) showed that application of dicyandiamide at rates as high as 0.5 kg per 100 m^2 resulted in leaf scorch and chlorosis in lettuce and other Brassica crops, thus, affecting yield and quality of the crop.

On the other hand, Scaife et al., (1986) found that lettuce can be grown satisfactorily in the glasshouse with a very low nitrate content when supplied with ammonium sulphate and a nitrification inhibitor.

Although the use of nitrification inhibitors successfully reduced leaf nitrate levels, Richardson (1987) suggested that further work is needed to confirm that their use does not reduce crop yield.

2.2.4 Critical N Levels in Vegetables

The prediction of the N status of crops from plant analysis can be based on the critical concentration of a nutrient within the plant (Maynard et. al., 1976). Ulrich and Hills (1967) defined critical concentration as the nutrient concentration in the plant when the nutrient is just deficient for maximum growth. As a matter of convenience and practice, the critical concentration usually has been determined at a 10% reduction in growth resulting from a deficiency of the nutrient under study.

With respect to cabbages, a survey in the literature (Table 2.1) indicates that there is limited information on the critical N concentration for cabbages. These critical values were established following the critical concentration concept i.e., by plotting final yields against plant N concentrations at specific growth stage.

The conventional approach of deriving critical nutrient concentration in

Table 2.1 Nitrogen levels in cabbages as reported in the literature.

Time of sampling[1]	Plant Part	N levels	Reference
Heads, 1/2 grown	Young wrapper leaf	3.0-4.0% total N (common ranges)	Geraldson et al., (1973)
Heading	Midrib wrapper leaf	5000 NO_3-N, ppm[2] (deficient)	Lorenz and Tyler (1978)
		9000 NO_3-N, ppm[2] (sufficient)	"
Heading	Midrib wrapper leaf	2000 sap NO_3,ppm[3] (deficient)	Univ of California (1978)
		4000 sap NO_3,ppm[3] (sufficient)	"
40-day plant age	Whole plant	4.5% total N (critical)	MAF (1986)
80-day plant age	"	4.0% total N (critical)	"
Over the growth period	Oldest leaf	3000 sap NO_3-N,ppm[3] (critical)	Huett and Rose (1989)
Pre-heading	Youngest fully expanded leaf	4.10% total N (critical)	"
Post-heading	"	3.10% total N (critical)	"

[1]All data were established from field trials except that of Huett and Rose (1989) which were derived from sand culture experiment. N levels were measured by [2]Acetic acid extraction; [3]Merck test strips (as cited by Cornforth, 1980) and [3]Merck test strips.

plants e.g., sap nitrate concentration, has been criticized by some workers (Scaife et al., 1983; Scaife and Turner, 1984; Scaife 1988). Scaife et al., (1983) found that graphs of final yield against sap nitrate concentration in a range of vegetable crops showed radically different optima at every growth stage. Comparisons between results from different seasons with the same crop, plotted in the same way, sometimes showed very different sap concentrations at very similar growth stages. They argued that with the conventional approach, the critical concentration differed both with seasons and with stage of growth and therefore casts doubt on its usefulness as a basis for assisting with plant N requirements determination.

Scaife (1988) later argued that the conventional method of determining critical nutrient concentration is fundamentally flawed because it is not always safe to assume that yield differences at final harvest were a true reflection of nutrient concentration differences measured at early dates. He pointed out that what actually happens is that nutrient deficiencies, which might be quite transient, reduce the growth rate of the crops at certain growth stage. The size of reduction may then increase, or diminish, depending on whether the supply of nutrients to the roots is falling, or increasing. This particularly applies to N where a reasonable proportion of plant N is derived from mineralisation of organic N, the rate of which can vary depending on a range of soil and climatic conditions.

To overcome this discrepancy of varying critical concentrations, Scaife (1988) used results from a brussels sprout N experiment conducted over three seasons to develop a model which derived a single critical nutrient concentration. The model consists of 2 elements: an equation for the potential growth rate of the fully-nourished plant, and another for the depressive effect of nutrient deficiency on its potential growth rate. The actual growth rate at any instant is the product of these two elements.

In testing the model, Scaife (1988) employed two approaches which both require an estimate of the growth rate of the non-limited crop throughout its life. He sought a function in which growth rate was simply a function of plant weight given as:

$$RGR = \exp (k_1 + k_2 * W) \qquad (2.1)$$

where W is the plant weight and k_1 and k_2 are growth rate coefficients.

The first approach calculated the ratio of the observed growth rate to its potential value for each growth period and each treatment. The ratio of the actual/potential growth rate (or S, the nutrient stress factor - Scaife and Barnes, 1977) is plotted against the arithmetic mean over the sampling interval sap NO_3-N to derive the critical concentration.

The second approach using a simulation model, is based on the same growth equation (2.1) but instead of estimating actual and potential growth rate over relatively long periods between samplings, the potential growth rate is estimated daily, or more frequently, for the estimated actual weight at the time, and the actual growth rate is estimated from this using a function of the plant nutrient concentration at the time. Finding S by this approach is given as:

$$S = N/(N + N_h) \qquad (2.2)$$

where S is the nutrient stress factor; N is the plant nutrient concentration, and N_h is the value of N at which S is 0.5. S is multiplied by the potential growth rate at every step time to give the actual growth rate.

Whether or not these two approaches could be used for winter cabbages is not known.

2.3 EFFECT OF FERTILIZER FORM ON GROWTH AND YIELD OF CROPS

2.3.1 Effect of N Fertilizer Form

The main forms of N taken up by plants under natural conditions are the

ions, NH_4^+ and NO_3^- (Haynes and Goh, 1978). Each ion produces a different physiological response within the plant. Plants also vary greatly in their ability to absorb and utilise each ion. In arable or cropping conditions, N is extracted from the soil mainly as NO_3^- because nitrification is a rapid process and little NH_4^+ is left unconverted. Most common crops readily absorb NH_4^+ and, if preference exists, it is usually in favour of NH_4^+ early and NO_3^- late in the growing season (Olson and Kurtz, 1982).

Many studies on the relative merit of nitrate and ammonium nutrition have been made (Barker and Mills, 1980). Results of solution culture and glasshouse studies involving vegetable crops e.g., spinach and beetroot (Goh and Vityakon, 1983) and tomatoes (Hartman et al., 1986) have indicated the superiority of nitrate nutrition over ammonium in relation to yield and quality of crops.

Several hypothesis have been offered to explain the poorer growth of plants on NH_4-N nutrition (Allen and Smith, 1986):

1. Acidification of the root medium during NH_4^+ assimilation may be responsible for decreased growth in some plant species. Vegetable crops such as red beets, lettuce, spinach, and onions have been shown to be very sensitive and make poor growth in acid soils (Pombo and Smith, 1986). When grown on soil with pH 5.5, snapbean vine weights and pod yields were not affected, tomato yields tended to be lower and red beet yields were substantially reduced.
2. Carboxylate accumulation in NH_4^+-N plants may reach such low levels that growth is inhibited.
3. A deficiency in inorganic cations, particularly K^+, and Ca^{++}, has been implicated in NH_4^+ toxicity.
4. Carbon substrate availability may limit the rate at which NH_4^+ has been detoxified by assimilation into compounds such as amides.

Some reports, however, are also available to indicate favourable response of beans (Barker et al., 1966); tomatoes (Ganmore-Newmann and Kafkafi, 1980); field grown spinach (Goh and Vityakon, 1983) and lettuce (Scaife at al., 1986) to ammonium nutrition over nitrate. The favourable response of sand cultured bean plants (Barker et al., 1966) to ammonium nutrition depended primarily on the control of acidity in the root environment. This was carried out by mixing relatively insoluble carbonates (NH_4CO_3) with the sand medium or maintaining the pH of the nutrient solution near neutrality with NaOH. By maintaining the surrounding solution near neutrality, a series of reactions resulted in more efficient conversion of ammonium to amino acid and amides in the root tissue of the bean plants. Subsequently, more shoot growth may occur because the toxic concentrations of ammonium have been alleviated.

The significantly higher yield of spinach in the field (Goh and Vityakon, 1983) obtained with NH_4^+ nutrition rather than with the NO_3^- treatment was explained on the basis of leaching losses of NO_3-N. The high rainfall (total = 450 mm) that occurred during the experimental period was thought to have leached the NO_3^- down the soil profile making the NO_3^- form of N fertilizer less effective than the NH_4^+ form.

It appears that the majority of studies to determine the effect of N fertiliser form on vegetable crop yield and quality were done under artificial conditions. Because a large number of NZ vegetable crops are grown in the field and different N fertilizer forms are used, further studies comparing N fertilizer forms are needed.

2.3.2 Effect of Fertilizer (N/P) Forms

Apart from N, phosphorous (P) is a major nutrient added to crops. For cabbages, the preliminary water culture experiment of Hara and Sonoda (1979) showed that the effect of P on cabbage head yield is highest at the first growth stage. This suggests that the availability of P during the early growth of cabbage is an important component of yield variability.

Thus, the form of P fertilizer applied at crop establishment may affect the final yield and quality of cabbages. However, results of field trials in the UK (Greenwood et al., 1980a) have shown that applications of P fertilizers had little effect on any of the *Cruciferae* crops including winter cabbages, even though the soils had less than 18 mg bicarbonate soluble P/kg and had received no P fertilizer for more than 12 years. This was later confirmed by the experimental results of Alt (1987) in the UK and Germany. The most responsive crops were lettuce, carrots and beans. Crop responsiveness was related to the efficiency of root system for P uptake.

Normal crop mix fertilizers for cabbage production in NZ include a wide range of the readily soluble N and P forms like ammonium phosphate or mixtures of sulphate of ammonia, urea and monocalcium phosphate or superphosphate. Due to increased costs of phosphate rock, transport and spreading of fertilizers, the manufacture and evaluation of alternative P fertilizers like partially acidulated phosphate rock (PAPR), which can be cheaper and as effective as superphosphate, have been done. The majority of studies to assess the agronomic effectiveness of these products, however, were mainly using pasture responsiveness. Results from greenhouse and field studies (Rajan, 1985; 1987) have consistently shown equal effectiveness of PAPR and TSP as maintenance P fertilizer in pasture. Studies elsewhere obtained similar results for some field crops like wheat and corn (McLean et al., 1965; Garvouchev, 1981; Hagin and Katz, 1985).

In NZ, the only published work to date on the effect of PAPR on the growth and yield of vegetable crop (hybrid squash) is by Buwalda et al., (1987). The field experiment was conducted on a clay loam soil (initial $NaHCO_3$-soluble P, 64 ppm) and compared the effect of PAPR (30% and 50%) with triple superphosphate (TSP), applied at different rates, on soil P fertility, growth and yield of hybrid squash. The results indicated that PAPR had less effect than TSP on $NaHCO_3$-soluble P levels in the soil, plant dry weight and tissue P concentration soon after emergence and subsequently final crop yield. On average, PAPR increased crop yield by

about 70% of that following the application of the same quantity of P as TSP. The lower effectiveness of PAPR for hybrid squash was explained in terms of its lower solubility and hence smaller effect on $NaHCO_3$-soluble P in the soil during early growth, when the crop is most sensitive to soil P fertility.

Whether the above findings of Buwalda et al., (1987) apply to other vegetable crops, such as winter cabbages, is unknown. Although Hara and Sonoda (1979) have indicated that the greatest effect of P on cabbage head yield is at early stage of growth, the evidence was established under artificial conditions of solution culture.

2.4 FATE OF FERTILIZER N IN SOILS

2.4.1 Value of ^{15}N Labelled Fertilizer

Formulation of a N fertilizer recommendation for a particular crop involves an understanding of several aspects of the soil-plant system in question. The recommendation requires an accurate estimate of crop N demand and soil N supply. Also, it is necessary to estimate the efficiency of applied fertilizer to a crop. Fertilizer N use efficiency is defined as the percentage recovery of fertilizer N by a crop (Parr, 1973). This efficiency will vary depending on the N source, the rate applied, method and time of application, type of crop grown and its N requirement, extent of microbiological and chemical immobilisation of the applied N, and a host of soil, climatic and management factors. An accurate quantitative information on how N fertilizer use efficiency by a crop varies with these factors can only be obtained with the use ^{15}N labelled fertilizer (Hauck and Bremner, 1976). With ^{15}N labelled fertilizer, the amount of the fertilizer taken up by plants, the N remaining in the soil and the N lost from the soil can be accurately measured. Without ^{15}N labelled fertilizer, the soil-derived (unlabelled) N by the crop cannot be distinguished from the fertilizer-derived (labelled) N (Netsinghe, 1978).

The conventional method (difference method) of estimating N fertilizer use efficiency i.e., the difference in total N uptake by fertilized and unfertilized plants and expressed as a percent of the N applied (Hauck and Bremner, 1976) is used in the absence of ^{15}N labelled fertilizer. Users of this method, however, assume that immobilisation-mineralisation and other transformations during the course of the experiment are the same for both fertilized and unfertilized soils (Westerman and Kurtz, 1973) which may be an erroneous assumption. According to Netsinghe (1978) the difference method may give a reliable estimate of the actual fertilizer N use efficiency when the experiment is carried out on a soil of moderate N deficiency and when the fertilizer applied makes no difference to the uptake of soil nutrient between fertilised and unfertilised plots. However, it may overestimate the amount of fertilizer N absorbed by the plant when the experiment is conducted on a soil highly deficient in N. Many studies (Jenkinson et al., 1985) have shown that plants given fertilizer N would take up more unlabelled N from the soil than plant receiving no N. Such an increase in N derived from soil following fertilizer additions is sometimes referred to as "priming effect" (Hauck and Bremner, 1976). This priming effect or "added nitrogen interaction" (ANI) effect (Jenkinson et al., 1985) greatly complicates the interpretation of experiments determining the fate of fertilizer N in soil-plant system in question.

The high cost and limited availability of ^{15}N have restricted its large-scale use in field studies and often have dictated the size and nature of the few studies which have been made in the field (Hauck, 1973). Because smaller plots are usually used in ^{15}N studies, a test for the extrapolation of the results to the rest of the whole field is usually done.

2.4.2 Fertilizer N Balance Studies

Numerous field studies with winter wheat have been conducted in the balance of added fertilizer N using ^{15}N. Olson et al., (1979) assessed the influence of rates (50 and 100 kg N ha^{-1}) and times of N fertilizer

application (autumn and spring) on the fate of N applied. The N balance indicated 9.7-10.3 kg N ha^{-1} unaccounted for in the 50-kg N rate treatment and 19.7-23.4 kg, at the 100 kg rate. Considerably more N was removed by the crop and less remained in the soil from spring than autumn application which suggests a significant role for N immobilisation. Losses did not differ significantly between application times. Since they found little evidence of fertilizer N moving below about 50 cm in the soil, losses evidently occurred in gaseous forms. At the end of the experiment, most of the fertilizer N in the 0 to 10-cm layer was immobilised with only 9.6-11.5% remaining in inorganic forms. Although precipitation during the growing season was above normal, immobilisation was the principal reason for the limited N leaching loss,

The above study was continued for another five crop seasons (Olson and Swallow, 1984) with annual applications of 50 and 100 kg N ha^{-1} to further assess the effect of time and rate of N application on the fate of applied N. Each year, the amounts of labelled fertilizer N used by the crop, remaining in the soil and lost from the system were calculated. The N balance for the 5-yr period of the experiment indicated that of 250 kg fertilizer N ha^{-1} applied during the 5 yr with the 50-kg/year rate, 66.8 kg (26.7% of that applied) were removed in the grain with the autumn treatment and 76.2 kg (30.5%) with the spring treatment. With 500 kg ha^{-1} applied during 5 yr with the 100-kg rate, 151.9 kg (30.4% of that applied) was in the grain for the autumn application and 165.8 kg (32.2%) for spring. In each case, spring applications gave a significantly higher fertilizer use efficiency than autumn treatments as earlier found by Olson et al., (1979). Amounts of fertilizer N found in the soil and lost did not differ significantly with autumn and spring application. Losses averaged 15.6% of N applied for 50-kg treatments and 20.2% for 100-kg treatments.

In another study using winter wheat, Riga et al., (1980) compared two time of applications (3-split dressings; end of tillering, first node, flag leaf stage and 2-split dressings; autumn sowing, end of tillering) of 100 kg ha^{-1} N dressing applied as $Na^{15}NO_3$ and $(^{15}NH_4)_2SO_4$. The percentage uptake of the fertilizer N by the crop was markedly related to time of application,

and to a lesser extent, to the kind of carrier. Significantly higher N fertilizer uptake value (57%) was found for the 3-split dressings over the 2-split dressings (46%). This difference was related to the climatic conditions during the cropping season. The autumn split of the $Na^{15}NO_3$ dressing did not suffer any loss through leaching beyond the rooting depth, notwithstanding the drainage conditions prevailing during the autumn and winter months, but lost half its N through denitrification in the early spring.

More recently, Riga et al., (1988) recorded significantly different fertilizer recoveries(%) in winter wheat and soil depending on source of N ($Na^{15}NO_3$ and $(^{15}NH_4)_2SO_4$) and timing (end of tillering; heading; end of flowering) of fertilizer N application. With 100 kg ha^{-1} application rate, they recorded recoveries in the grain, straw and soil of 72%, 78% and 81% of the applied NO_3-N fertilizer, respectively, from the first to the third split applications. With NH_4-N fertilizers, they measured 74%, 77% and 81%, which did not differ significantly to the respective split applications for NO_3-N fertilizer. There were no differences found for each split application between the two carriers as far as unaccounted fertilizer N was concerned. The average losses were 26%, 22% and 18% of the applied N regardless of source for the three split applications, respectively. They assumed that the unaccounted fertilizer N was lost through denitrification and not leaching and volatilisation.

Recous et al., (1988) conducted a field experiment to follow the fate of N applied to winter wheat in two dressings (tillering stage and at the beginning of stem elongation) using 3 fertilizer labelled N forms: ^{15}N-urea, $^{15}NH_4NO_3$ and $NH_4{}^{15}NO_3$. The N uptake efficiency of labelled nitrate was higher than that of labelled ammonium or labelled urea over the whole growth cycle for both dressings. N uptake efficiencies were 74, 53 and 45% for the $NH_4{}^{15}NO3$, ^{15}N-urea and $^{15}NH_4NO_3$ treatments at day 42 when N uptake efficiency reached maximum. Two possible processes were given to explain this (1) the plant depletes the NO_3 pool in preference to the NH_4 pool (while both pools are present in large amounts); (2) at the same time, the NH_4 pool is preferentially immobilised by the heterotrophic

microflora. The ^{15}N recoveries in plant and soil ranged from 71% to 94% at anthesis. The deficits were mainly attributed to nitrate and ammonia losses from the soil and crop.

To date, there appears to be very little published information available on the fate of ^{15}N labelled fertilizer applied to vegetable crops. This situation is probably a result of a lack of interest in N fertilizer efficiency as fertilizer costs are a low proportion of total costs associated with production. A very recent NZ study by Ledgard et al. (1989) involved the application of ^{15}N as ammonium sulphate to an established crop of asparagus at 50 kg N ha^{-1} at different times (pre-fern growth, December; pre-picking, September; and prior to the period of rapid spear growth, October). The recovery of applied ^{15}N in harvested spears was low - 3.4, 1.7 and 0.4% for the December, September and October applications, respectively. Corresponding values for ^{15}N remaining in roots + crown at the end of the picking season were 21.6, 8.9 and 3.5%, respectively. Thus, the December application resulted in a much greater plant recovery than for other treatments. However, more than 50% of the ^{15}N applied was unaccounted for, the cause of this apparent loss, was uncertain. About 60% of the ^{15}N from the September and October application remained in the soil at the end of the picking season. A large component of this (October application) was still present as plant- available inorganic ^{15}N; thus it is likely that a significant proportion of this ^{15}N will be taken up into the plant during the next period of fern growth (October to December). In contrast, most of the ^{15}N in soil from the October application was immobilised into organic ^{15}N.

The above mentioned results using ^{15}N demonstrate that rate of N fertilizer application, form of N fertilizer and time of N fertilizer application are important considerations in studying the overall fate of applied N in plant-soil systems. It appears that the efficiency of of N fertilizer would be higher from split application than from single application (i.e., application at sowing). Whether the higher efficiency of split application would be affected by the rate of sidedressing is not mentioned in the literature review. Additionally, the above studies are

mostly of local interest and few considered horticultural crops. Since uptake and efficiency of fertilizer N are influenced by a wide range of factors, it is difficult to extrapolate these results to other areas with different climatic and environmental conditions unless the effects of these factors are evaluated (Mohammed et al., 1987a).

2.5 MODELLING THE N FERTILIZER REQUIREMENTS OF CROPS

The N fertilizer requirements of crops are normally determined by conducting field trials from which N response curves or surfaces are derived (Mohammed et al., 1984). Data from each trial are essentially site and season specific hence they have limited applicability to other sites. This limitation of field trials can be reduced by using simple models developed from relevant information, from one site, which can be readily modified to apply to other sites.

Published models are variable in their approach and utility in successfully predicting N fertilizer requirements of crops. Models can be either correlative or conceptual (Tinker and Addiscott, 1984). Correlative models (such as that of Soper and Huang, 1963; Soper et al., 1971; Giles et al., 1975;) are based on statistical analysis of past results and are developed from relationships between yield or N requirement and factors such as previous cropping and N nutrition, soil type and weather. The level of complexity in such models depends mainly on the number of factors involved. The weakness of this modelling approach is that it does not take proper account of many interacting processes that influence fertilizer response and the way they differ from one situation to another (Greenwood, 1982). The final equation is of use only in the locality or in the soils which it was developed.

An alternative modelling approach is based on mechanistic (conceptual) interpretation of soil and plant processes. This approach is based on encapsulating existing knowledge about the most important processes that

determine crop response to N fertilizers into dynamic models (Greenwood et al., 1985a; 1987a; 1989a). The processes are defined by equations with coefficients that are remarkably constant over a wide range of crops and growing conditions. In developing the models, Greenwood et al., (1985a) proceeded first to use results from N fertilizer trials to establish quantitative relationships detailing how the processes produce N response (under optimum conditions) including the growth and N uptake of a crop. A simulation model which incorporates the various relationships is then constructed and used to predict N response curves for new sites and growing conditions.

Dynamic N response models have been developed and validated experimentally for potatoes in Netherlands (Greenwood et al., 1985a; 1985b) and for winter wheat in the UK (Greenwood et al., 1987a; 1987b). These previously derived models were found to give a reasonably good description of dry matter and N content responses of diverse arable and vegetable crops (Greenwood and Draycott, 1989a; 1989b). The models, however, were found giving poor estimates of dry weight and N uptake in three experiments: one each with radish, swede and winter cabbage. Poor plant recovery of fertilizer N due to leaching was thought to be the reason for the discrepancy in the measured and predicted values for winter cabbages.

Although the above models provide information about optimum N requirements, they do not predict what the N fertilizer requirements (rate, form, frequency) are needed to attain optimum N requirements.

In order to determine N fertilizer requirements of crops it is necessary to predict the effects of different N supply levels and the effects in relation to optimum N requirements. This approach was used to predict the response of potato to N fertilizer at 7 N fertilizer levels in 61 field experiments in Netherlands (Neeteson et al., 1988). On the basis of the predicted yields for each experiment a predicted N fertilizer response was calculated from which an optimum N fertilizer application rate was derived. The predicted optimum N fertilizer rate was compared with the measured optimum N rate for each site. It was found that if the

predicted optimum application rate of N fertilizer had been applied in the 61 experiments, the yield deficits from the maximum obtainable yields would have been less than 2% in 84% of the experiments. Thus, the dynamic model reliably predicted the optimum application rate of N fertilizer for potato in the experiments.

Although several relationships for components of crop growth have been quantified and modelled (Greenwood et al., 1989a), models that describe the rate of crop growth and crop N uptake under different N supply levels are crucial factors in determining N fertilizer requirements of crops. For cabbages in NZ, there appears to be a lack of information regarding the rate of growth and course of N absorption under field conditions of different N status. As a consequence, models that predict cabbage N fertilizer requirements have not been developed.

To determine or predict the rate of fertilizer N required to achieve an optimum growth and yield of a crop, a simple and direct model (multi-component static model) has been given by Parr (1973) and Stanford (1973). The model is based on N balance system i.e., N fertilizer requirement is calculated as the difference between the potential demand of the crop for N and the amount that can be supplied by the soil to the depth of rooting when no N fertilizer is applied.

Thus:

$$N_f = (N_y - N_s - N_m)/E_f \qquad (2.3)$$

where:

N_f = N fertilizer requirement

N_y = N requirement for optimum crop growth

N_s = Mineral N (NO_3^- and NH_4^+) in the root zone at planting

N_m = N mineralised from soil organic matter

E_f = Efficiency factor

All terms except E_f(%) are expressed in kg/ha.

Stanford (1973) has mentioned that the validity of the model will be dependent on the degree of success achieved in estimating its components. The initial essential step leading to a meaningful fertilizer recommendation is an accurate estimate of the amount of N needed by the crop (internally) to produce the expected attainable yield (i.e., expected dry matter yield x N content). The constancy of the percentage N in the crop at near maximum yield permits an estimate of internal N requirement for an attainable yield. The assessment of a yield estimate depends on climate, soil conditions and management factors (Stanford and Hunter, 1973). Variations in yield from year to year generally are less in irrigated and humid regions than under sub-humid or semi-arid dryland conditions. Estimates should be based on local rather than regional production and climatological records. A criticism of this approach is that N sufficiency throughout growth is also important.

In Equation (2.3) N supply in the unfertilized soil is the sum of mineral N soil at planting (N_s) and N mineralized (N_m) from soil organic matter during crop growth. The depth of soil for measuring N_s would depend on the effective rooting zone of the crop. In most models based on soil tests (Myers, 1984), N_s and N_m are closely correlated, so that only one of the terms appears in the model. In another model, developed by Quin et al., (1982) for determining wheat yields and N requirements in NZ, N_m was estimated to be twice the increase in the initial mineral N based on aerobic incubation for 7 days at 37°C.

Another important component in Equation (2.3) is the efficiency of N uptake. Plants do not recover all soil mineral N or fertilizer N. Two efficiency factors are therefore needed to account for this; one is the efficiency of uptake of soil mineral N and the other is the efficiency of uptake of fertilizer N. Parr (1973) and Stanford (1973) have assumed that N_s and N_m are utilised at the same efficiency as N_f. The efficiency of N_f is influenced by N application rate; time and method of N application; and growing conditions affecting yield potential, e.g., soil properties, other essential nutrients, soil management, climate, rainfall, and irrigation

practices. The efficiency factor (E_f) is expected to range from 50 to 70% for appropriate rates and timing of N application (Stanford, 1973). Among the factors, proper timing of N application has been considered by many workers to be the most important consideration for increasing N_f efficiency. Sidedressed N or split application of the total N dressings in corn (Welch et al., 1971), winter wheat (Riga et al., 1980) and some vegetable crops e.g., cauliflower (Welch et al., 1985) and garlic, hybrid squash and potato (Buwalda and Freeman, 1987) has been reported to have a higher efficiency than a single application at sowing. This is because when fertilizer N is applied far in advance of the time of maximum N demand by the crop, there is greater probability of loss (e.g., leaching). If applied at a growth stage when there is peak demand for N by the crop, such as in a sidedress application, less total N may be required to produce a similar yield from an initial application.

Parr (1973) and Stanford (1973) have sucessfully used Equation (2.3) in determining initial (at sowing) N fertilizer requirements of corn in the USA. A similar approach but with more inputs was used for winter wheat (Remy and Viaux, 1982) in France which also proved effective. The calculated N_f requirement was within 20 kg N ha^{-1} of the measured optimum between 45 and 60% of trials in northern and eastern regions of France. Many French farmers have accepted the practice and often do the necessary calculation themselves (Meynard et al., 1982).

Like most models, Equation (2.3) has a degree of site specificity and parameters would need to be altered to utilise at other sites. Some of the inputs in the model are measured but some can be estimated. To extend the utility of the model to other situations, subsidiary models could be used to predict values of some inputs like N_y and N_s and N_m. To determine N_y, both the dry matter production and N concentration in the plant under optimum conditions, need to be predicted at final harvest. If a reduction in plant N uptake from optimum levels can be predicted at a critical stage of growth, steps such as sidedressing with additional N fertilizer, could then be taken by growers or advisers to rectify any trend in plant N uptake which departs from that planned to obtain maximum

yield (Mohammed, 1983).

The uptake of N (N_y) needed for maximum growth depends in part on the rate of growth when this is not limited either by lack of water or nutrients. According to Greenwood et al., (1977) the rate of dry matter production at any given radiation intensity increases in a "diminishing returns" way with plant weight until the onset of senescence. This type of relationship is expressed as:

$$dW/dt = k_2 W/k_1 + W \qquad (2.4)$$

where W is weight per unit area of plant dry matter exclusive of fibrous roots, t is time, k_1 is a growth constant which is equal to 1 t ha^{-1} for all crops and k_2 is a growth coefficient characterizing crop growth when there is ample mineral N available in the soil.

k_2 is calculated from the integral of Equation (2.4) which is:

$$k_2 = (k_1 \ln W_h + W_h - k_1 \ln W_p - W_p)/t_h - t_p \qquad (2.5)$$

where W_h is the maximum plant weight obtained with any level of N fertilizer at the time of final harvest (t_h) and W_p is the dry weight of seed or transplants at planting (t_p).

In accordance with Equation (2.5) when W is small, growth is exponentially related to time; when W is large, growth is proportional to time. Thus, k_2 is approximately equal to the relative growth rate in the early stages of growth and the absolute growth rate in the later stages.

Using 12 different vegetable crops including winter cabbages in the UK (Greenwood et al., 1989b) the average value of k_2 was 0.1678 t ha^{-1} d^{-1} (range 0.12-0.21). According to Greenwood et al., (1977; 1985b), soil type and inter-year variation in weather would not affect values of k_2 by more than 25%. Values of W_p, however, vary considerably from crop to crop, hence, all the substantial differences in curves relating dry matter to time

of the various vegetable crops can be attributed to the differences in W_p rather than to differences in species or weather.

The above equations have been used successfully in the UK (Greenwood and Draycott, 1989a) to predict the dry weights of 12 different vegetable crops except for radish, swede and winter cabbage (for reasons mentioned earlier) well supplied with water and nutrients during the main growing period from May (spring) to September (summer). They found that the maximum dry weights (W) obtained with any level of N-fertilizer were approximately linearly related to time (days, D). Therefore, the growth time-curve of the various crops was determined by W_p and the growth rate coefficient k_2.

The maximum N uptake (N_y) also depends on the percentage of N in the dry matter of crops which decline as they grow, even when there are ample supplies of N (Greenwood, 1983). The minimum %N (N_m) needed for maximum growth rate and dry weight for a range of widely different crops (including cabbages, red beet, and peas) grown with adequate N fertilizer in the field was found to fit about a curve defined by the equation (Greenwood, 1986):

$$N_m = 1.33 + \exp(1.4 - 0.26W) \qquad (2.6)$$

where W is the dry weight (t/ha) of the plant material.

Since crop demand (N_y) is the product of plant dry weight (W) and the minimum %N (N_m) in the dry matter needed to permit maximum growth rate, then, for each day the potential maximum increment in N plant uptake (N_u) by a crop grown on plots with N non-limiting is calculated as:

$$N_u = W \times 10\,[1.33 + \exp(1.4 - 0.26W)] \qquad (2.7)$$

Instead of using calendar time (days), some workers have used growing degree days (GDD) or accumulated heat units as a time-base to describe growth and development of vegetable crops such as winter heading

cauliflower (Wurr et al., 1981); broccoli (Marshall and Thompson, 1987); potato, onion, garlic and hybrid squash (Buwalda and Freeman, 1987). The growth of the above NZ sown crops (Buwalda and Freeman, 1987) correlated closely with temperature, and was described using low-order polynomial regressions with GDD as a time-base. The work of Buwalda and Freeman (1987) mainly examined the effect of 5 levels of N on the growth, tissue concentration and yields of crops. Assessing N fertilizer requirements of crops was not evaluated by their model.

The use of GDD provides a unifying, temperature-modified time scale on which to express the progress of a crop towards maturity (Monteith, 1981). Thus, the variations in rates of crop development between seasons and sites could be accounted for by using GDD instead of calendar days as a time-base.

Accumulated GDD above a base temperature for a particular crop can be calculated using a formula (Anonymous, 1954) based upon the following:

a) If $T_{min} > T_b$

$H_u = T_{mean} - T_b$

b) If $T_{min} < T_b$ and $T_{mean} > T_b$

$H_u = (T_{max} - T_b)/2 - (T_b - T_{min})/4$

c) If $T_{max} > T_b$ and $T_{mean} < T_b$

$H_u = (T_{max} - T_b)/4$

d) If $T_{max} < Tb$

$H_u = 0$

where:

H_u = Heat unit;

T_{max} = Maximum temperature;

T_{min} = Minimum temperature;

$T_{mean} = (T_{max} + T_{min})/2$;

T_b = Base temperature

It appears, therefore, that the model (Equation 2.3) can be made more mechanistic by using some existing dynamic models such as those by

Greenwood et al., (1977; 1986) to estimate some of the inputs. This will extend the utility of the model for predicting N fertilizer requirements of a crop in other situations. Mechanistic models with several outputs are also useful in indicating consequences of N input effects such as environmental contamination potential of practices such as overfertilisation with N fertilizers.

CHAPTER 3

METHODS OF MEASURING SAP NITRATE CONCENTRATIONS IN CABBAGES

3.1 INTRODUCTION

Rapid tests have been developed for measuring the nitrate (NO_3) concentrations in plant sap and have proved particularly useful for monitoring changes in crop N status during growth and for detecting the onset of N deficiency (Scaife and Stevens, 1977; 1983). Such tests should provide a basis for either assessing the need to apply a sidedressing of N fertilizer to an established cabbage crop prior to maximum N demand or determining the adequacy of initial applications.

A semi-quantitative field testing kit for the measurement of NO_3 in plant sap has been commercially marketed by E. Merck, Darmstadt, F.R. Germany. The test which makes use of "Merckoquant" NO_3 test strips has provided an adequate means of measuring petiole sap NO_3 in vegetables i.e., brussels sprouts, carrot, leek, lettuce, onion and spinach in the UK (Scaife and Turner, 1984; 1987) and carrots, celery, potato, sweet corn and tomato in NZ (Prasad and Spiers, 1984b). As far as can be ascertained, this simple field test has not been evaluated for field use with cabbages either in NZ or overseas, although very recently Huett and Rose (1989) used the test with spring cabbages grown in sand culture. Evaluation of a rapid sap NO_3 test for use by cabbage growers would likely improve N management as large amounts of N (up to 500 kg N ha^{-1}; MAF, 1984) are used in NZ cabbage production and underuse could reduce returns and overuse could lower maximum yield and also lead to environmental contamination.

3.2 OBJECTIVE

The objective of the glasshouse study was to evaluate the potential of using a rapid sap NO_3 test (Merck test strip) for measuring sap NO_3-N concentrations to indicate the adequacy of N nutrition in cabbages.

3.3 MATERIALS AND METHODS

3.3.1 Soil

The soil used in the experiment was Manawatu fine sandy loam (coarse loamy mixed mesic Dystric Eutrochrept) - a typical horticultural soil in the region. Some characteristics of the soil are shown in Table 3.1. In relation to cabbage nutrition, the pH of the soil is within the optimum pH (5.8-6.8) for cabbage growth (MAF, 1984). The P level of this low P retention soil is well above the target soil test P value for maximum cabbage yield (MAF, 1986). The K level is also above the target soil test K value for a sandy loam soil (MAF, 1986).

3.3.2 Plant Growth

Thirty-day old and uniformly sized cv. wintercross cabbage seedlings were planted on 5 May 1986 in plastic bags (14 x 14 x 28 cm diameter) containing 4 kg air dry soil which had been prewetted to 80% of the field capacity. Saucers were placed under the pots to catch any leachate. If there was any leaching, the contents of the saucers were poured back in the bag. The pots were watered to field capacity from transplanting up to the final harvest.

Table 3.1 Properties of Manawatu fine sandy loam topsoil used in the glasshouse experiment.

		Reference (Measurement technique)
Organic matter	3.7%	Bremner and Jenkinson (1960)
Organic C	2.1%	"
Total N	0.13%	Bremner (1965a)
pH (water)	6.4	Blakemore et al., (1987)
CEC (1M NH_4OAc pH 7.0)	20 meq/100 g	"
NH_4OAc extractable K	180 μg/g	"
Olsen P	65 "	Olsen et al., (1954)
2M KCl extractable NH_4-N	70 "	Bremner (1965b)
" NO_3-N	42 "	"
Mineralisable N (aerobic incubation)	2 μg/g/d	Carter et al., (1974)
NH_4-N fixing capacity	58% (50 μg/ml NH_4-N added)	Nommik and Vahtras (1982)
	40% (100 μg/ml NH_4-N added)	

3.3.3 Fertilizer Treatments

According to MAF (1986) winter cabbages planted in the field at a population of 25000 plants ha^{-1}, can take up 200 kg N ha^{-1} associated with maximum yield. Assuming equal efficiency, an individual cabbage plant would take up 8 g N to produce an average fresh head yield of 2.5 kg. The fertilizer treatments in this experiment were calculated based on this anticipated N uptake data. Other experiments in the glasshouse with *Cruciferae* indicated that the expected maximum fresh head yield attainable in this glasshouse experiment would be about 1.0 kg requiring 3.2 g N $plant^{-1}$ to produce it. Maximum yield was expected to be lower in the glasshouse than in the field due to restricted root volume and maturity time was expected to occur earlier as minimum temperature (10°C) was higher than normal field temperature conditions.

To achieve a 1.0 kg fresh head yield in this experiment, there was a need to apply at least 2.0 g N pot^{-1}. This is after taking into account the initial available N content of the soil (100 μg g $soil^{-1}$ which is equal to 0.4 g N pot^{-1}; Table 3.1) and assuming (see Chapter 2 section 2.2.1) that the amount of mineralisable N was twice the initial available N (0.8 g N pot^{-1}; also reflected in Table 3.1). The percent recovery of all N sources - initial available N; mineralisable N; and N fertilizer was assumed to be 100%.

Treatments consisted of eight rates of N (0; 0.392; 0.784; 1.176; 1.568; 1.960; 2.352; and 2.744 g N pot^{-1}) as calcium ammonium nitrate (CAN) to create a range of N status in the plants. CAN was used to minimize the confounding effect of soil pH changes. Treatments were arranged in randomized complete block design with four replications.

Half the quantity of fertilizer in each N treatment was applied basally by thoroughly mixing with the soil prior to planting. Likewise, phosphorus (P) as superphosphate at the rate of 0.078 g P pot^{-1} and potassium (K) as potassium sulphate at the rate of 0.393 g K pot^{-1} were also applied prior to planting by thoroughly mixing with the soil. The other half of the N

treatment was sidedressed at early heading stage about 61 days after transplanting (DAT). Time of sidedressing was planned on the basis of the physical appearance of the plants i.e., when they started to develop an aggregate of folded leaves (wrapper leaves). Similar rates and sources of P and K were also sidedressed at 100 and 60 DAT; respectively. Complete micronutrient solution excluding Mn (Middleton and Toxepeus, 1973) was applied four times for the entire growing period of the plants.

3.3.4 Plant Harvest

Whole cabbage plants (including roots) were harvested at different dates - 40; 60; 100; and 140 DAT - to correspond with the vegetative; heading; mid-maturity and maturity stages of cabbage growth, respectively. The plant tops were cut just below the node of the first leaf. Fresh and dry weights of plant samples were recorded.

3.3.5 Plant Analysis

3.3.5.1 *Petiole sap NO_3-N*

At each plant sampling date, petiole sap was collected by separating 2-3 young mature leaves from each plant and chopping the petioles into small pieces (5-10 mm long) and expressing the sap using a garlic press. The sap was collected in small vials. The concentrations of NO_3-N in the petiole sap were determined by the Merck test strip the principles of which had been discussed in Chapter 2 (2.2.2.3). For calibration purposes, the NO_3-N concentrations in the sap were also determined by autoanalyser methods (Technicon, 1976 and Downes, 1978).

In addition to the standard sampling dates, petiole sap NO_3-N concentrations were measured at 80 and 90 DAT (to cover the phases of heading stage) by the Merck test strips and the results were calibrated

against the acetic acid soluble NO_3-N concentrations.

3.3.5.2 *Xylem sap NO_3-N*

At each plant sampling date, xylem sap (stem exudate) was collected in calibrated capillary tubes (10 $\pm$ 0.05 μl micro pipettes). Each tube was immediately placed into a sealed vial which was placed in a freezer to await dilution and analysis. The concentrations of NO_3-N in the xylem sap were determined by autoanalyser methods.

At harvest 2, the above method (capillary tube technique) for collecting xylem sap was compared with a modified technique as follows: The xylem sap was collected by wetting a preweighed filter paper strip in the bleeding stem (Figure 3.1) that had been previously washed with deionized water and blotted with a tissue. The filter paper was immediately replaced into a vial which was placed in a freezer to await dilution and analysis.

To compare the two methods, xylem sap samples were randomly collected from plants of varying N status in order to create a range of N concentrations in the sap. This allowed comparison of the methods for a wide range of N concentrations in the sap.

3.3.5.3 *Acetic acid soluble NO_3-N*

Samples of ground composite petioles of young mature leaves (100 mg sample) were weighed into 50 ml centrifuge tubes to which 25 ml of 2% acetic acid was added together with a drop of wetting agent (Triton x 100). The tubes were shaken for 10 minutes and filtered (Prasad and Spiers, 1984). The concentration of NO_3-N in the filtrates were determined by autoanalyzer methods.

Figure 3.1 Method of xylem sap collection using filter paper strips.

3.3.5.4 *Total N in whole plants*

Samples of ground composite plant tops and roots (100 mg) were digested separately with 4 ml Kjeldahl digest mixture. Total N and P concentrations in the plant samples were determined by the autoanalyser methods (Twine and Williams, 1971; Technicon, 1976).

3.3.6 Soil Analysis

The mineral N content of the soils was measured at each sampling by extracting fresh subsamples with 2M KCl solution (dry soil:solution ratio 1:10). The NO_3^- and NH_4-N concentrations in the extracts were determined by autoanalyser methods.

3.3.7 Statistical Analysis

Analysis of variance was used to compare treatment means. The least significant differences (LSD) between means were calculated using the technique described by Gomez and Gomez (1984). Treatment effects which were significant have been denoted as follows: $P<0.05$ = *, $P<.001$ = **. Non significant effects have been denoted by ns. Regression analysis was used to evaluate the relationship between the Merck test strip and laboratory methods of measuring NO_3-N concentrations in plant sap or tissues.

3.4 RESULTS AND DISCUSSION

3.4.1 Effect of N on Yield

The relationship between N added and fresh head yields of cabbages is shown in Figure 3.2. The curve is generated by the modified Mitscherlich

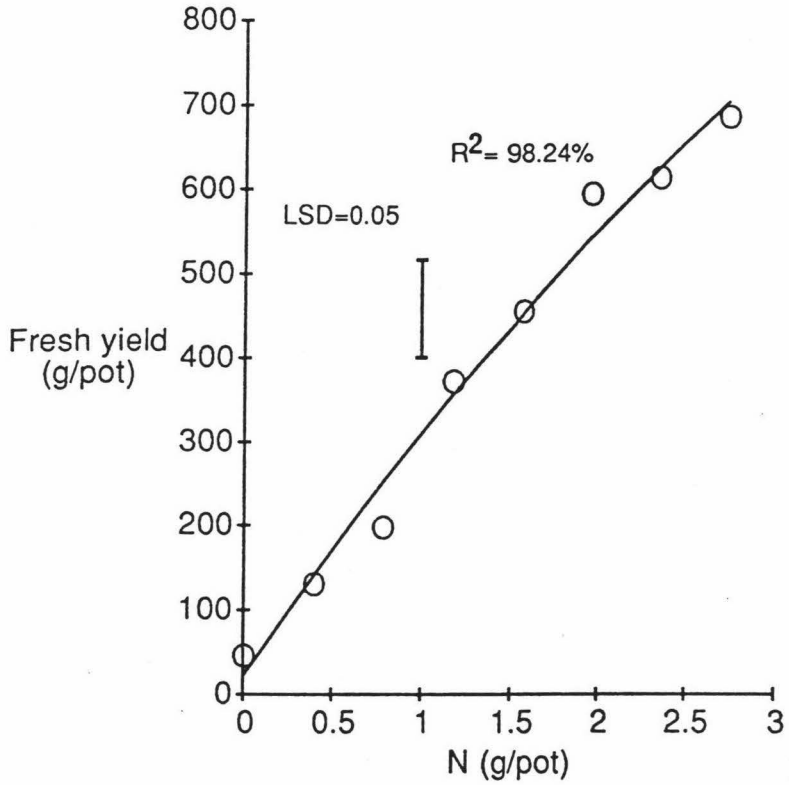

Figure 3.2 The effect of N application rate on fresh head yield of cabbages at final harvest.

growth model [Y = A + B*(1 - exp(C*X)] which gave a slightly better fit than the linear model. The highly significant correlation (R^2 = 0.98**) suggests that the Mitscherlich model adequately described the variation when N supply is considered as predictor of the yield variations and other factors effectively interacted uniformly with all experimental treatments.

Nitrogen application significantly increased the fresh head yield of cabbages. From LSD values the highest yield was obtained with N application rates >1.960 g N pot^{-1} (Figure 3.2).

The response of dry matter yields at four stages of growth to N application is summarized in Table 3.2. The highest yield at maturity (140 DAT) was obtained with N application rates not lower than 1.568 g N pot^{-1} although it would be unwise to conclude that this N rate achieved maximum yield as the yield obtained (121.24 g) was very nearly significantly less than the yield obtained from the maximum rate used in the experiment.

Yield differences between fertilized treatments became very apparent at later dates.

3.4.2 Effect of N on Total N Uptake

The relationship between N added and total N uptake by cabbages at maturity was highly correlated (R^2 = 0.98**; Figure 3.3) as described by the simple linear model. Except at 40 and 60 DAT, there was a consistent linear increase in N uptake with increasing rate of N applied (Table 3.3). From LSD (Table 3.3) it would appear that the maximum N uptake at maturity was not reached in this experiment as the two highest rates of fertilizer are significantly different.

The general decline of total N uptake at 140 DAT (compare values with 100 DAT) was probably due to the significantly lower N concentrations of the plants (see Figure 3.8) although dry matter yields were higher at final

Table 3.2 Total dry matter yield (g/pot) of cabbages at different sampling dates.

N g/pot	Time of sampling (DAT) 40	60	100	140
0	4.83	12.49	14.70	21.24
0.392	6.09	18.07	34.16	48.31
0.784	6.77	20.41	54.05	67.46
1.176	8.10	25.20	73.16	95.88
1.568	6.35	27.57	69.96	121.24
1.960	6.92	26.14	80.07	130.36
2.352	6.91	28.50	86.20	128.76
2.744	5.54	25.29	94.81	136.15
$LSD_{.05}$	1.63	5.26	9.46	16.70

Table 3.3 Total N uptake (N g/pot) by cabbages at different sampling dates.

N g/pot	Time of sampling (DAT) 40	60	100	140
0	0.16595	0.22712	0.29252	0.27352
0.392	0.17610	0.51919	0.75446	0.66364
0.784	0.20866	0.72229	1.15321	0.92745
1.176	0.26031	0.78193	1.71281	1.30829
1.568	0.23074	1.15062	1.85916	1.84543
1.960	0.24322	1.11199	2.17104	2.16322
2.352	0.22763	1.42599	2.68063	2.26588
2.744	0.16232	1.15999	2.92980	2.61863
$LSD_{.05}$	ns	0.35996	0.34114	0.26919

ns = not significant

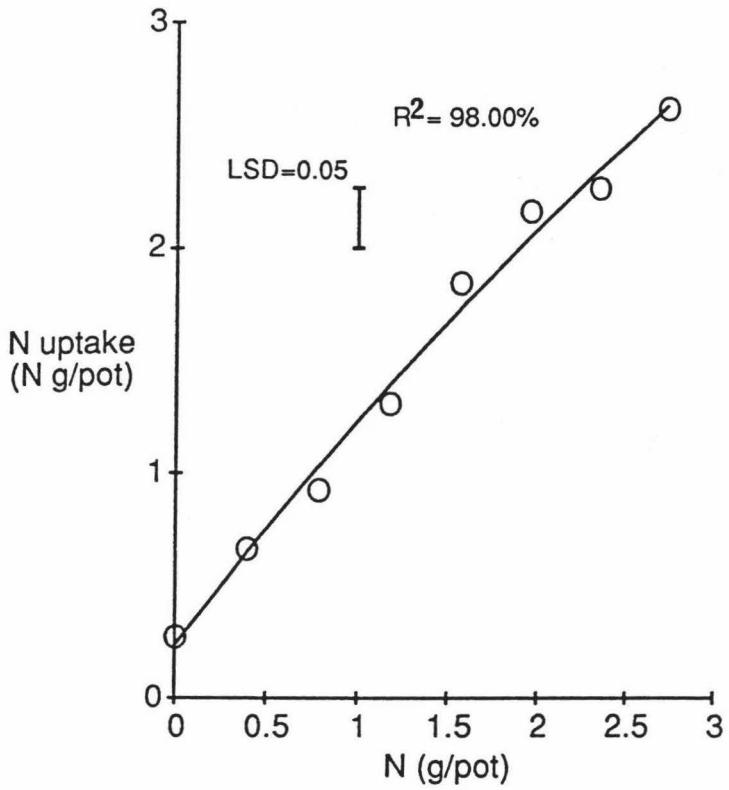

Figure 3.3 The effect of N application rate on total N uptake by cabbages at final harvest.

harvest (Table 3.2).

Plants which had the highest N uptake also produced the highest yields. The linear correlation between yield and total N uptake at maturity was highly significant ($r = 0.97^{**}$).

3.4.3 Relationship Between Total Plant N and Plant Sap NO_3-N Concentrations and Rate of N Application

Second order polynomials provided the line of best fit for plant total N and sap NO_3-N concentrations and the rate of N application. Table 3.4 summarizes the correlation coefficients relating plant N measurements and N application rate. Although some measurements were better related than others, all parameters were significantly correlated at most times of sampling indicating that they all reflected the supply of N from fertilizer plus soil.

3.4.3.1 *Effect of N on petiole sap NO_3-N*

The effect of N fertilization on petiole sap NO_3-N concentration at various sampling times is shown in Figure 3.4 (measured by Merck test strips) and Figure 3.5 (measured by the AA method). For ease of presentation only 4 treatments - 0; 0.784; 1.568; and 2.352 g N pot^{-1} designated as N0; N1; N2: and N3; respectively; are shown in the figures. N0 represents the control plants; N1 low-N plants; N2 mid-N plants and N3 high N-plants.

Irrespective of the method of measurement, the concentration of NO_3-N in the petiole sap with N0 and N1 decreased markedly after 60 DAT. Sap NO_3-N concentration in N3 increased at 60 DAT, then decreased along with N2 at 100 DAT. All treatments had negligible NO_3-N concentrations at final harvest.

Table 3.4 Correlation between N application rate and sap NO_3-N; acetic acid soluble NO_3-N and total N using a quadratic function (n=32).

	Time of sampling (DAT)					
	40	60	80	90	100	140
Psap NO_3-N (AA)	0.20^{ns}	0.82^{**}	ND	ND	0.79^{**}	0.93^{**}
Psap NO_3-N (Merck)	0.23^{ns}	0.85^{**}	0.95^{**}	0.91^{**}	0.71^{**}	0.64^{**}
Xsap NO_3-N (AA)	0.33^{ns}	0.63^{**}	ND	ND	0.78^{**}	0.83^{**}
Acetic NO_3-N	0.22^{ns}	0.86^{**}	0.87^{**}	0.88^{**}	0.74^{**}	0.23^{ns}
Total N	0.20^{ns}	0.38	ND	ND	0.64^{**}	0.69^{**}

** = Significant at 1%, ns = not significant
Psap = Petiole sap
Xsap = Xylem sap
ND = Not determined

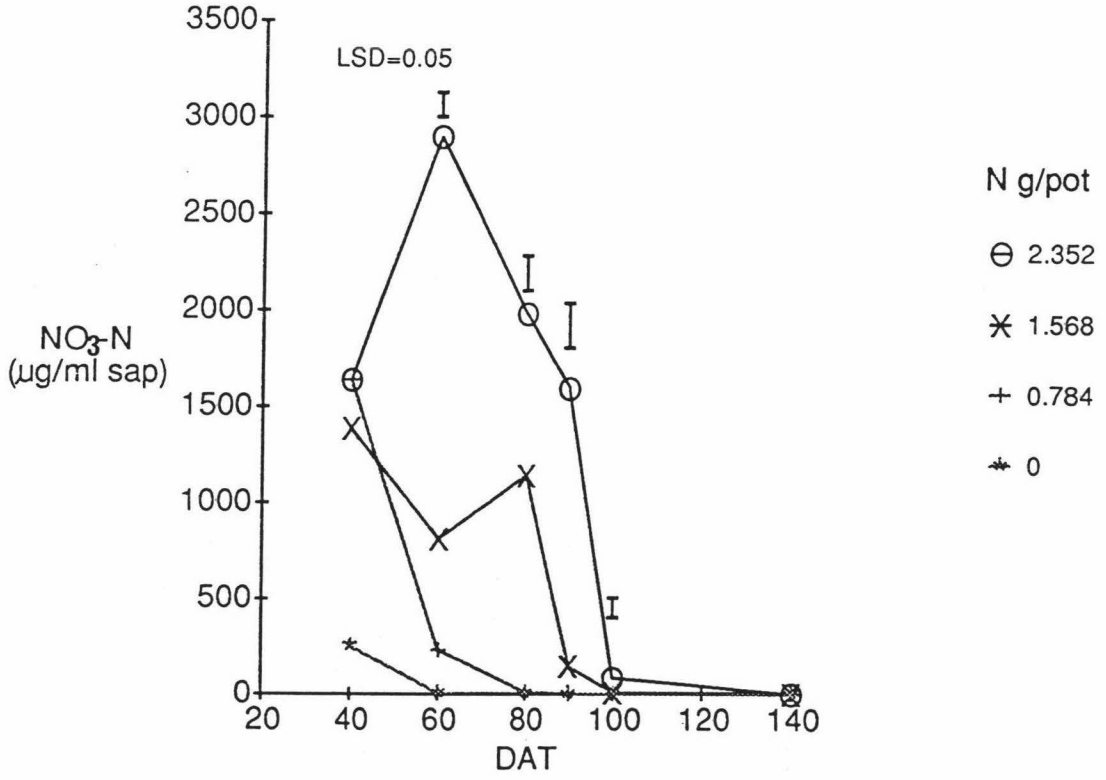

Figure 3.4 The effect of N application rate on petiole sap NO_3-N concentration measured by the Merck teststrip.

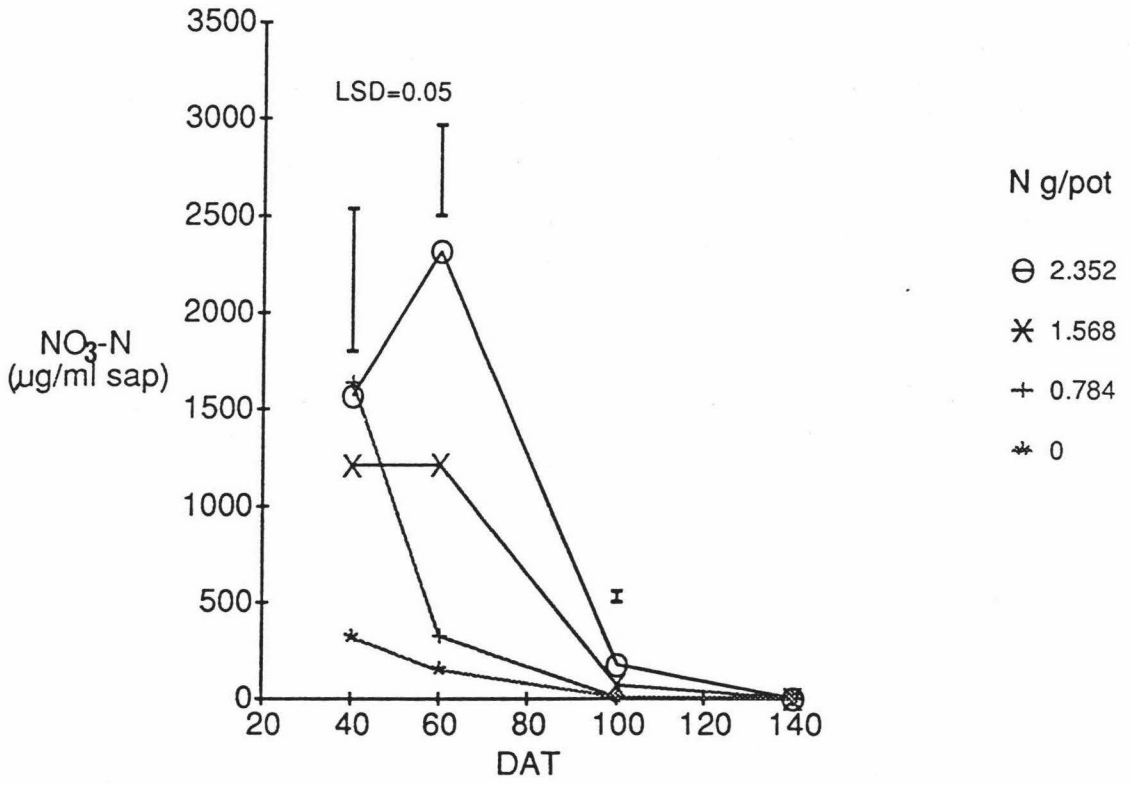

Figure 3.5 The effect of N application rate on petiole sap NO_3-N concentration measured by the autoanalyser method.

The general trend of petiole sap NO_3-N concentrations was to decrease as the crop advanced in growth stage. This could be attributed to faster assimilation of the absorbed NO_3 into plant protein than the rate of uptake late in the season (Maynard et al., 1976).

At 60 DAT (early heading stage), N application rate significantly increased petiole sap NO_3-N concentrations (Table 3.5). At this time N0, N1 and N2 rates had petiole sap NO_3-N concentrations lower than the critical level (1300 μg ml^{-1} sap) recently reported by Huett and Rose (1989) for diagnostic purposes for cabbages at similar growth stage. Their reported critical level was measured by the Merck test strip using a similar leaf position as in the present study but plants were grown in sand culture. Plants treated with N3 rate (2.352 g N pot^{-1}), which was assumed to achieve final maximum yield (Table 3.2), had petiole sap NO_3-N concentrations well above the critical level of 1300 μg ml^{-1} sap.

3.4.3.2 *Effect of N on xylem sap NO_3-N*

Figure 3.6 shows a general decline of NO_3-N concentrations in xylem sap with advancing cabbage growth stage. Xylem sap NO_3-N concentrations for fertilized plots ranged from 212-442 μg ml^{-1} sap at 40 DAT; 46-514 at 60 DAT; 6-322 at 100 DAT; and 0-8 at 140 DAT. To date there has been no published data on xylem sap NO_3-N concentrations in relation to N nutrition of cabbages.

In comparison with petiole sap NO_3-N levels, xylem sap had generally lower NO_3-N concentrations at a given harvest (compare values in Table 3.5 for 60 DAT). This suggests the ready translocation of NO_3 from the xylem into sites of N synthesis in the leaves. The distinction between the two sap measurements is that xylem sap reflects the actual N supply from soil at the time of sampling whereas petiole sap represents the difference between rates of absorption and rates of assimilation within the plant (Maynard et. al., 1976). During sub-optimal N supply petiole sap may include N that has been re-translocated from old leaves. Thus, NO_3-N

Table 3.5 The effect of N fertilizer rates on N concentrations in cabbages at 60 DAT.

N g/pot	Psap* AA NO_3-N	Psap* Merck NO_3-N	Xsap** AA NO_3-N	Total plant N Acetic NO_3-N	Total plant N Total N
		μg/ml sap		%	
0	147	2	32	0.26	1.92
0.784	325	232	104	0.43	4.76
1.568	1211	811	309	1.13	4.26
2.352	2314	2898	530	2.38	5.18
$LSD_{.05}$	432	134	216	0.45	1.48

Based from ANOVA of all treatments
*Petiole sap
**Xylem sap

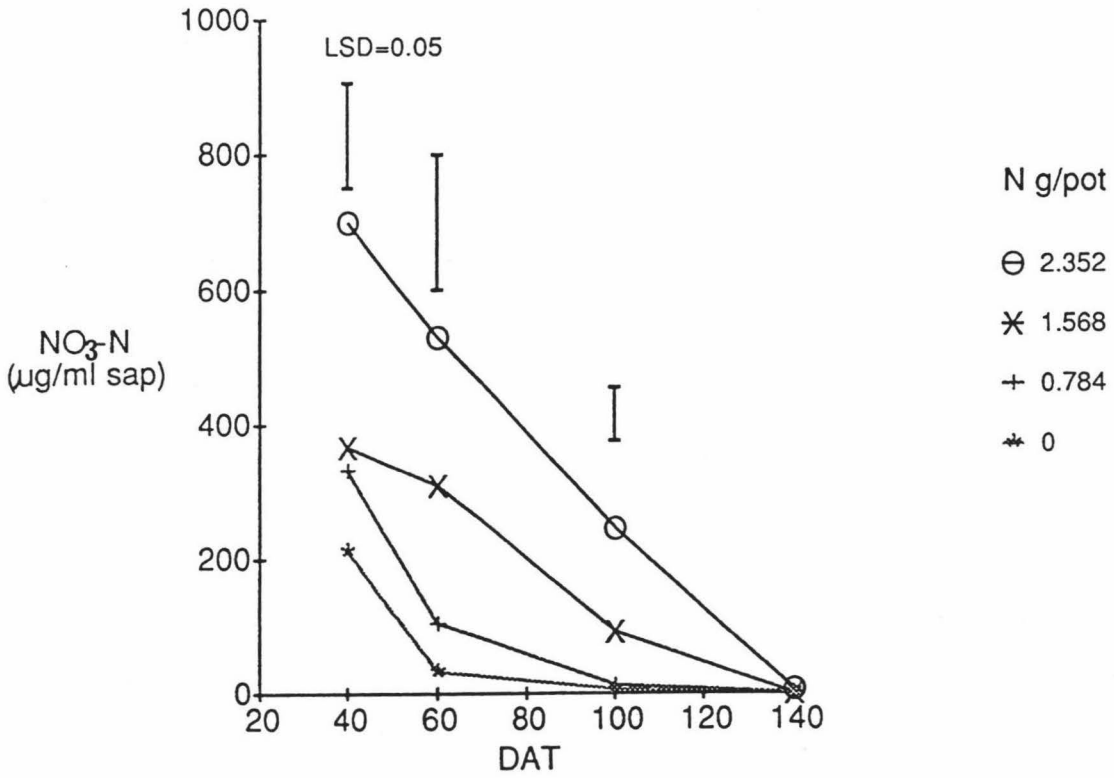

Figure 3.6 The effect of N application rate on xylem sap NO_3-N concentration measured by the autoanalyser method.

concentration in petiole sap may be a misleading measure of current plant N status.

The main disadvantage of using xylem sap to measure NO_3-N concentrations, to indicate plant N status, lies in the destructive nature of plant sampling. Because there was no major increase in the accuracy of prediction by xylem sap (see Table 3.9), a grower may prefer using petiole sap if a considerable number of plant samples is required for xylem sap analysis.

3.4.3.3 *Effect of N on acetic acid soluble NO_3-N*

The acetic acid soluble NO_3-N contents in cabbage tissues at various sampling dates are presented in Figure 3.7. At 40 DAT, treatment N0 had significantly lower tissue NO_3-N concentration than the other treatments. Marked differences in tissue NO_3-N concentration between treatments were observed at 60 and 80 DAT.

At 60 DAT, N0 and N1 rates had tissue NO_3-N concentrations below the sufficiency level (0.9%) stated by University of California (1978) while N2 rate had tissue NO_3-N concentration (1.1%) almost at this level. Treatment N3 (2.4%) was well above this sufficiency level.

The sufficiency level comparison, however, is not strictly comparable because the cited sufficiency level was measured from the midrib of the wrapper leaf. In this present study, petioles of young mature leaf, which according to Maynard et al., (1976) may have higher tissue NO_3-N concentration than any other part within a plant, were used in measuring tissue NO_3-N concentrations.

3.4.3.4 *Effect of N on total N*

At 40 DAT, the concentration of total N (roots + shoot) in cabbages was

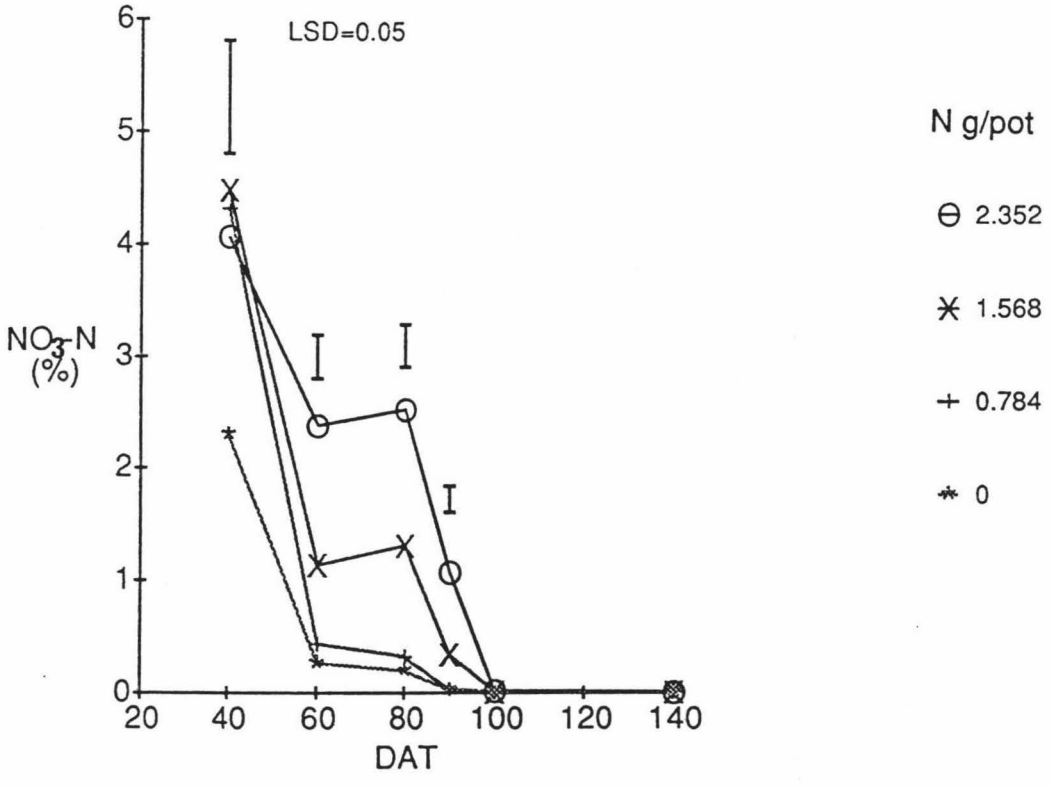

Figure 3.7 The effect of N application rate on acetic acid soluble NO_3-N in cabbage tissues.

not affected by rate of N application (Figure 3.8). Treatment differences were evident at the following sampling dates when total N concentrations increased with applied N. Total N concentrations generally decreased with plant age which can be attributed to changes in the growth phase of the plant (Greenwood, 1979). As the plant increases in size, it rapidly accumulates the carbohydrate products of photosynthesis which effectively dilute the plant N concentration.

In New Zealand, MAF (1986) reported 4.5 and 4.0% as the critical total N concentrations in winter grown cabbages at 40 and 80-day plant ages, respectively. Assuming that 80-day plant age would correspond to the 60 DAT sampling time in this study, then, the total N concentrations for all treatments except N0 were above the critical level (Table 3.5). In this case, total N is not a suitable diagnostic test considering that N1 and N2 produced significantly lower fresh head yield (Figure 3.2) than N3 rate.

3.4.4 Effect of N on soil NO_3^- and NH_4-N

The levels of NO_3^- and NH_4-N in the soils steadily decreased with sampling time (Figure 3.9). The exhaustion of the mineral N supply in the soil is associated with the decline of NO_3-N concentrations in the xylem and petiole sap. This suggests a possible direct relationship between soil N supply and plant N status as was also found by Darby et al., (1986). In their field experiment the concentrations of NO_3-N in xylem sap of winter wheat remained high until most of the soil NO_3-N had been removed by the crop. This relationship was also found in this glasshouse study (Figure 3.10).

At 60 DAT, on N0, N1 and N2 treatments only trace amounts of available soil N (20 mg N pot^{-1}; Table 3.6) were measured. This suggests a likely need to add fertilizer N as there is a high demand of N for head development at this period (Hara and Sonoda, 1979). The plants in these treatments also started to show visual sign of N deficiency such as yellowing of the lower older leaves. Despite the sidedressing with N (half

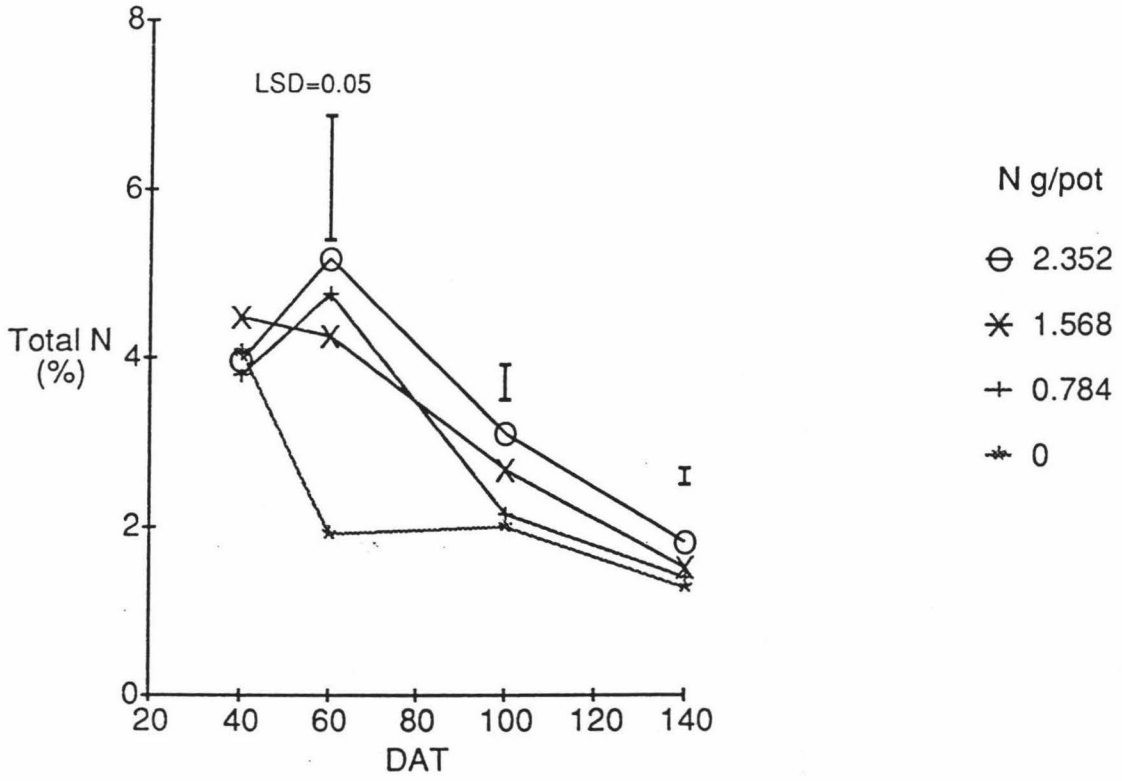

Figure 3.8 The effect of N application rate on total N contents (roots + shoots) in cabbages.

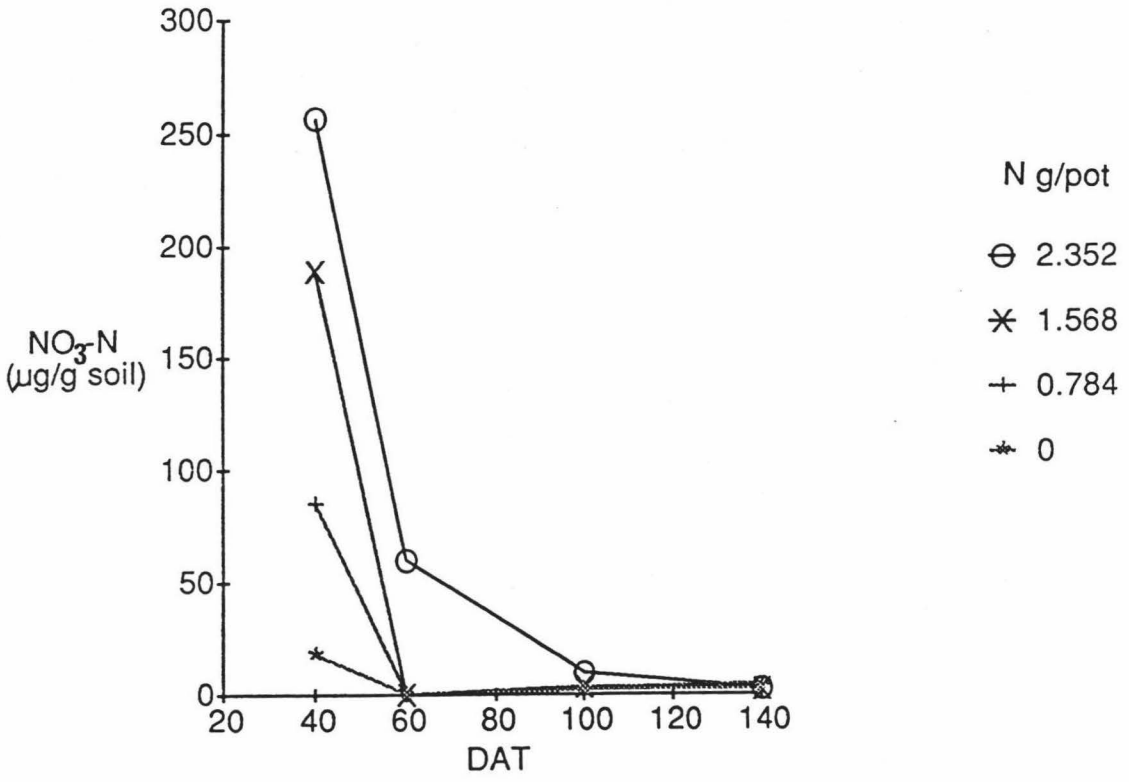

Figure 3.9 The effect of N application rate on NO_3-N concentration in the soil.

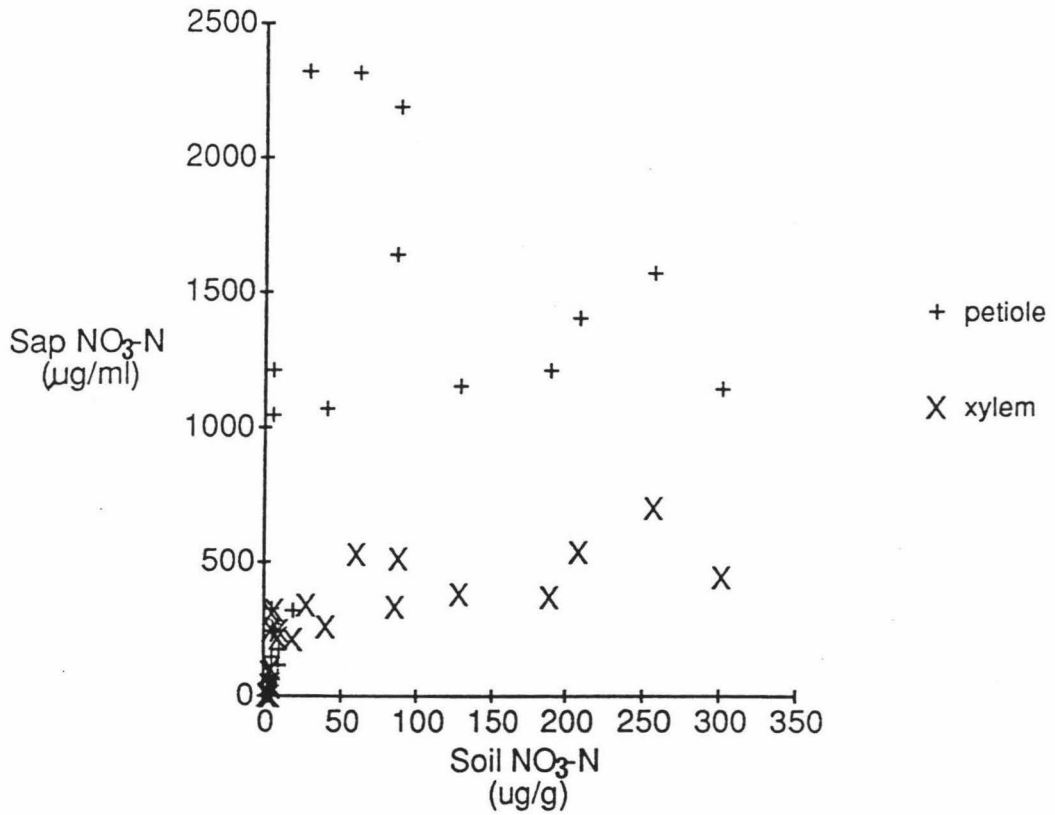

Figure 3.10 The relationship between soil and sap tests.

Table 3.6 Soil NO_3^- + NH_4-N ($\mu g/g$ soil) after each harvest.

N g/pot	Time of sampling (DAT) 40	60	100	140
0	17.8	nd	1.9	2.3
0.784	85.2	nd	2.6	4.3
1.568	188.8	nd	3.5	2.2
2.352	256.9	60.0	9.6	2.5
$LSD_{.05}$	41.1		1.3	ns

Based from ANOVA of all treatments
ns = not significant
nd = not detectable

of the total N treatments) at 61 DAT, the amounts of available N in these treatments at 100 DAT remained very low (<10 mg N pot^{-1}) while N3 had about 25 mg NO_3-N pot^{-1} (Table 3.6).

3.4.5 Relationships Between the Merck Test Strip and the Standard Laboratory Methods of Measuring NO3-N

At most sampling times, the Merck test strip results (Table 3.7) were highly correlated with the standard methods of measuring NO_3-N in plants namely; acetic acid extraction (standard procedure for most horticultural crops including vegetables; University of California, 1978) and the autoanalyser method.

The significant relationships between the Merck test strip and the two conventional methods found in this study indicate the suitability of the rapid sap NO_3 test for use in routine monitoring the N status of cabbages. This finding complements the work of Prasad and Spiers (1984b) who showed a range of highly significant relationships between the rapid test and acetic acid extraction (R^2 = 0.58-0.90; n=24) with carrot, celery, potato, sweet corn and tomato at different sampling dates.

The linear regression equations relating Merck test strip and the autoanalyser method are summarized in Table 3.8. The negative intercepts in the equations at 60 and 140 DAT suggest that the Merck test strip is less sensitive than the AA method at very low concentrations of plant sap NO_3-N. For instance, it was not able to detect any NO_3-N in the sap (<5 μg NO_3-N ml^{-1}) for some treatments at 100 and 140 DAT but the autoanalyser measured values within this range. The inability of the Merck test strip to measure very low sap NO_3-N concentrations may be due to the masking effect of chlorophyll in some crops (Prasad and Spiers, 1984b), possibly due to some chemical interference from an undetermined chemical in the plant tissue with test strip colour development (Shaefer, 1986) and/or due to non-uniform colour development on the strip pad (Jemison and Fox, 1988). In actual practice, this limitation of the Merck test strip

Table 3.7 Linear correlation coefficients (r) between Psap NO_3-N concentrations determined by the Merck test strip and the autoanalyser method and acetic acid extraction (n=32).

	Time of sampling (DAT)					
	40	60	80	90	100	140
Autoanalyser	0.82**	0.94**	ND	ND	0.88**	0.80**
Acetic acid	0.38ns	0.95**	0.91**	0.88**	0.80**	0.23ns

** = Significant at 1%, ns = not significant
ND = not determined

Table 3.8 Linear regression equations showing the relationship between Psap NO_3-N concentrations measured by Merck test strip and autoanalyser method (n=32).

DAT	Prediction Equation (Y = a + bX)
40	Merck sap = 27.0 + 1.09AA R^2 = 0.68**
60	Merck sap = -353.0 + 1.32AA R^2 = 0.88**
100	Merck sap = 3.8 + 1.97AA R^2 = 0.78**
140	Merck sap = -0.1 + 0.09AA R^2 = 0.64**

** = Significant at 1%

may not be of significance because at very low sap NO_3-N concentrations plants will be very N deficient.

In this study the Merck test strip was found to overestimate NO_3-N especially at higher concentrations at 60 DAT (compare sap values at the highest application rate in Table 3.5). This limitation may be partly attributed to the difficulty of recording the accurate time in seconds for the colour to develop to that of the 500 ppm standard in the tube. This creates much subjective judgement of colour and time involved in using the Merck test strips for high NO_3-N concentrations. This limitation was partly overcome in this study by quantitative dilution of the sap to the working range of the strips (up to 500 ppm NO_3).

3.4.6 Comparison of the Methods for Xylem Sap Collection

In comparing the two methods for xylem sap collection, it was assumed that the capillary tube method was more accurate as it was more quantitative in sampling sap and involved less sampling errors than the filter paper method. As shown in Figures 3.11a and 3.11b, the methods of xylem sap collection did not influence sap NO_3-N concentrations <500 μg ml^{-1} and NH_4-N concentrations <100 μg ml^{-1}. At sap concentrations greater than these values, the filter paper method tended to underestimate sap NO_3 and NH_4-N concentrations.

The result suggests that if the filter paper method is used to determine the adequacy of plant N status, any value >500 μg ml^{-1} maybe an underestimate of actual values, but this may not be a great disadvantage provided sap values are correlated against yield response trials.

3.4.7 Relationship Between Plant N Concentrations and Final Yield

Treatment differences in NO_3-N concentrations either in plant sap or

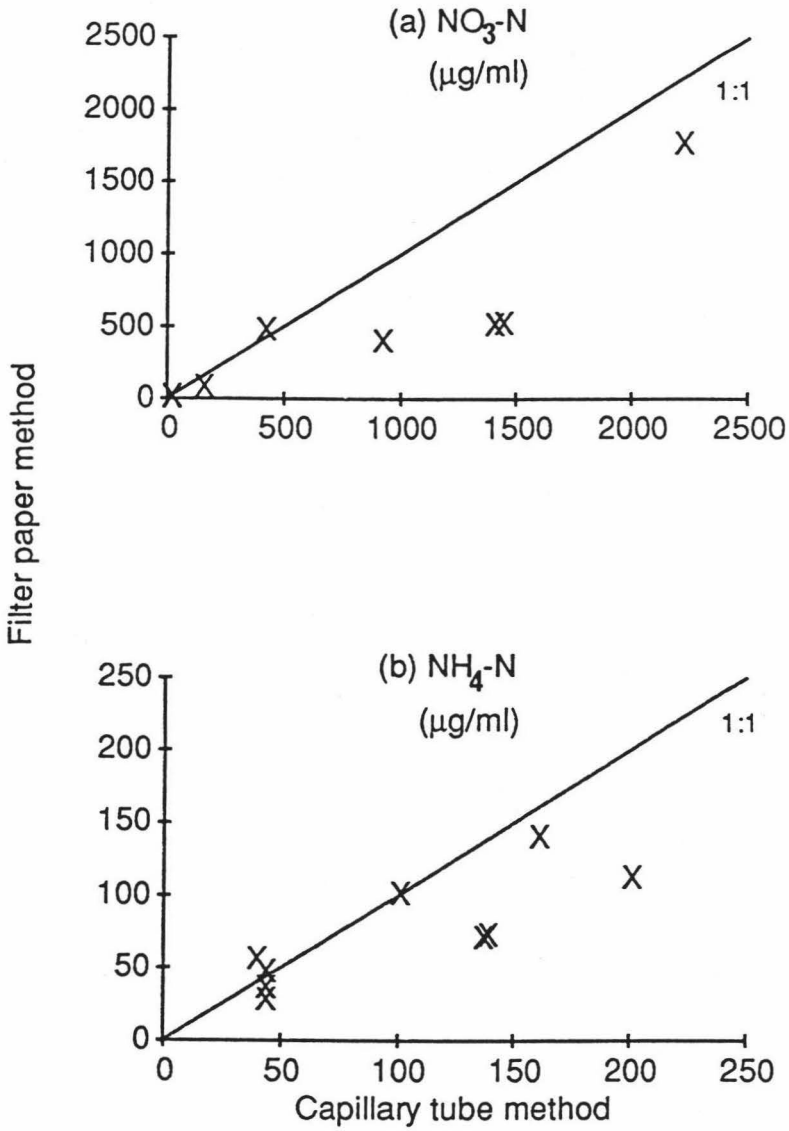

Figure 3.11 Comparison of (a) NO_3-N and (b) NH_4-N concentrations in xylem sap of cabbages collected by different methods.

tissues were very pronounced at 60 DAT (early heading) unlike at 40 DAT (pre-heading); at 100 DAT (post-heading) and at 140 DAT (maturity) when plant sap or tissue NO_3-N concentrations were within narrow ranges. Therefore, the growth stage of cabbages that is most likely to be useful for diagnostic purposes is at early heading although this stage tends to be subjective.

At 60 DAT, all plant N parameters were strongly correlated with final yield (Table 3.9). Plant N parameters measured at 40 DAT were poor predictors of final yield. Scatter diagrams of the 60 DAT data showed that the trend of all the relationships except total N could be better shown by Mitscherlich type curves. Simple linear regression provided the line of best fit for the relationship between total N and final yield. The order of decreasing ability of the various crop N parameters at 60 DAT to predict final yield of cabbages is: Petiole sap NO_3-N (Merck) > Xylem sap NO_3-N (AA) = Acetic acid NO_3-N (AA) = Petiole sap NO_3-N (AA) > Total N.

For the determination of critical plant test levels it is necessary to maximise yield in this experiment with the N rate treatments. Some uncertainty exist as to whether or not the maximum yield was achieved. For example the initial assumptions (section 3.3.3) used to determine N rates, assumed that the amount of N to be mineralised during cabbage growth would be 2x's the initial available N. This was not found to be so as total N plant uptake at final harvest (Table 3.3), irrespective of N rate treatment, was less than the total N input (soil + fertilizer N). Additionally, the efficiency of soil and fertilizer N use was less (85%) than the predicted (100%).

Therefore the values of critical plant test levels reported in this study are very tentative. Assuming that fertilizer rates >1.960 g N pot^{-1} (Figure 3.2) with 50% applied at planting and 50% at early heading gave the maximum growth and yield then the estimated critical (average of the top 3 N rates) sap NO_3-N concentrations at 60 DAT (early heading) are 2800

Table 3.9 Summary of regression coefficients (R^2) of the predictive equations relating plant N parameters at 60 DAT and final yield of cabbages (n=32).

	R^2
Psap NO_3-N (Merck)	0.8758**
Psap NO_3-N (AA)	0.7113**
Xsap NO_3-N (AA)	0.7474**
Acetic NO_3-N	0.7261**
Total N	0.3471^{ns}

** = Significant at 1%, ns = not significant

$\mu g\ ml^{-1}$ in the petiole sap of young mature leaves by Merck test strip; 2300 $\mu g\ ml^{-1}$ in the petiole sap by autoanalyser method; 460 $\mu g\ ml^{-1}$ in the xylem sap by autoanalyser method; and 2.5% as acetic acid soluble NO_3-N and 4.8% as total N. The values for acetic acid soluble NO_3-N, total N and petiole sap NO_3-N (Merck test strip) are much higher than the critical levels for cabbages at heading as reported by University of California (1978); MAF (1986) under field conditions and Huett and Rose (1989) in sand culture, respectively.

These tentative critical values require to be assessed under field conditions and will be further researched and reported in Chapter 6.

3.5 CONCLUSION

Results from this study indicate that the Merck test strip accurately measured the NO_3-N concentrations in petiole sap of cabbages over a range of concentrations likely to be found in practice. The rapid test has potential in a routine monitoring role for evaluating the N status of cabbages.

The most suitable time to diagnose the N status of cabbage is at early heading (60 DAT) because the different levels of soil N status are better reflected at this plant growth stage. At 60 DAT, all plant parameters, except total N, were strongly correlated with final yield. Sap concentration in the petioles of young mature leaves at this stage needs to be at least 2300 $\mu g\ ml^{-1}$ of NO_3-N and 460 $\mu g\ ml^{-1}$ of NO_3-N in the xylem sap (both measured by the AA) inorder to obtain maximum yield. Soil N level at this stage needs to be at least 60 $\mu g\ g\ soil^{-1}$ in the growing medium.

Although there was no direct relationship between the NO_3-N concentration in the petiole or xylem sap and amount of NO_3-N contained in the soil, it is clear that the concentration of NO_3-N within the plant

decreased as the amount of soil NO_3-N declined. The possible relationship between concentrations of NO_3-N in plant sap and soil under field conditions is further assessed and reported in Chapter 6 (6.4.5).

CHAPTER 4

FACTORS AFFECTING SAP NUTRIENT CONCENTRATIONS IN CABBAGES

4.1 INTRODUCTION

Although the concentration of NO_3-N in petiole sap is often a very sensitive indicator of plant N status for a range of vegetable crops as discussed in Chapter 2 (2.2.2.3) it has been found to be influenced by the genetic make up of the plant, the N supplying-power of the soil, and the environmental conditions under which the plant is grown (Maynard and Baker, 1976). The effects of time of day, leaf position and inter-plant variation on NO_3-N concentrations in petiole sap have been reported for summer cabbages (Scaife and Stevens, 1983) grown in the UK but not for winter cabbages. It is essential to characterize the influence of these factors on plant sap test results so that reliable guidelines for comparing and interpreting test results taken at different sites and times can be developed.

4.2 OBJECTIVE

The objective of the study was to examine some factors affecting NO_3 and NH_4-N concentrations in the xylem and petiole sap of cabbages.

4.3 MATERIALS AND METHODS

Preliminary experiments to examine some factors (leaf position, storage time) affecting NO_3 and NH_4-N concentrations in the xylem and petiole sap of cabbages were conducted in the glasshouse. The details of the methodology and sap sampling techniques were already given in Chapter 3 (3.3.5.1 and 3.3.5.2). The modified method (use of filter paper strips) for

collecting xylem sap was adopted in this study as this was found to be as accurate as the use of a capillary tube (see 3.4.6) provided measured NO_3-N concentrations are <500 μg ml^{-1} and NH_4-N concentrations are <100 μg ml^{-1} (see Figures 3.11a and 3.11b). The tendency of the filter paper method to underestimate concentrations higher than these levels may be of little practical significance if the objective is to detect N deficiency status in cabbages. Furthermore the filter paper method is sensitive to increasing levels of N nutrition and less time consuming than the capillary tube method.

Other factors studied and reported in this chapter (time of day, plant age, rate of N fertilizer application) were examined in a field trial the details of the methodology used in the conduct of the trial are in Chapter 6 (6.3).

4.4 RESULTS AND DISCUSSION

4.4.1 Effect of Leaf Position

In the glasshouse study, sap NO_3-N concentrations in the petioles of young mature leaves (YML) and wrapper leaves (WL) were measured at heading (leaf position within the plant is shown in Figure 4.1). Leaf position within the plant influenced sap NO_3-N concentrations (Figure 4.2a). At lower rates of N application (<0.784 g N pot^{-1}), NO_3-N concentrations were similar in both leaf petioles but at higher rates, petioles of YML had significantly higher NO_3-N concentrations than WL. These results compare very well with the recent findings of Huett and Rose (1989) on spring cabbages grown in sand culture. They found that the petiole sap NO_3-N concentrations measured by the Merck test strip increased as leaf age increased from the youngest fully opened leaf (YFOL) to youngest fully expanded leaf (YFEL) and the oldest leaf (OL) at the higher N application rates (14, 29 and 43 mmol/L). At the lowest (2 mmol/L) N application rate, NO_3-N concentration in all leaves were negligible and did not differ significantly. The YFOL and YFEL would correspond to the WL and YML,

Figure 4.1 Showing the position of (a) young mature leaf (YML) and (b) wrapper leaf (WL) within a cabbage plant.

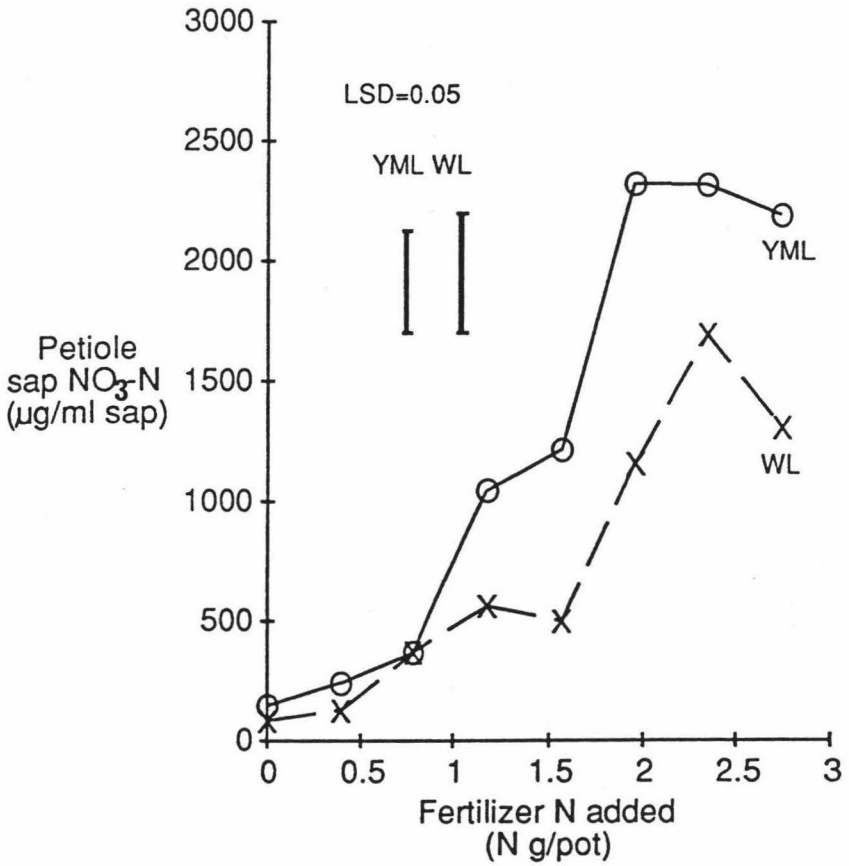

Figure 4.2a The effect of leaf sampling position on the petiole sap NO_3-N concentration of cabbage at heading (glasshouse experiment).

respectively, in the present study. The lower concentrations in petioles of YFOL or WL can be explained by the greater rate of translocation of NO_3-N to the leaf blade where it is reduced and metabolized (Maynard et al., 1976).

Using a field crop of 3-month old summer cabbages, Scaife and Stevens (1983) found that there were large differences in NO_3-N concentrations with leaf position, the middle leaf having the highest, followed by those of the upper leaf and those of the lower leaf. Their result, however, was based on only one rate (total of 236 kg N ha^{-1}; 86 kg N applied at transplanting and 150 kg N as topdressing) of N application. As found in this glasshouse experiment and the experiment of Huett and Rose (1989), it appears that the effect of leaf position on petiole sap NO_3-N concentration is dependent on the rate of N supply to the plant. This effect of N supply was later observed in the field (Figure 4.2b).

In the present study, despite the sap NO_3-N concentration differences, petioles from either leaf position can be used for plant N status diagnosis because their sap NO_3-N concentrations were highly correlated with final yield ($r = 0.87^{**}$; n=32). Since the variability in NO_3-N concentration in YML was lower than that in the WL (compare the calculated LSD's in Figure 4.2a) and because it is easier to visually select samples with petioles of YML than WL, YML are the preferable leaves to sample. On the basis of this result, all other petiole sap NO_3-N and NH_4-N concentrations reported in the present study were taken from YML's.

4.4.2 Effect of Time of Day

To determine the diurnal variation in petiole and xylem sap NO_3-N concentrations, field grown cabbages were sampled every 2 hr from 8 am until 4 pm on a clear sunny day with a total sunshine of 9 hr and maximum/minimum temperature of 13.7/5.6°C. At each sampling time, 5 plants was chosen at random and xylem and petiole sap were collected.

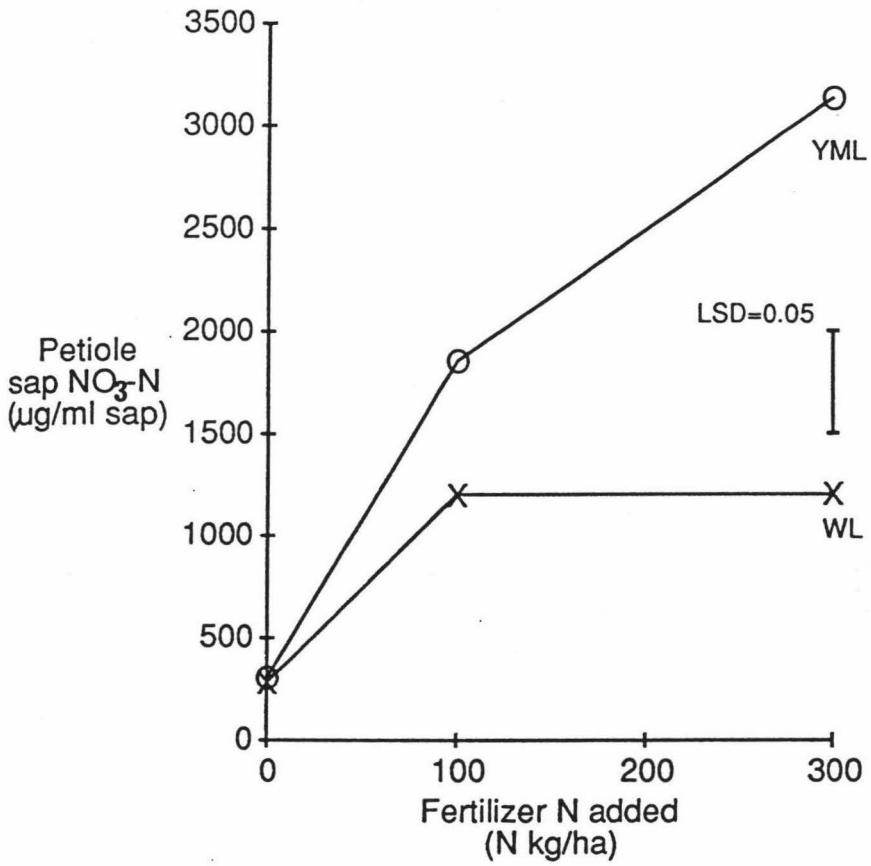

Figure 4.2b The effect of leaf sampling position on the petiole sap NO_3-N concentration of cabbage at heading (field experiment).

In this field study, petiole sap NO_3-N concentration was not affected by the time of day (Figure 4.3) during which sampling could be realistically conducted. This result is in agreement with the findings of Scaife and Stevens (1983) for summer cabbages and Coltman (1987) for tomatoes. On the other hand, large diurnal effects, which were consistent with variations in NO_3 reductase activity, have been reported for corn (Hageman et al., 1961) and beets (Minotti and Stankey, 1973). The variations in NO_3 reductase activity in corn were related to the level of light intensity incident at leaf surfaces while air temperature which diverged widely during the sampling period was responsible in beets.

Xylem sap NO_3-N concentrations were highest at 8 am and decreased rapidly over the next 2 hr. A slower rate of decrease occurred between 12 am and 4 pm (Figure 4.3). The changing NO_3-N concentrations in the xylem sap probably reflects the variation in nitrate uptake by cabbages which may be related to the transpiration rate which was not recorded. Emmert (1974) has illustrated the inverse sap concentration/transpiration rate relationship for P in which concentration in the sap is higher at night (when transpiration is low) than by day (when transpiration is high).

Based on the results of the present study, it is recommended that sap nitrate testing in winter cabbages should be done on a reasonably clear sunny day between 10 am and 4 pm. When sap testing is done on a dull or overcast day measured NO_3-N concentrations can be higher as the plant is not undergoing active photosynthesis when the supply of carbohydrate tends to outstrip the nitrate supply in the light (Scaife, 1979).

4.4.3 Effect of Sample Storage Time

Where laboratory analysis of sap samples taken from the field is required, they may not be able to be undertaken immediately due to the unavailability of transport and distance problems. Results from the glasshouse study (Figure 4.4) for xylem sap indicate that significant changes occur in NO_3 and NH_4-N concentrations over time suggesting that

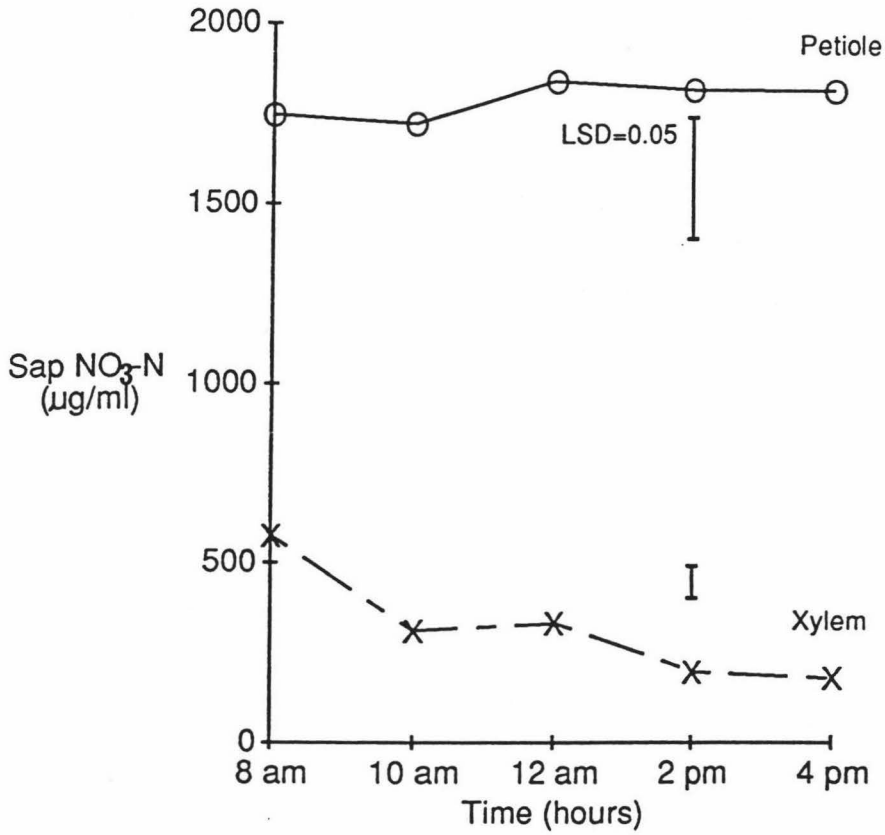

Figure 4.3 The effect of time of day on xylem and petiole sap NO_3-N concentrations in cabbages.

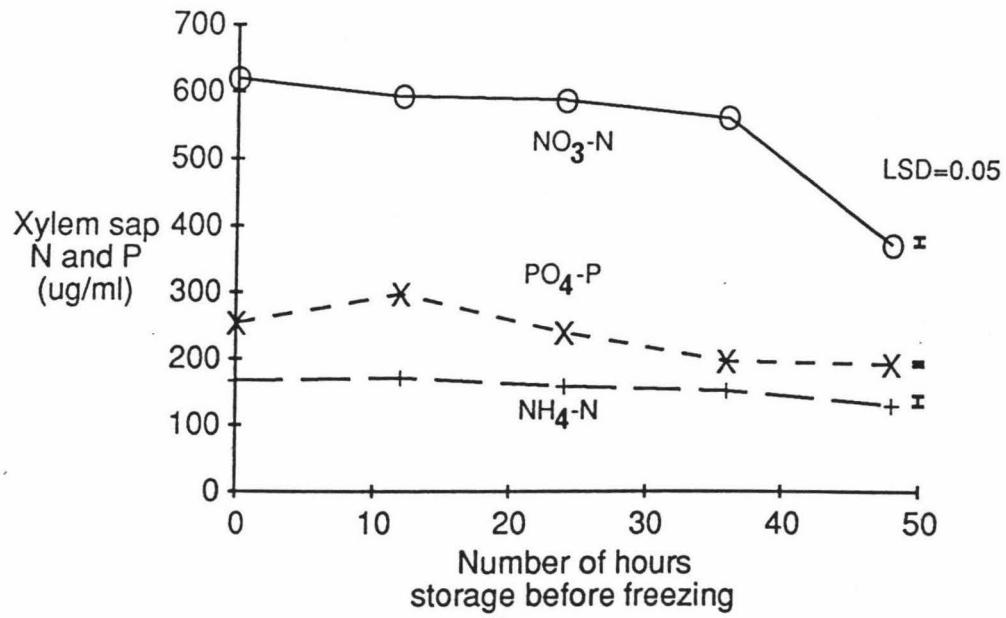

Figure 4.4 The effect of sample storage time on xylem sap N and P concentrations in cabbages.

sap samples should be placed in the freezer immediately after collection. However, some latitude exists in the first 36 hours because critical levels of sap NO_3-N have a range $\pm$ 50 $\mu g\ ml^{-1}$ of the true mean (Bonoan et al., 1989). Analysis of fridgerated samples showed a similar trend to those not in fridge.

A similar trend of results could be expected for petiole sap as concentration changes in either xylem or petiole sap would depend on similar factors such as light, temperature and NO_3 reductase activity.

4.4.4 Effect of Plant Age

Cabbages from the field were sampled to determine the effect of plant age (a term covering the interactions between physiological changes in the plant, climate and soil N supply) on the relationship between sap N concentration and the amount of N supplied.

Concentrations of NO_3-N in the xylem and petiole sap generally decreased with plant age (Figure 4.5a and 4.5b) irrespective of the level of fertilizer N applied. Workers at the National Vegetable Research Station in the UK (Scaife, 1979) have found that petiole sap of many young crops would contain about 1000 $\mu g\ ml^{-1}$ during early growth, and that this declines to nearly zero at harvest. These reported values agree with the concentrations of NO_3-N in petiole sap measured in the present study.

Petiole sap NO_3-N concentrations in the low N plants decreased rapidly at an early plant age (60 DAT) while the decrease for the high N plants occurred at a later plant age (90 DAT). At all N rates plants had nearly zero NO_3-N concentrations in the petiole sap at 100 DAT (midmaturity).

At cabbage-head development phases (60-80 DAT), the decrease in NO_3-N concentration was more abrupt in the petiole sap than in the xylem sap indicating that petiole sap NO_3-N concentration may show greater sensitivity to N stress in plants.

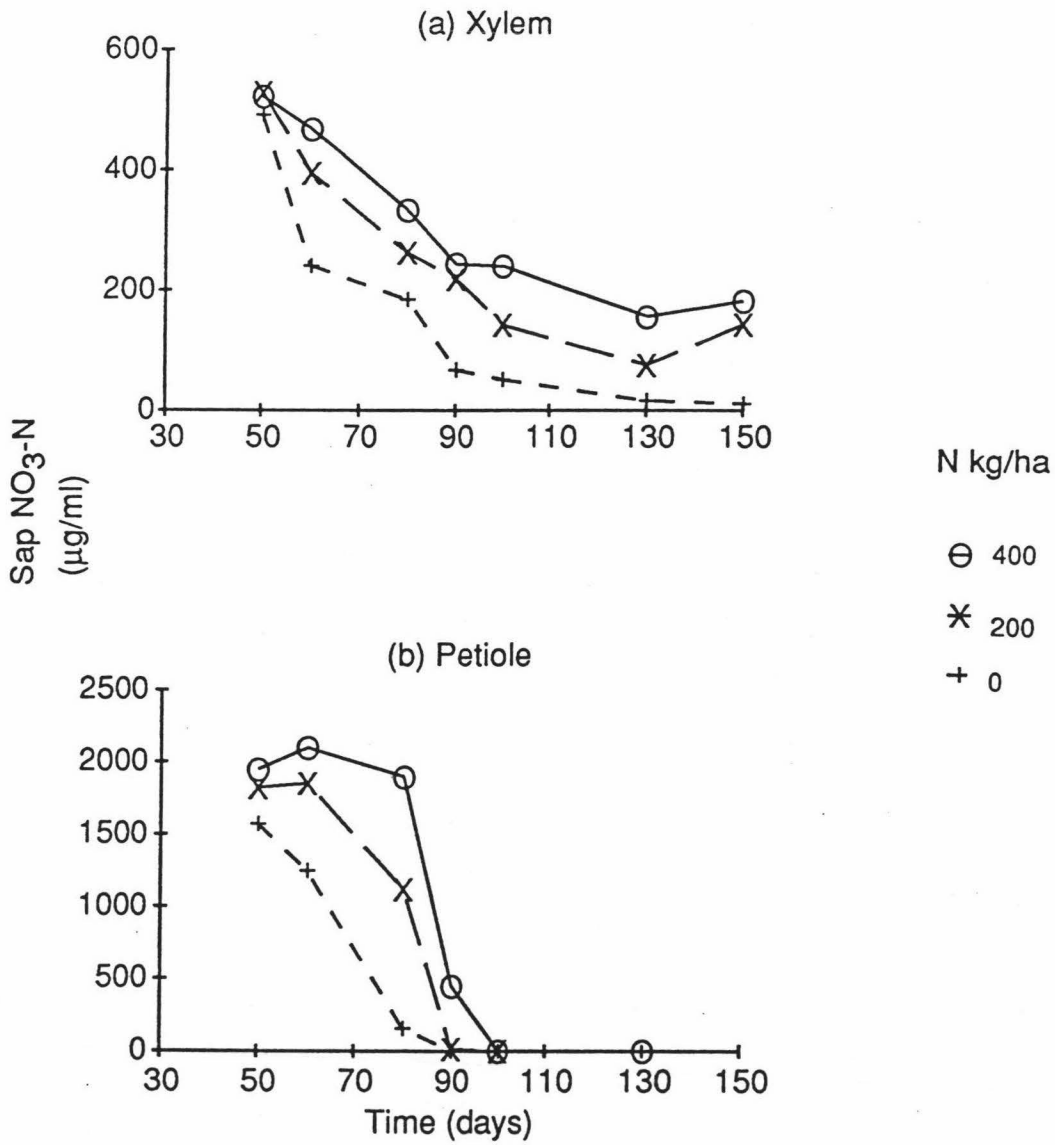

Figure 4.5 The effect of plant age and rates of N application on (a) xylem and (b) petiole sap NO_3-N concentrations in cabbages.

4.4.5 Plant to Plant Variability of Petiole Sap NO_3-N

In an attempt to determine the variability of petiole sap NO_3-N concentration from plant to plant, YML's from 25 randomly selected plants receiving similar fertilizer treatment were collected from the field experiment later described (Chapter 6 section 6.3). Two YML's were sampled from each plant (in this case there was a total of 50 YML's) to ensure that enough sap for NO_3 analysis was obtained for each plant.

The minimum number of plants (n) needed to ensure that 95 times out of 100 the observation would be within 10% of the true mean, was calculated from the formula by Steyn (1961):

$$n = 2(t)^2 (d)^2/(D)^2 \qquad (4.1)$$

where t = Student's "t" (in this case 2.06 on 24 d.f.), d = coefficient of variation (%), and D permitted variation of observed mean from true mean (in this case 10%)

Applying Equation (4.1):

$$n = 2(2.06)^2 (12.4)^2/(10)^2$$
$$n = 13 \text{ plants}$$

The data indicate that about 13 plants (2 YML's per plant) would be required by a more or less uniform cabbage area of 0.1 ha to provide a sap sample with a limit of 10% of the true mean.

Using ginger as test crop, Lee et al., (1981) found that for uniform areas of crop, 45 leaves would be needed per 0.15 ha of crop to ensure that the observed mean is within 2.5% of the true mean, whereas for noticeably variable sections of crop, as many as 140 leaves might be needed.

4.5 CONCLUSION

Results from a series of experiments indicated that leaf position, time of day, sample storage time and plant age are important considerations for relating plant sap N concentrations to N status of cabbages.

Petioles of young mature leaves (YML), compared with wrapper leaves (WL), are the preferable leaves to sample for sap NO_3 analysis due to lower variability in NO_3-N concentration. It is also easier physically and visually to select samples from petioles of YML than WL.

In a limited assessment on a clear sunny day, time of day did not influence sap NO_3-N concentration in petiole sap but affected NO_3-N concentration in xylem sap. Nitrate concentration gradually decreased with time of the day which was probably a reflection of the variation in NO_3 uptake by cabbages.

Time of sample storage was found to have an influence on NO_3 and NH_4-N concentration in xylem sap. Concentrations decreased significantly when sap samples were not placed in the freezer after collection.

Nitrate-N concentrations in petiole and xylem sap generally decreased with plant age. This is in line with the general finding that N assimilation rate in the leaves of most crops exceeds the N uptake during the latter stages of growth. Thus, it is essential to standardize the stage of crop growth in interpreting and comparing plant nutrient levels for diagnostic and prognostic purposes.

To ensure that the observed petiole sap NO_3-N mean is within 10% of the true mean, at least 13 plants (two-YML petiole samples per plant) are required from a more or less uniform cabbage area of 0.1 ha.

CHAPTER 5

INFLUENCE OF FERTILIZER FORMS ON SAP NUTRIENT CONCENTRATIONS AND YIELD OF WINTER CABBAGES

5.1 INTRODUCTION

The influence of several factors (leaf sampling position, time of day, storage time and plant age) on xylem and petiole sap NO_3 and NH_4-N concentrations in winter cabbages was investigated and reported in Chapter 4. Apart from these factors, the form of N fertilizer has been shown to have a marked effect on NO_3-N concentration in petiole sap of glasshouse grown lettuce (Scaife et al., 1986) and on the accumulation of NO_3-N in spinach and table beet (Barker et al., 1971; Peck et al., 1971). There is a lack of information in the literature on the effect of N, P and combined N/P fertilizer forms on the sap nutrient concentrations in winter cabbages.

Form of fertilizer has also been reported to influence the growth and yield of some vegetable crops (see Chapter 2 section 2.3). Normally, fertilizers for cabbage production in NZ and overseas include a range of the readily soluble N and P forms like ammonium phosphates or mixtures of sulphate of ammonia or urea and single superphosphate (SSP) or triple superphosphate (TSP). More recently, partially acidulated phosphate rock's (PAPR's) have been suggested as having a niche in vegetable production (Buwalda et al., 1987; Rajan, 1989). They are prepared by treating reactive phosphate rocks with only a portion of the H_2SO_4 or H_3PO_4 required for making SSP or TSP. Since H_3PO_4 is expensive, PAPR's offer cheaper sources of P for horticulture than the fully acidulated fertilizers (e.g., TSP) if they can be shown to be effective carriers of plant available P. If combined with an ammoniacal-N fertilizer they may have the advantage that the acid generated by nitrification of NH_4^+ ions may increase the amount of plant available P (Apthorp et al., 1987). The potential for using N/PAPR as starter fertilizers for winter cabbage production is unknown.

5.2 OBJECTIVES

1. To determine the influence of straight nitrogen and combined nitrogen and phosphorous fertilizer forms on nitrate, ammonium and P concentrations in the xylem sap;
2. To determine the effect of fertilizer form on growth and yield of winter cabbages; and
3. Evaluate the potential of nitrogen/partially acidulated phosphate rock (N/PAPR) as N and P sources for winter cabbages.

5.3 MATERIALS AND METHODS

To achieve the above objectives laboratory, glasshouse and field experiments were conducted.

5.3.1 Laboratory Experiment

Commercial N/PAPR fertilizers with suitable N and P grade are not yet available thus prototype fertilizers had to be manufactured for these experiments.

5.3.1.1 *Preparation of PAPR*

North Carolina reactive phosphate rock (NCPR, 13.2% P) was ground to the following particle size specifications 100% <150 μm; 80% <75 μm. The rock was acidulated to a nominal 50% with commercial grade Texas Gulf H_3PO_4 (22.7% P). Based on the results from previous experiments, 180 g of this acid is required to acidulate 250 g NC phosphate rock to achieve approximately a 50% level of acidulation (Harrison and Hedley, 1987).

The phosphate rocks (500 g) and acid (360 g) were weighed separately in beakers and they were preheated to 60°C. Then the phosphate rock was transferred to a heat resistant plastic mixing bowl. The rock was stirred with a Kenwood food mixer while the required amount of acid was slowly poured into the phosphate rock in 15 seconds. The mixture was then thoroughly stirred for a further 45 seconds. The product was immediately transferred to an insulated container for denning. After 15 minutes, the ex-den mixture (temperature at 64°C) was placed on a clean plastic tray, then covered with a clean sheet of paper and dried in the oven overnight at 60°C. Four separate batches of PAPR were prepared.

The PAPR product was ground to pass through a 500 μm sieve. A composite sample of the product was analysed for total P content using a triacid digestion method (5.3.1.4). The value obtained (18.9% P) was slightly higher than the reported value for a similar product, 18.5% P by Harrison and Hedley (1987). The former value was used in the calculation of PAPR weights needed in the manufacture of N/PAPR fertilizers.

5.3.1.2 *Preparation of N/PAPR*

Commercial grade urea (46% N), ammonium sulphate (21% N), potassium nitrate (13% N) and monocalcium phosphate (24% P) were ground to pass through a 500 μm sieve. The weights of each N fertilizer and PAPR needed in the manufacture of N/PAPR fertilizers were calculated from their theoretical N contents and from the measured P content of PAPR (18.9% P). The ratio of N:P in the mixture was maintained at approximately 1:1. The straight N fertilizers i.e., urea, ammonium sulphate and potassium nitrate and straight P fertilizers, i.e., MCP and PAPR, were mixed with finely ground soil (<500 μm) equivalent in weight to the PAPR that was added to the equivalent N/PAPR mixture.

Soil was added to the straight N and P fertilizers only inorder to provide granules with similar %N and %P by weight to the N/P mixtures. This ensured that a similar number of fertilizer granules were applied to each

pot in the glasshouse trial. Application of uniform number of granules per pot is essential to attain a uniform fraction of the soil that is fertilized because according to Barber (1984), P uptake by plants increases as the fraction of the soil that is fertilized is reduced.

The N/PAPR, N/soil, P/soil fertilizer mixtures were thoroughly mixed before putting them in a drum granulator. Deionized water was sprayed on to the mixture in order to attain the desired granule sizes. The products (slightly wet) were dried overnight at 60°C. Granule sizes of 1-2 mm were collected and stored in sealed plastic containers. Granules >2.0 and <1.0 were again ground to pass a 500 μm sieve and regranulated following the same procedure.

The different N/PAPR fertilizers and other N and P fertilizers that were granulated are shown in Table 5.1. The weights of each fertilizer material as well as the amounts of soil used as filler with the N only and P only fertilizers are also shown in Table 5.1.

The final yield of the fertilizer mixtures after granulation are also listed in Table 1. Losses in the granulator, however were not accounted for. Significant losses of fertilizer materials occurred during the granulation process as the mixtures adhered to the drum walls. This was a particular problem with the very soluble forms i.e., N fertilizers in combination with MCP.

5.3.1.3 *Moisture content of the fertilizers*

The initial moisture contents of the fertilizers expressed as percent of dry weight loss on heating triplicate samples of 1-2 g of each fertilizer material at 90°C for 24 hours are in Table 5.2. The N/MCP had higher moisture contents than the N/PAPR mixtures which can be attributed to the more hygroscopic nature of both fertilizer forms in the mixture. The fertilizers granulated with soil had less than 10% moisture contents. The fertilizers were stored in sealed plastic bags after drying.

Table 5.1 Yield weights of the different fertilizer materials[1].

Fertilizer	Wt (g)		Total wt of mixture (g)	Yield wt (g)
Urea/PAPR	Urea	297.82	1022.69	887.35
	PAPR	724.87		
Urea/MCP	Urea	297.82	868.65	680.90
	MCP	570.83		
AmS/PAPR	AmS	652.38	1377.25	191.68
	PAPR	724.87		
AmS/MCP	AmS	652.38	1223.21	207.16
	MCP	570.83		
KNO_3/PAPR	KNO_3	1053.85	1778.72	741.02
	PAPR	724.87		
KNO_3/MCP	KNO_3	1053.85	1624.68	481.32
	MCP	570.83		
Urea	Urea	167.31	574.72	397.97
	soil	407.41		
AmS	AmS	399.91	807.40	696.06
	soil	407.41		
KNO_3	KNO_3	691.02	1166.33	865.81
	soil	475.31		
PAPR	PAPR	520.27	1029.53	827.40
	soil	509.26		
MCP	MCP	481.25	1092.36	870.31
	soil	611.11		
AmS/NCPR	AmS	342.86	888.15	833.15
	NCPR	545.29		

[1]Loss in granulator not measured

Table 5.2 Total N (%N) and total P (%P) contents of the N/PAPR fertilizers (oven-dry basis, 90°C for 24-hr).

Fertilizer	%N[a]	%P[b]	N:P	%Moisture content
Urea/PAPR	15.95	14.62	1.0:0.92	7.16
Urea/MCP	21.14	19.48	1.0:0.92	13.75
AmS/PAPR	10.00	10.51	1.0:1.05	11.77
AmS/MCP	12.71	12.31	1.0:0.97	22.17
KNO_3/PAPR	10.33[c]	8.89	1.0:0.86	16.52
KNO_3/MCP	9.16[c]	10.08	1.0:1.10	18.82
Urea + filler	20.49	-	-	3.15
AmS + filler	10.15	-	-	6.97
KNO_3 + filler	7.97[c]	-	-	5.64
PAPR + filler	-	8.83	-	7.98
MCP + filler	-	9.60	-	9.06
AmS/NCPR	8.70	8.87	1.0:1.02	4.74
NCPR(std)	-	13.60		

[a]Measured by Kjeldahl digestion
[b]Measured by triacid digestion
[c]Measured by 1M HCl extraction

5.3.1.4 *Total N and P contents of the fertilizers*

Ammonium-N analysis was carried out after a Kjeldahl digestion (concentrated H_2SO_4). Three hundred milligrams of each fertilizer sample were digested with 4 ml Kjeldahl mixture. For nitrate-N fertilizer forms i.e., KNO_3/PAPR, KNO_3/MCP and KNO_3; the samples were extracted with 1M HCl. The concentrations of NH_4-N and NO_3-N in the samples were determined by autoanalysis methods as described by Technicon (1976) and Downes (1978).

The alternative digestion procedure i.e., using triacid mixture (5:5:7 HNO_3:HCl:$HCLO_4$) was used for P analysis. One gram of each sample was digested with 25 ml of the acid mixture at 260°C until white fumes built up inside the flask. The digest was filtered through Whatman's No.40 filter paper and made up to 100 ml. The concentration of P in the diluted digest was measured using the vanadomolybdate method (AOAC, 1975).

The %N and %P values in Table 5.2 were used in the determination of amounts of each fertilizer mixture required per treatment(g N/P pot^{-1}) in the glasshouse trial. It was however not possible to maintain exactly 1:1 weights of N and P added to each fertilizer treatment because of the slight differences in %N and %P contents of the fertilizers (Table 5.2). Similar units of N but not P were applied in the fertilizer treatments.

5.3.1.5 *Solubility of the fertilizers*

To establish the chemical quality of the fertilizers, the solubilities of the N/PAPR and P/filler mixtures were tested using standard methods namely - water solubility and solubility in 2% citric and 2% formic acid. In NZ, 2% citric acid is usually used as standard extractant (The Fertilizer Regulations, 1969). On the other hand, European countries have used the

P solubilities in 2% formic acid as a criterion for selecting "soft rock phosphates" for using as a direct application fertilizers (EEC reg. L213/8; 1977).

For each extraction, 0.4 g sample of each fertilizer source was extracted with 40 ml of the reagents for 30 min. The sample was centrifuged at 10000 rpm for 10 min on a Sorvall RC5C centrifuge using a SS-34 head and the solution was filtered through Whatman No 41 filter paper. Solution P was determined in individual filtrates either by metavanadate (AOAC, 1975) or phosphomolybdate (Murphy and Riley, 1962) method.

The water soluble P content of NC phosphate rock (Table 5.3) is very low (0.04% of the total P). This is due to the stability of apatites of the francolite group in water (Khasawneh and Doll, 1979). Acidulating it with 50% H_3PO_4 and granulating with soil filler produced a product with 46% of the total P as water soluble P. This value is much lower than the reported % water solubility (75-77%) for a product with similar acidulation level (Rajan, 1985; 1987) but the latter product was not granulated with a soil filler. When soil was used as a filler the solubility of PAPR in water was reduced (Table 5.3) probably due to the fact that the soil sorbed large amounts of water soluble fertilizer P during the water extraction. This was supported by the low % water soluble P of MCP (highly soluble P fertilizer) in the presence of soil.

As expected, the solubilities of the N/PAPR products are higher in 2% citric acid and 2% formic acid than in water as the acids extract the residual phosphate rock and also some phosphate from iron and aluminium impurities plus the soluble P extracted by water (Braithwaite, 1987).

5.3.2 Glasshouse Experiment (1987)

Topsoil (0-20 cm) of the Manawatu fine sandy loam (recent alluvial soil of low P retention; pH 5.4; CEC 20.12 me 100 g^{-1} soil; Ca 6.26 me 100 g^{-1} soil) was collected, air-dried and passed through a 2-mm screen mesh

Table 5.3 The total P content and the percentage P extracted from different N/PAPR products by water, 2% citric and 2% formic acid.

Fertilizer	%Total P[1]	Water	2%Citric	2%Formic
Urea/PAPR	13.57	9.16	11.20	10.76
		(68)[a]	(82)	(79)
Urea/MCP	15.63	11.73	14.76	14.91
		(75)	(94)	(95)
AmS/PAPR	9.27	5.88	7.91	7.80
		(63)	(85)	(84)
AmS/MCP	9.59	8.08	8.84	9.02
		(84)	(92)	(94)
KNO_3/PAPR	7.42	4.74	6.24	6.09
		(64)	(84)	(82)
KNO_3/MCP	8.18	6.30	7.61	7.76
		(77)	(93)	(95)
PAPR+filler	9.18	4.22	6.86	6.26
		(46)	(75)	(68)
MCP+filler	10.42	5.82	9.55	8.86
		(56)	(92)	(85)
AmS/NCPR	8.46	0.02	4.91	6.01
		(0.24)	(58)	(71)
NCPR(std)	13.60	0.005	4.92	8.70
		(0.04)	(36)	(64)

[1]Wet basis, moisture contents are given in Table 5.2
[a]Figures in parentheses indicate the percentage of total P

before potting. Each pot (14 x 14 x 28 cm diameter) contained 4600 g air dry soil which had been prewetted to 80% of the field capacity. Soil moisture in each pot was maintained to this level by weight during the experiment.

To check whether high rates of N and P application would depress yields, a preliminary trial using broccoli as test crop was conducted. Rates of N and P application to the seedlings were 0, 0.5, 1.0, 1.5, 2.0, 3.0, 4.0 and 8.0 g pot^{-1} using AmS/MCP and Urea/MCP. Results indicated that 8.0 g N and P pot^{-1} using AmS/MCP was enough to cause seedling death two days after application (Table 5.4). From this result the highest rate of initial fertilizer application in the glasshouse trial was reduced to 5.0 g N and P pot^{-1}.

Fertilizer treatments consisted of 8 levels of N/P (Table 5.5) and 4 levels of N or P. At planting (17 May 1987) the fertilizer material was incorporated thoroughly with 600 g soil and placed in bands 4 cm beneath the soil surface in each pot. Nylon mesh was used to separate the fertilized layer from the adjoining soil layer. Each pot was planted with one "Wintercross" variety cabbage. Basal application of K_2SO_4 was done to supply equal rates of K and S to all treatments. Complete trace element(-Mn only) solution (Middleton and Toxepeus, 1973) was also applied during cabbage growth.

Treatments were replicated 3 times and arranged in randomized complete block design. There were 3 sets of each replication to allow 3 harvesting dates: 40, 60, and 160 DAT to correspond with the vegetative, heading, and maturity stages of cabbage growth; respectively.

At each sampling date, fresh and dry weights of plants (above ground parts) were recorded. Xylem sap was collected following the technique described in Chapter 3 (3.3.5.2) and NO_3^- and NH_4-N concentrations in the sap were determined as described in Chapter 3 (3.3.5.1). The P concentration in the sap was determined by autoanalyser methods of Twine and Williams (1971) and Technicon (1976). Xylem sap was analysed in

Table 5.4 Dry matter yield (g/pot) of broccoli from the preliminary glasshouse experiment[1].

g N/P pot^{-1}	AmS/MCP	Urea/MCP
Control	4.9	4.9
0.5	23.7	6.8
1.0	32.8	7.2
1.5	32.5	7.9
2.0	27.6	8.4
3.0	9.2	9.1
4.0	6.6	9.2
8.0	+	7.0

[1]Unreplicated
+Senesced 2 DAT

Table 5.5 Forms and rates of N/P; N or P application in the glasshouse trial.

Fertilizer Form	P added (g/pot)
For the following eight rates of P addition for N/P fertilizers, the corresponding rates of N application were: 0; 0.5, 1.0, 1.5, 2.0, 3.0, 4.0 and 5.0 g/pot. The application rates at 1.0, 2.0 and 4.0 g/pot were prepared in triplicate and the 0.5, 3.0 and 5.0 g/pot remained unreplicated.	
Urea/PAPR	0, 0.45, 0.91, 1.38, 1.83, 2.75, 3.67, 4.58
Urea/MCP	0, 0.43, 0.86, 1.29, 1.71, 2.57, 3.43, 4.29
AmS/PAPR	0, 0.52, 1.05, 1.57, 2.10, 3.15, 4.19, 5.25
AmS/MCP	0, 0.48, 0.97, 1.45, 1.94, 2.91, 3.88, 4.85
KNO_3/PAPR	0, 0.43, 0.86, 1.29, 1.72, 2.58, 3.44, 4.30
KNO_3/MCP	0, 0.55, 1.10, 1.65, 2.20, 3.30, 4.40, 5.50
	N added (g/pot)
Urea	0, 1.0, 2.0, 4.0
AmS	"
KNO_3	"
	P added (g/pot)
PAPR	0, 1.0, 2.0, 4.0
MCP	"

preference to petiole sap because the concentrations of NO_3-N, NH_4-N and P in xylem sap would be more related to external N and P supply than petiole sap (see Chapter 2 section 2.2.2.3).

After each harvest, extractable NO_3^- and NH_4-N levels in air-dry soils were measured following a similar procedure to that described in Chapter 3 (3.3.6).

The conductivity (soluble salts) of the soils in saturated $CaSO_4$ extracts (soil:solution ratio 1:2.5) was measured following the procedure of Winsor et al., (1963).

5.3.3 Field Experiment (1988)

Following the glasshouse trial described above, a field trial was conducted on a Karapoti fine sandy loam (details of the experiment are in Chapter 6) to evaluate different N/P fertilizer products (Urea/PAPR, Urea/Super and CAN/Super) for winter grown cabbages. Urea/PAPR was prepared in the laboratory following procedures similar to those previously described (5.3.1.2). Each fertilizer product was applied at 2 rates of N (100 and 200 kg ha^{-1}) and at constant P (100 kg ha^{-1}) in 3 replicates. A control treatment (-N -P) was included for comparison.

Five plant harvests (60, 80, 100, 130 and 150 DAT) were taken during the trial and fresh and dry weights of plants measured at each harvest. Harvestable fresh head yield was also recorded at final harvest. Total N and P concentrations in plants were determined as given earlier (3.3.5.4).

5.4 RESULTS AND DISCUSSION

5.4.1 Glasshouse Experiment

5.4.1.1 *Effect of N fertilizer form on NO_3- and NH_4-N concentration in xylem sap*

The concentration of NO_3^- and NH_4^+ in xylem sap (Figure 5.1a) was found to be affected by the form of N fertilizer applied (Appendix i). At any sampling date and at a given rate of N application, NO_3-N concentrations were consistently higher in xylem sap from plants treated with KNO_3 rather than urea or AmS. For instance at 60 DAT, when there was a marked effect of rate of applied N on plant growth, sap NO_3-N concentrations were highest (850-2570 $\mu g\ ml^{-1}$) when N was in the nitrate form (KNO_3); with urea sap NO_3 concentrations were lower (300-600 $\mu g\ ml^{-1}$) and even lower with AmS (300-400 $\mu g\ ml^{-1}$). Nitrate-N detected in plants supplied with urea and AmS was probably derived from nitrification in the rhizosphere. The reverse trend was observed when NH_4-N concentration in xylem sap was considered (Figure 5.1b) i.e., NH_4^+ concentrations were higher when N was in the ammoniacal form (AmS and Urea) than when N was in nitrate form (KNO_3).

Although the experiment was not designed specifically to study NH_4 and NO_3 nutrition differences in cabbages, the results from soil analyses and plant composition provide indirect evidence that:

1. NO_3^- is the major form of N transported up cabbage stems;
2. NO_3^- is preferentially utilised by cabbages over NH_4^+ when both ions are present in soil solution; and
3. There is little NO_3 reductase activity in the roots, thus, the leaves are the principal location of NO_3 reduction in cabbages.

The above findings support the utility of sap NO_3 testing as an indicator of N nutritional status of cabbages.

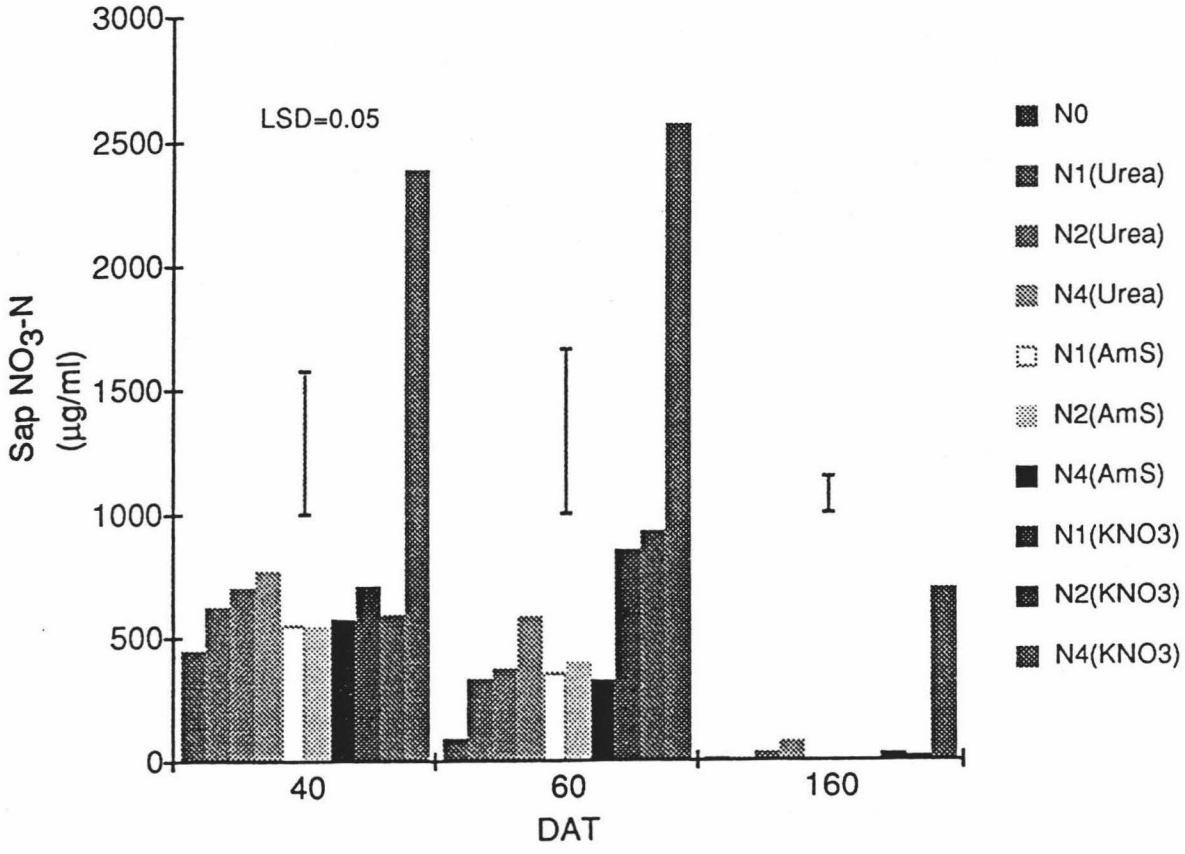

Figure 5.1a The effect of N fertilizer form on NO_3-N concentration in xylem sap of cabbages. Rate of N application (N g/pot): N0(0); N1(1); N2(2) and N4(4).

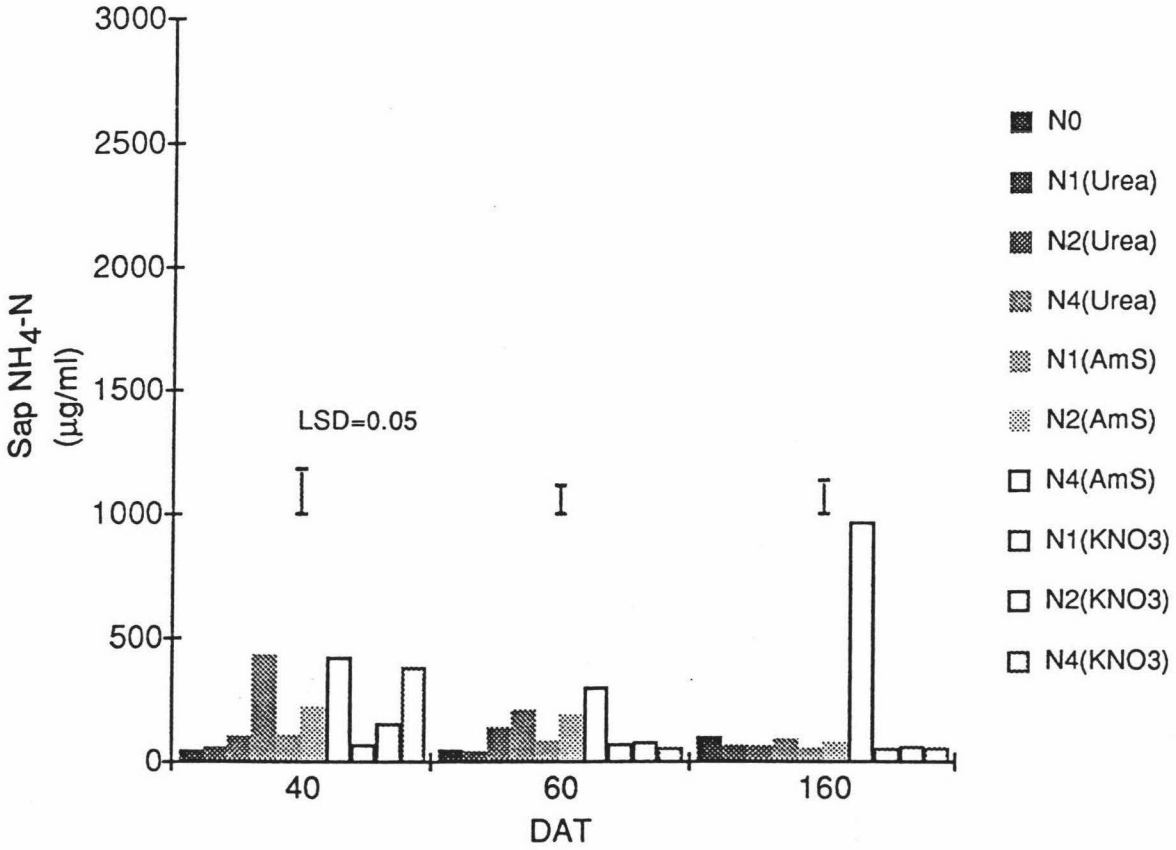

Figure 5.1b The effect of N fertilizer form on NH_4-N concentration in xylem sap of cabbages. Rate of N application (N g/pot): N0(0); N1(1); N2(2) and N4(4).

5.4.1.2 *Effect of P fertilizer form on NO_3^- and NH_4-N concentration in xylem sap*

The NO_3^- and NH_4-N concentrations in xylem sap of cabbages fertilized with AmS in combination with MCP (readily soluble P), PAPR (50% soluble P) or NCPR (slowly soluble P) form are shown in Figures 5.2a and 5.2b. AmS treatment was selected as this N fertilizer form was in combination with all forms of P studied. At a high rate (4 g/pot N/P) of application, concentrations of NO_3-N (Figure 5.2a) in xylem sap at 40 DAT were highest (1096 $\mu g\ ml^{-1}$) in plants supplied with AmS/MCP and this was comparable with AmS/PAPR (1081 $\mu g\ ml^{-1}$) but significantly higher than that (769 $\mu g\ ml^{-1}$) in AmS/NCPR fertilised plants (see Appendix ii). The results can be related to the NO_3^- supply in the soil. At 40 DAT, the levels were found to be 132 $\mu g\ g^{-1}$ (AmS/MCP); 117 $\mu g\ g^{-1}$ (AmS/PAPR) and 92 $\mu g\ g^{-1}$ (AmS/NCPR). At 60 DAT, plants receiving AmS/PAPR had higher NO_3-N concentrations (940 $\mu g\ ml^{-1}$) than the AmS/MCP plants (546 $\mu g\ ml^{-1}$). Data for AmS/NCPR was not determined at this sampling date. Again, the result was consistent with the differences in NO_3^- levels in the soil i.e., higher with AmS/PAPR (95 $\mu g\ g^{-1}$) than AmS/MCP (81 $\mu g\ g^{-1}$), indicating that plant xylem sap NO_3-N concentrations reflected the NO_3 status of the soils.

In terms of NH_4-N concentrations in xylem sap at 40 DAT, at a high rate (4 g/pot N/P) of application, concentrations were higher in plants supplied with AmS/MCP and AmS/PAPR than with AmS/NCPR (Figure 5.2b). At 60 DAT, AmS/PAPR treated plants had higher concentrations than the AmS/MCP treated plants. The results relate well with the variations in NH_4^+ levels in the soil at each sampling date (compare values in Table 5.8). The AmS/MCP and AmS/PAPR treated plants generally had significantly higher xylem sap NO_3^- and NH_4-N concentrations than the control or the N fertilizer only fertilizer treatments.

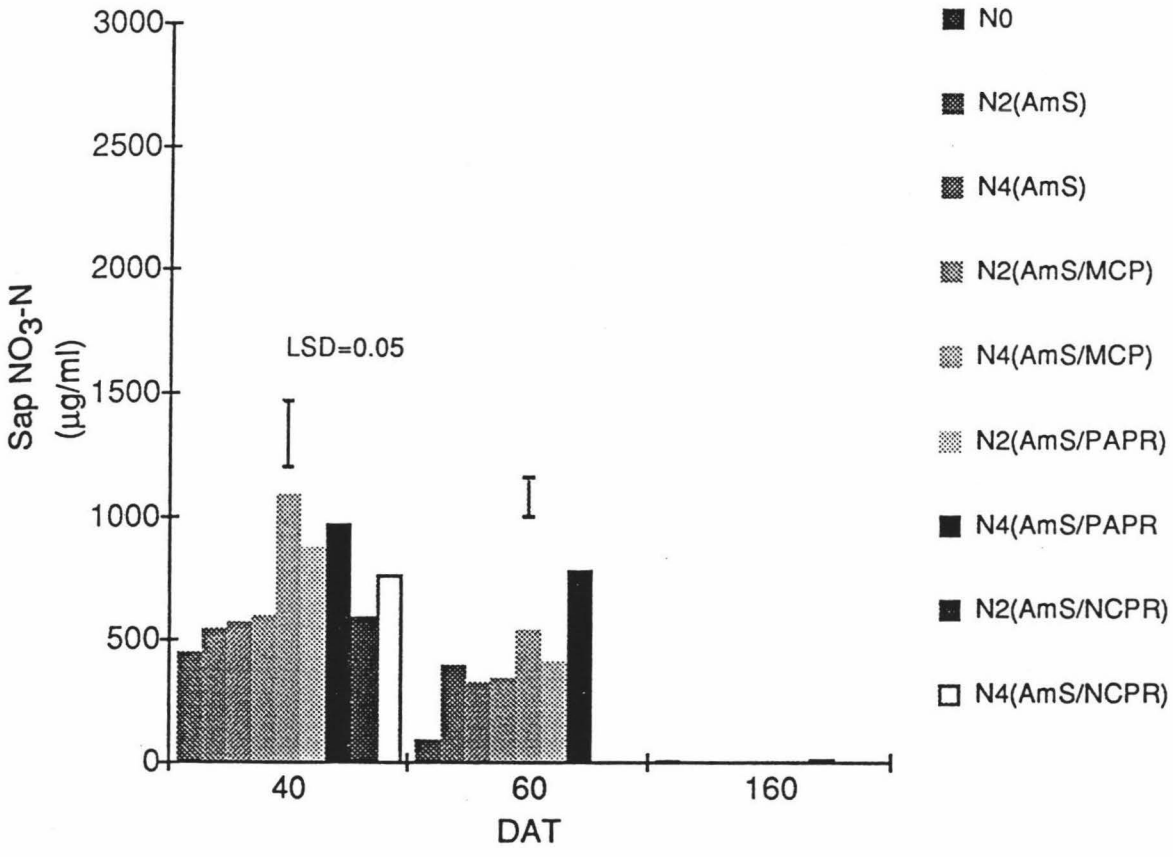

Figure 5.2a The effect of P fertilizer form on NO_3-N concentration in xylem sap of cabbages. Rate of N/P application (N/P g/pot): N0(0); N2(2) and N4(4).

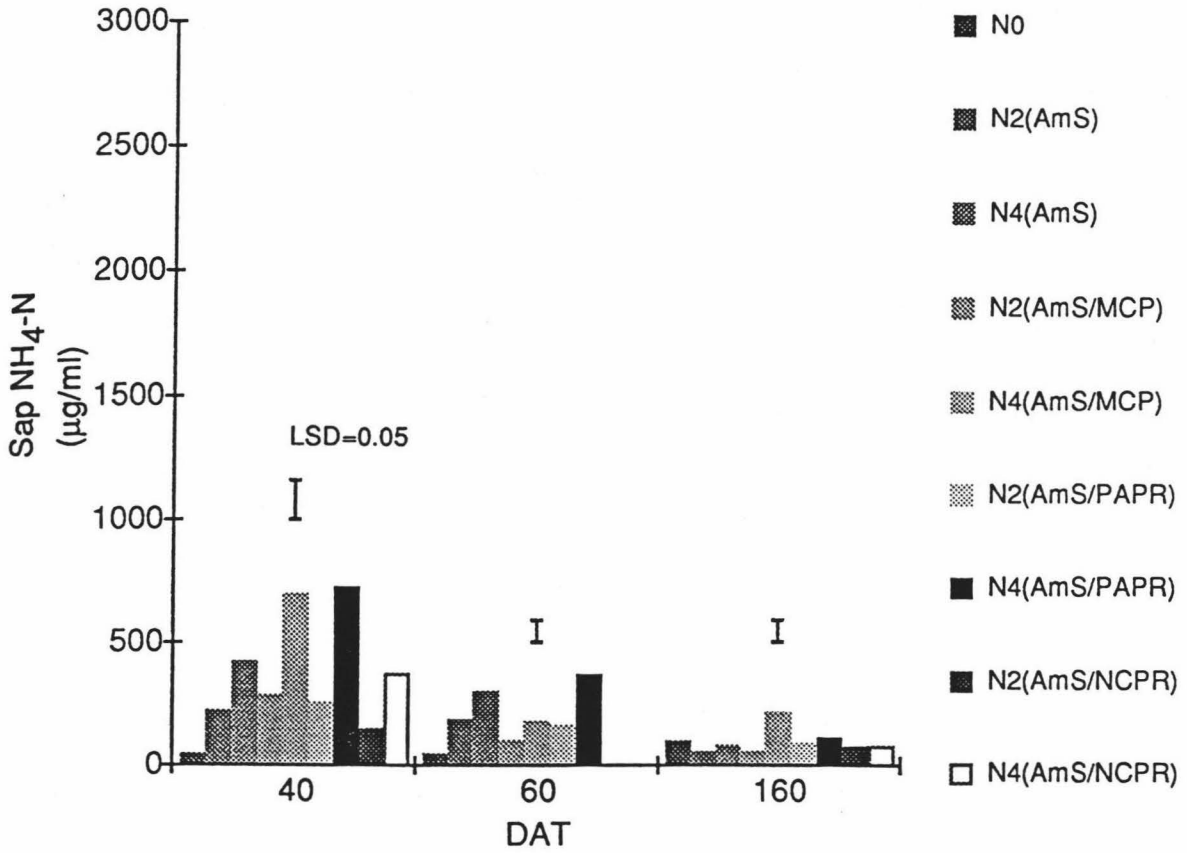

Figure 5.2b The effect of P fertilizer form on NH_4-N concentration in xylem sap of cabbages. Rate of N/P application (N/P g/pot): N0(0); N2(2) and N4(4).

5.4.1.3 *Effect of N fertilizer form on PO_4-P concentration in xylem sap*

The effect of N fertilizer form (AmS vs KNO_3), when in combination with MCP, on the concentrations of P in xylem sap is summarised in Appendix iii. In this case, N was initially present in either nitrate (KNO_3) or ammonium (AmS) form. At a given rate of application (Figure 5.3), the form of N did not significantly influence the P concentration in xylem sap at any harvest. Results in the present study, however, are not strictly comparable as the amounts of P added for a given rate varied between N/P fertilizer source (see Table 5.5).

At early heading (60 DAT), sap PO_4-P concentrations in the KNO_3/MCP treatment were 115-373 $\mu g\ ml^{-1}$ sap, in the AmS/MCP treatment were 125-324 $\mu g\ ml^{-1}$ sap while on the control treatment was 60 $\mu g\ ml^{-1}$ sap. The changes in the rate of P application appear to relate well with the changes of P concentration in xylem sap indicating the sensitivity of P concentration in xylem sap to P fertilization. Information on the levels of PO_4-P in xylem sap of cabbages has not been reported in the literature.

5.4.1.4 *Effect of fertilizer form (N/P) on PO_4-P concentration in xylem sap*

As indicated in Table 5.5, similar units of N but not P were applied in the fertilizer treatments. To account for the uneven rate of P added, a curvilinear regression model in the form of $[Y = a + b_1N + b_2(N)^2 + b_3P + b_4(P)^2]$ with N and P (as water soluble P) as independent variables was found to give the best model of xylem sap. This model was used to determine the individual effect of N and P in each fertilizer form on P concentration in xylem sap of cabbages at 60 DAT. Xylem sap data at 60 DAT were selected because differences in plant sap N and P concentrations were largest at this plant age.

With any N/P fertilizer form, only the N component and not the P

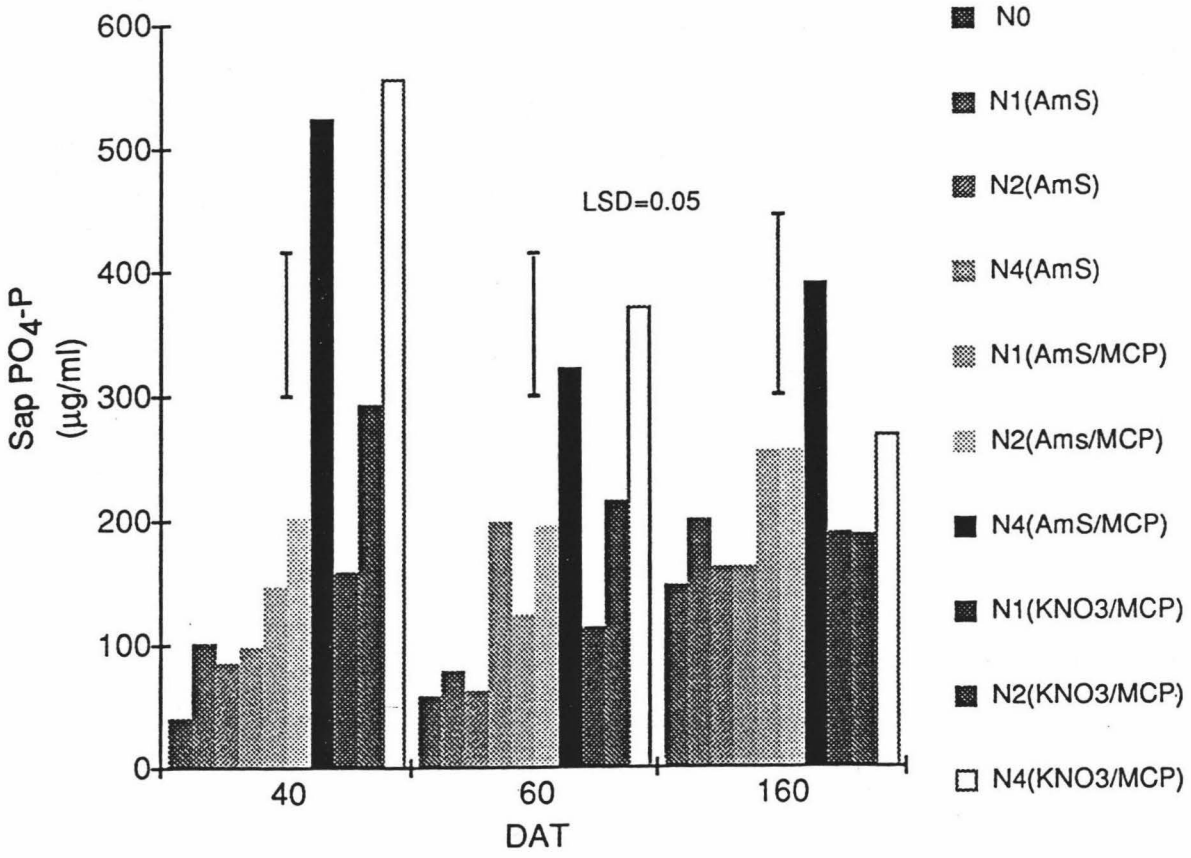

Figure 5.3 The effect of N fertilizer form on PO_4-P concentration in xylem sap of cabbages. Rate of N application (N g/pot): N0(0); N1(1); N2(2) and N4(4).

component influenced the concentration of P in xylem sap of cabbages (Appendices iv-vi). Using Urea/P as an example (Figure 5.4), the effect of N is to increase P concentration with increasing rate of N application. If P concentration in xylem sap is taken as an indicator of available P in soils, then, it would appear that the availability of P to plants is influenced by the rate of application of the companion N fertilizer in the N/P product.

5.4.1.5 *Effect of straight N and straight P fertilizer form on dry matter yield*

Addition of straight N fertilizer, namely urea, AmS and KNO_3 (Figure 5.5a) significantly increased the dry matter yield of cabbages at final harvest. Irrespective of N fertilizer form, maximum yield (75 g DMY pot^{-1}) was obtained at an application rate of 2 g N pot^{-1}. Application rates above this caused severe yield reduction with AmS (125%) and KNO_3 (350%) but not with urea fertilised plants.

Plant dry weights (Figure 5.5b) were not increased by straight P application regardless of form. This indicates that the growth of cabbages in this soil was not responsive to P fertilization alone. Plants fertilized with N or P alone, however, did not achieve the yield of those receiving both N and P.

5.4.1.6 *Effect of fertilizer form (N/P) on dry matter yield*

Using the curvilinear regression model [$Y = a + b_1N + b_2(N)^2 + b_3P + b_4(P)^2$], the individual effect of N and P (as either the amount of total P, water soluble P, citric acid soluble P or formic acid soluble P added) in each fertilizer form on dry matter yield of cabbages at final harvest was determined. Results of the regression analysis are summarised in Appendices vii-ix.

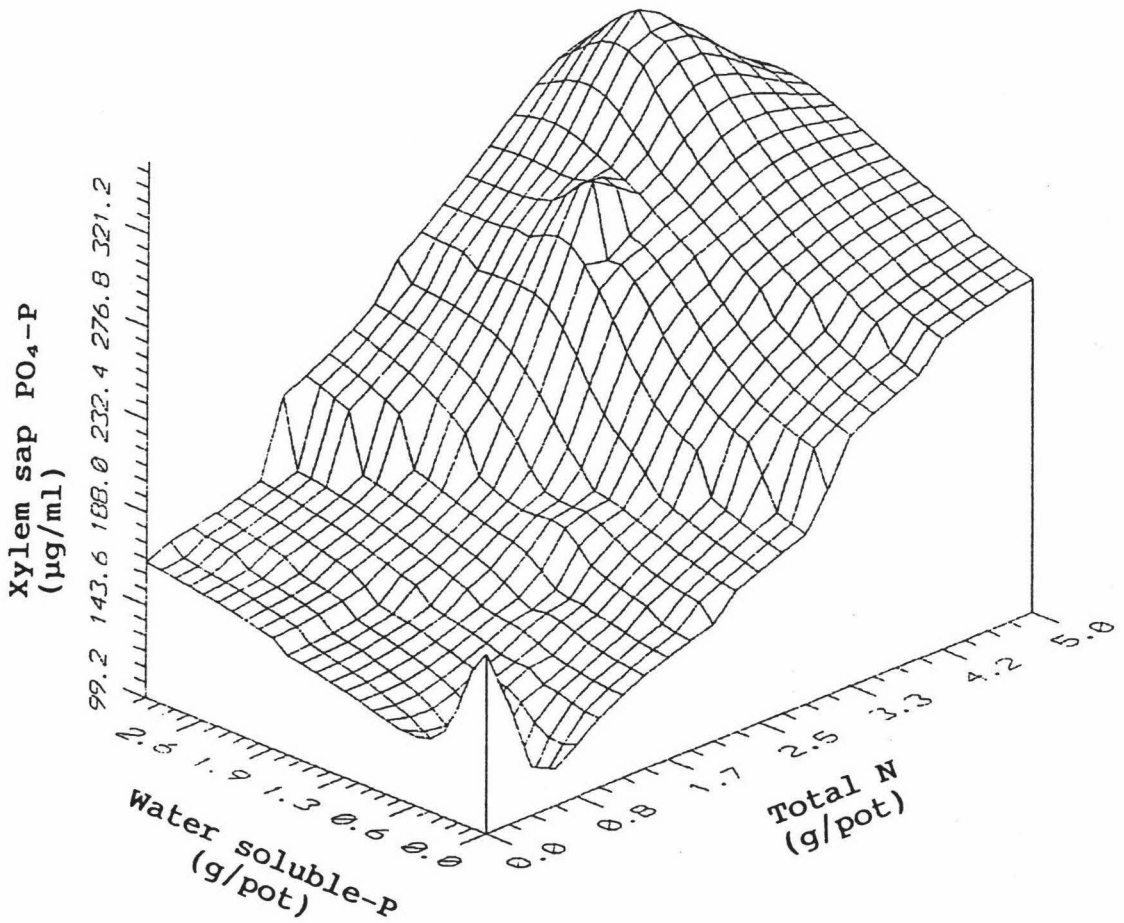

Figure 5.4 The effect of N/P fertilizer form as Urea/PAPR on P concentration in xylem sap of cabbages.

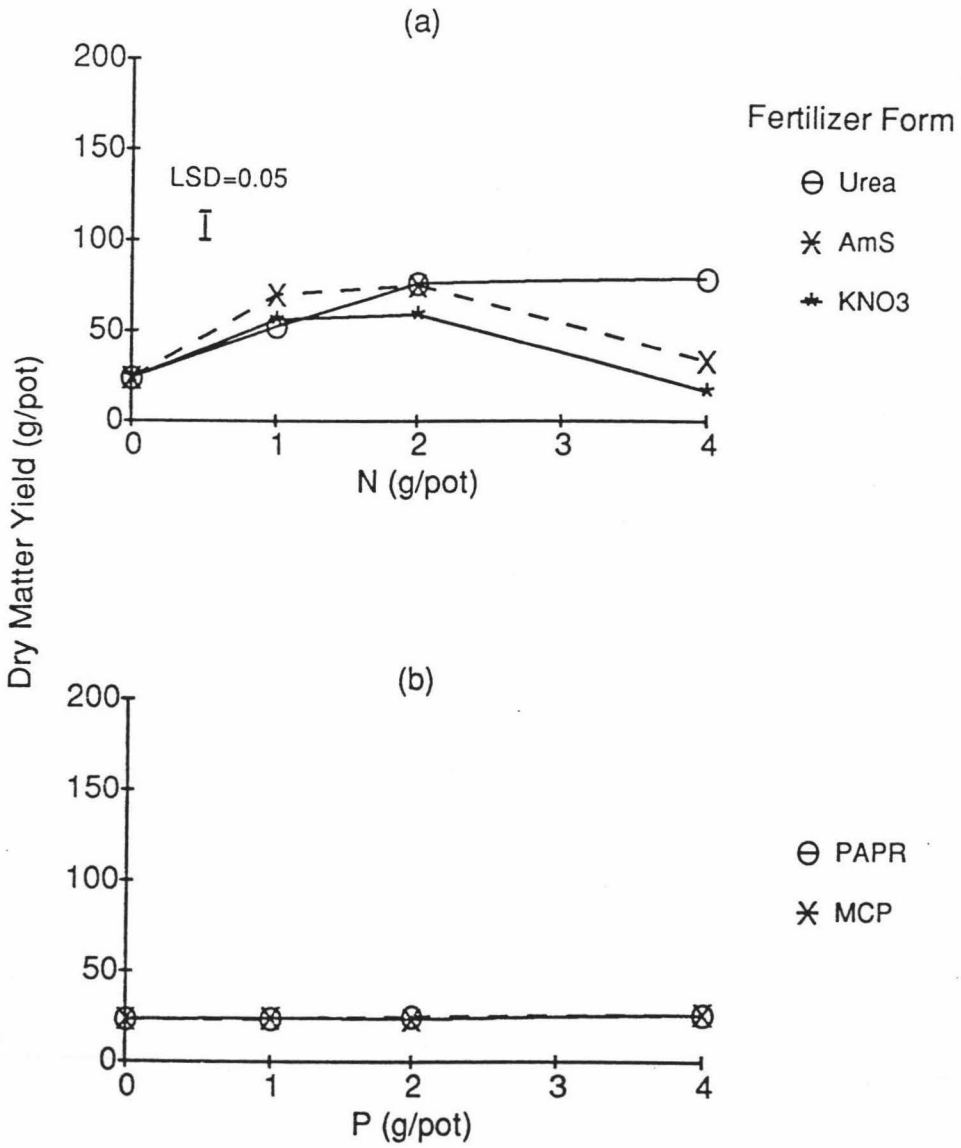

Figure 5.5 The effect of (a) straight N and (b) straight P fertilizer forms on dry matter yield of cabbages.

Regardless of N/P fertilizer form, the N component exhibited a highly significant linear and nonlinear effect on dry matter yield while P (irrespective of P availability index) had no effect as illustrated in Figure 5.6 using Urea/P data. This means that the dry matter yield differences from the different N/P fertilizer products were mainly due to variations in N rather than P supply. This supports the earlier findings of Greenwood et al., (1980a) and Alt (1987) that applications of P fertilizers do not appreciably increase yield of *Cruciferae* crops including winter cabbages.

At final harvest, on the Urea/P (Figure 5.7a) and KNO_3/P (Figure 5.7b) treatments, plant dry matter yield increased as application rate increased to 4 g/pot N/P, which gave 180 g DMY pot^{-1}. No further increases or a slight depression in yield occurred at the higher rate (5 g/pot N/P). For AmS/P plants (Figure 5.7c) maximum yield (110 g DMY pot^{-1}) was achieved at 2 g/pot N/P, rates above this caused yield reductions (15-30 g DMY pot^{-1}). Reasons for these yield reductions are explained later (see sections 5.4.1.7 to 5.4.1.9).

At a given rate of N/P application, the dry matter yield of cabbages at final harvest fertilised with either N/PAPR or N/MCP did not differ significantly. Excluding AmS/P treatments, where there was a depression in yield, the average maximum dry matter yield with N/PAPR treatments was 174 g DMY pot^{-1} while N/MCP treatments was 164 g DMY pot^{-1}. On this evidence these two N/P products appear to be equally effective N and P sources for cabbage nutrition. It must be emphasized though that the short-term nature of the glasshouse trial could not take into account the longer-term residual value of the N/PAPR products. Thus, the overall agronomic effectiveness of N/PAPR products cannot be fully assessed under glasshouse conditions.

Comparison among N/P products indicates that AmS/PAPR and AmS/MCP are as effective as Urea/PAPR, Urea/MCP, KNO_3/PAPR and KNO_3/MCP at lower rates (1 and 2 g/pot N/P) but are inferior at higher rates (4 g N/P pot^{-1}). Irrespective of N/P fertilizer form, plant dry matter yield at early growth (40 DAT) were severely reduced with the higher rates of

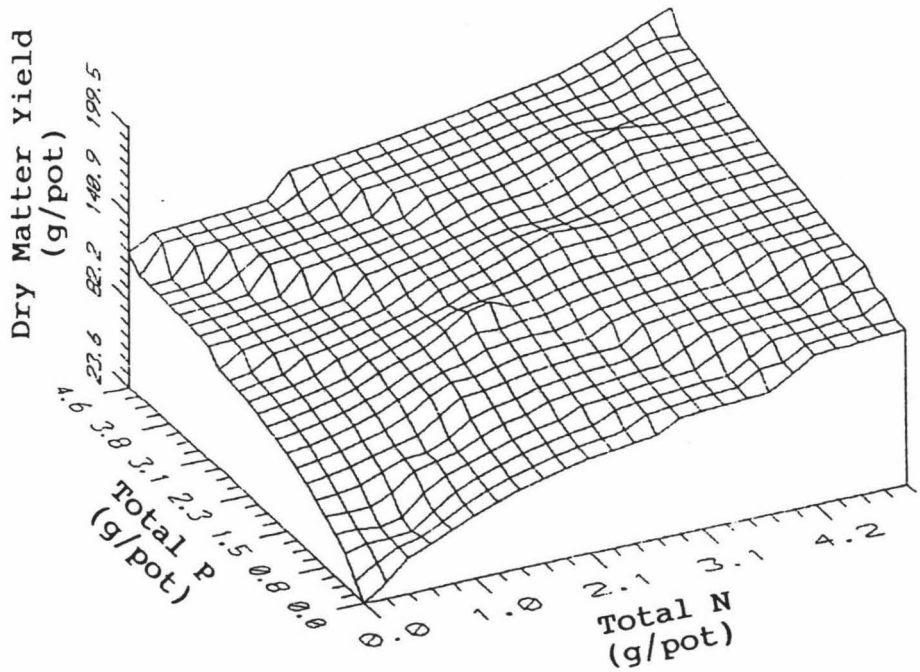

Figure 5.6 The effect of N/P fertilizer form as Urea/PAPR on dry matter yield of cabbages.

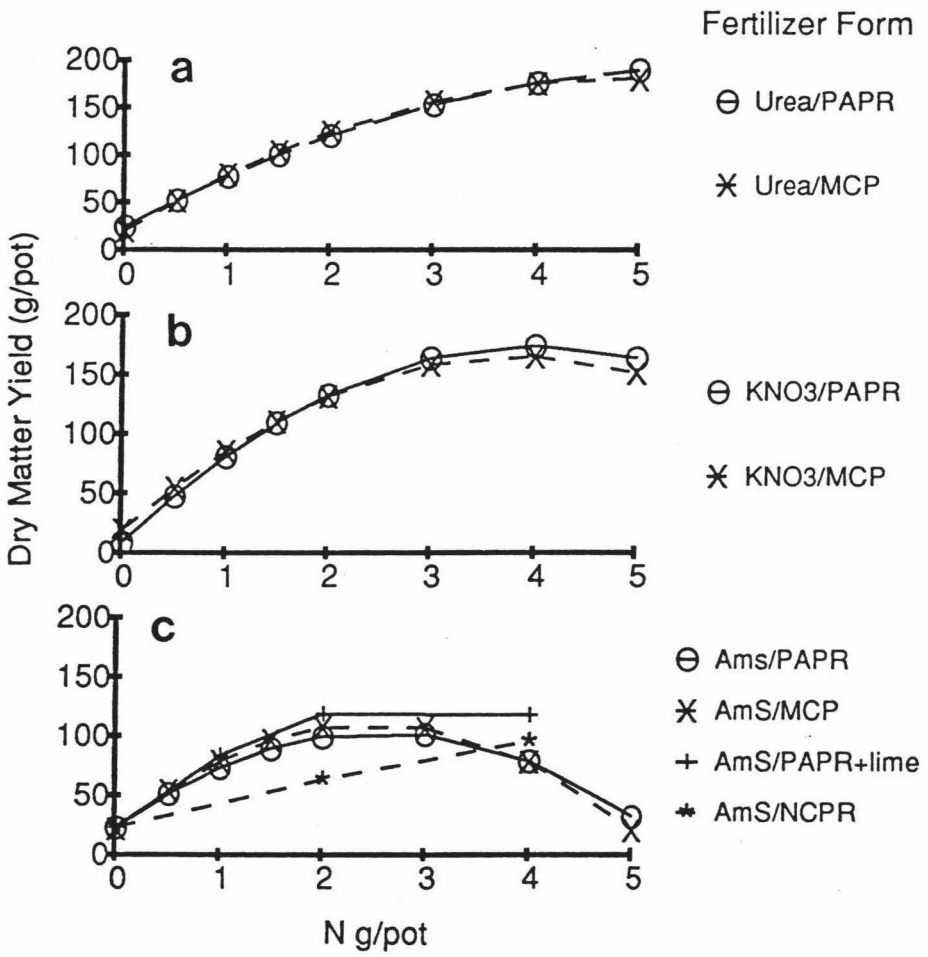

Figure 5.7 The effect of N/PAPR and N/MCP fertilizer forms on dry matter yield of cabbages. Rates of P application are given in Table 5.5.

application (Table 5.6). At mid-growth (60 DAT), this yield reduction was still evident on all treatments. While all the plants fertilized with 2 and 4 g N/P pot^{-1} generally had an initial "set back" in their growth only the AmS/P plants were unable to recover physiologically towards crop maturity. The lowest yields were recorded for this treatment.

5.4.1.7 *The effect of N fertilizer form on soil pH*

The reduced dry matter yield of AmS/P plants at final harvest was probably mediated through changing rhizosphere pH. At final harvest, soils fertilised with AmS/PAPR and AmS/MCP had the greatest reductions in soil pH (pH range = 3.9-4.2; Table 5.7) suggesting that intense soil acidity was probably a factor in the reduction of yields. The pH values are outside the optimum pH range (5.8-6.8) for cabbage growth as suggested by MAF (1984). The drop in pH was most likely caused by nitrification or through proton excretion from the plant roots as a consequence of cation uptake exceeding anion uptake under NH_4+ nutrition regime (Barker and Mills, 1980). Addition of lime (3 g $CaCO_3$ pot^{-1}) to the AmS/PAPR treatment tended to increase yield particularly at the higher rates of N addition, and this was accompanied by a rise in soil pH. This suggests that AmS/P can become effective fertilizer provided enough lime is added to counteract the potentially acidifying effect of NH_4-N fertilizers.

5.4.1.8 *Extractable NH_4^+ levels in the soil*

Ammonium toxicity symptoms (Figure 5.8) such as stunted, dark green and distorted plants with wrinkled edges on old leaves were exhibited by cabbages fertilized with AmS/PAPR and AmS/MCP at the 4 and 5 g/pot N/P application rates. This may have resulted due to high levels of residual NH_4^+ at any harvest (Table 5.8) as a consequence of the low pH conditions in the soils. Under low pH, the activity of nitrifiers is reduced (Barker and Mills, 1980) thus rhizosphere tends to accumulate toxic NH_4-N levels if NH_4^+ containing fertilizers are used. Under this condition

Table 5.6 Effect of fertilizer forms (N/P) on dry matter yield (g/pot) of cabbages.

Form	g N/P pot^{-1}	Time of sampling (DAT) 40	60	160
Control		2.8	6.8	23.6
Urea/PAPRR	1.0	5.1	14.3	77.9
	2.0	3.3	11.0	140.1
	4.0	0.8	2.8	165.5
Urea/MCP	1.0	4.6	14.9	78.7
	2.0	3.6	12.4	114.7
	4.0	0.6	2.4	172.9
AmS/PAPR	1.0	4.5	11.4	76.1
	2.0	2.5	8.4	108.4
	4.0	1.5	1.9	69.8
AmS/MCP	1.0	4.8	13.2	77.9
	2.0	2.2	9.8	100.4
	4.0	0.9	5.5	96.0
KNO_3/PAPR	1.0	2.7	11.3	72.6
	2.0	4.4	8.4	126.6
	4.0	0.5	3.5	181.5
KNO_3/MCP	1.0	2.4	11.1	72.6
	2.0	2.5	9.8	131.7
	4.0	2.4	0.4	155.2
Ams/NCPR	2.0	1.8	ND	64.1
	4.0	2.4	ND	96.5
AmS/PAPR	1.0	ND	ND	91.9
(+lime)[a]	2.0	ND	ND	114.0
	4.0	ND	ND	119.5
$LSD_{.05}$		2.3	4.7	20.0

[a]Lime added = 3.0 g $CaCO_3$/pot
ND = not determined

Table 5.7 Soil pH at each harvest.

Form	g N/P pot^{-1}	Time of sampling (DAT) 40	60	160
Control		4.9	5.2	5.1
Urea/PAPR	1.0	4.6	4.9	4.5
	2.0	5.6	5.1	4.6
	4.0	6.6	5.9	5.2
Urea/MCP	1.0	5.2	5.3	4.8
	2.0	5.5	5.3	4.8
	4.0	6.7	5.9	5.4
AmS/PAPR	1.0	4.6	4.5	4.2
	2.0	4.8	4.8	4.0
	4.0	5.0	5.1	4.1
AmS/MCP	1.0	4.7	4.5	4.1
	2.0	4.9	4.7	3.9
	4.0	5.3	5.1	4.0
KNO_3/PAPR	1.0	4.9	5.6	5.1
	2.0	5.0	5.4	5.2
	4.0	5.0	5.2	6.3
KNO_3/MCP	1.0	5.3	5.7	5.5
	2.0	5.5	5.8	5.9
	4.0	5.7	5.8	6.9
Ams/NCPR	2.0	5.0	ND	4.2
	4.0	5.4	ND	4.2
AmS/PAPR	1.0	ND	ND	4.2
(+lime)	2.0	ND	ND	4.2
	4.0	ND	ND	4.7
$LSD_{.05}$		0.4	0.2	0.3

ND = not determined

Table 5.8 Extractable NH_4-N levels ($\mu g/g$) in the soils and %N concentrations in plants after each harvest.

Form	g N/P pot^{-1}	Time of sampling (DAT) 40	60	160
Control		31 (4.8)[a]	27 (4.0)	8 (1.3)
Urea/PAPR	1.0	60 (5.9)	43 (5.2)	7 (1.5)
	2.0	260 (7.0)	113 (5.6)	9 (1.4)
	4.0	816(10.2)	567 (7.1)	12 (2.3)
Urea/MCP	1.0	73 (6.0)	47 (5.2)	10 (1.5)
	2.0	203 (6.6)	90 (5.4)	12 (1.7)
	4.0	763(10.4)	487 (7.2)	14 (2.1)
AmS/PAPR	1.0	267 (6.6)	153 (5.3)	11 (1.6)
	2.0	657 (9.6)	560 (6.1)	19 (2.2)
	4.0	1300 (8.2)	1147 (7.6)	358 (5.0)
AmS/MCP	1.0	261 (6.4)	123 (5.5)	13 (1.6)
	2.0	580 (7.6)	437 (5.9)	15 (2.0)
	4.0	1210 (6.5)	964 (7.2)	328 (6.0)
KNO_3/PAPR	1.0	43 (5.6)	47 (5.0)	13 (1.6)
	2.0	43 (5.2)	47 (5.0)	4 (1.7)
	4.0	53 (5.0)	50 (5.1)	8 (2.0)
KNO_3/MCP	1.0	34 (5.2)	47 (5.0)	7 (1.5)
	2.0	40 (5.4)	43 (5.1)	7 (1.8)
	4.0	79 (4.8)	59 (3.3)	15 (2.9)
AmS/NCPR	2.0	969 (7.4)	ND	10 (2.1)
	4.0	943 (8.8)	ND	41 (3.8)
AmS/PAPR	1.0	ND	ND	11 (1.6)
(+lime)	2.0	ND	ND	18 (2.1)
	4.0	ND	ND	100 (3.7)
$LSD_{.05}$		87 (0.5)	69 (0.4)	165 (0.2)

[a]%N concentrations are given in parentheses
ND = not determined

Figure 5.8 The symptoms of NH_4^+ toxicity exhibited by cabbage plants fertilised with AmS/PAPR at 4 and 5 g N/P per pot application rate.

accumulation of toxic concentrations of NH_4^+ in plants is possible as seen in Table 5.8. Amongst the plants, those fertilized with AmS/P at a higher rate (4 N/P g pot^{-1}) had N concentrations (5-6%) well above the critical N concentrations (3.0-3.7%) for cabbages at harvest (Piggott, 1986). Thus, N concentrations in these plants can be regarded to be within the toxic range. Shelp (1987a) also found that NH_4^+ fed broccoli plants grown in vermiculite in comparison to NO_3^- grown plants were stunted and exhibited signs of marginal necrosis on the old leaves, accompanied by an accumulation of NH_4^+.

5.4.1.9 *Soluble salt concentration in soil extracts*

High salt concentrations in the soils can result in reduced growth and yield of almost all crops under glass (Sonneveld and Van den Ende, 1975). As shown in Table 5.9, soluble salt contents in soils at 40 DAT measured from 2000 to 3000 μmhos cm^{-1} which according to Winsor et al., (1963) may be enough to restrict early growth of sensitive crops. In this study, yield was reduced to 80% or more of the maximum yield when specific conductance of soils was >2000 μmhos cm^{-1} regardless of N/P fertilizer forms (Figure 5.9).

High salt levels in soils have been found to affect the balance between root and foliage growth (Metivier and Dale, 1977) and the partitioning of assimilate between root and shoot (Boote, 1976) of some vegetable crops. In this study, plants fertilized with AmS/PAPR and AmS/MCP were visually assessed to have less extensive root system than the other fertilized plants.

5.4.2 Field Experiment

In comparison to the standard Urea/MCP fertilizer, Urea/PAPR appears to be an effective carrier of plant available N and P for cabbages under glass (Figure 5.7a). A field trial (details in 5.3.3) was conducted to further

Table 5.9 Conductivity of saturated soil extracts (μmhos/cm) at 40 DAT.

Form	g N/P/pot		
	1.0	2.0	4.0
Control (486)			
Urea/PAPR	756	1104	2002
Urea/MCP	651	1011	1731
AmS/PAPR	949	1497	2177
AmS/MCP	952	1438	1979
KNO_3/PAPR	1072	1550	1636
KNO_3/MCP	1268	1816	2934

$LSD_{.05}$ = 282

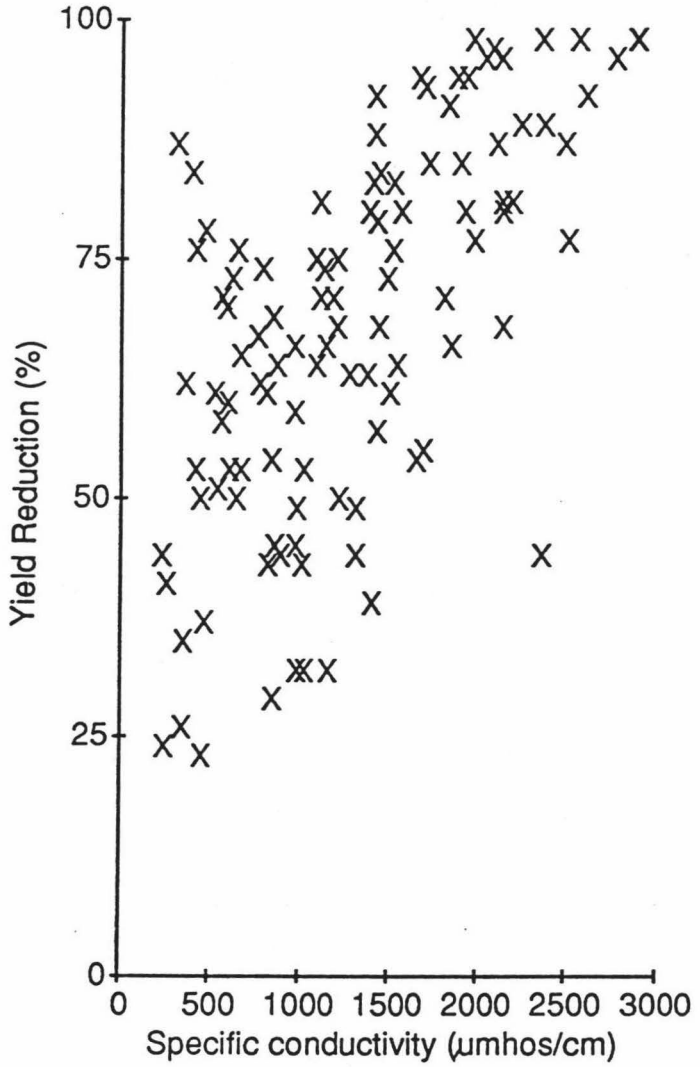

Figure 5.9 The relationship between specific conductivity and percent yield reduction of cabbages at 40 DAT.

assess the agronomic effectiveness of this N/P product under field conditions. Details of other data recorded in this trial are discussed in Chapter 6.

5.4.2.1 *Yield, N/P concentrations and N/P uptake*

The yield responses of cabbages at different sampling dates to applied N/P as Urea/PAPR, Urea/Super and CAN/Super are summarised in Table 5.10. At the lower rate (100 kg N/ha) of N application, both dry matter yield and fresh head yield at final harvest did not differ among N/P fertilizer products. Increasing the rate (200 kg N/ha) of N application resulted in higher fresh head yields on Urea/Super and CAN/Super treatments but not on the Urea/PAPR treatment. At the higher rate of N application (200 kg N/ha), CAN/Super (42 t/ha) and Urea/Super (39 t/ha) treatments outyielded the Urea/PAPR (23 t/ha) and the control (7.5 t/ha) treatments. This result reflects the effect of fertilizer rate rather than a fertilizer form effect.

At the lower rate of N application (100 kg N/ha), the N and P concentrations and uptake by the fertilised plants at final harvest, regardless of N/P fertilizer sources, were similar but higher than the control treatment (Table 5.11). Increasing the rate of N application (200 kg N/ha) tended to increase the N and P concentrations and uptake by the Urea/Super and CAN/Super treated plants. However, no increases were measured on the Urea/PAPR treated plants. The N concentrations in all plants except on the Urea/Super treatment were below the critical level (2.9%) while all the plants had P concentrations below the critical level (0.60%) reported by Piggott (1986) at final harvest.

The lower fresh head yield of Urea/PAPR treated plants than the other treated plants at the higher N rate (200 kg N/ha) could be explained on the basis of the slower growth rate of the plants at early stages of growth (60-80 DAT). Since crop growth rate is partly dependent upon the nutrient uptake per unit length of root (Mengel and Barber, 1974) which in turn depends upon the nutrient concentrations in the external solution, then, it

Table 5.10 The effect of fertilizer form on dry matter yield and fresh head yield (g/plant) of cabbages.

Form	kg N:P/ha	Time of sampling (DAT) 60	80	100	130	150	Fresh head yield (g)
Control		3.6	4.2	15.4	39.0	103.9	300 ± 38
Urea/PAPR	100:100	9.5	16.7	37.6	73.2	145.4	870 ± 124
Urea/Super	100:100	8.6	18.4	38.5	69.2	156.4	1005 ± 310
CAN/Super	100:100	9.1	17.7	40.5	78.0	163.5	1192 ± 185
Urea/PAPR	200:100	8.4	16.7	36.1	83.9	161.8	924 ± 64
Urea/Super	200:100	10.7	23.4	46.8	94.2	171.2	1551 ± 75
CAN/Super	200:100	11.4	23.3	55.2	118.4	210.5	1682 ± 208
$LSD_{.05}$		3.9	6.2	14.3	25.3	31.7	378
CV(%)		25.4	20.3	20.8	17.9	11.2	19

Table 5.11 N and P concentrations(%) and N and P uptake (g/plant) by cabbages at final harvest.

Form	kg N:P/ha	%N	N uptake	%P	P uptake
Control		1.6	1.8704	0.37	0.3830
Urea/PAPR	100:100	2.3	3.3442	0.41	0.6545
Urea/Super	100:100	2.4	3.9220	0.46	0.7318
CAN/Super	100:100	2.4	3.9120	0.46	0.7567
Urea/PAPR	200:100	2.3	3.8030	0.45	0.6688
Urea/Super	200:100	3.0	5.0630	0.58	1.0038
CAN/Super	200:100	2.7	5.7630	0.50	1.0597
$LSD_{.05}$		0.9	1.7322	0.11	0.2394

was possible that N and P were more limiting from Urea/PAPR than from the other 2 treatments at an early stage. The limited availability of N and P probably resulted in an early set-back which according to Burns (1987) would depress final crop yields. This is particularly true for P since the effect of this nutrient on cabbage head yield is critical at the early stage of growth (Hara and Sonoda, 1979).

The percent plant recoveries for fertilizer N and P from Urea/PAPR (Table 5.11) were also much lower than for the other N/P fertilizer forms. This could be another possible explanation for the lower fresh head yield on the Urea/PAPR treatment.

5.5 CONCLUSIONS

Results obtained in the glasshouse study indicate that N fertilizer form significantly influenced the concentrations of NO_3^- and NH_4-N but not PO_4-P in plant xylem sap. Nitrate-N concentrations were higher when N was applied in the NO_3-N fertilizer form while NH_4-N concentrations were higher when N was in the ammoniacal form. At a high rate of N/P application, NO_3^- and NH_4-N concentrations were higher when ammoniacal form of N was in combination with either the readily soluble P (MCP) or 50% soluble P (PAPR) than with slowly soluble P (NCPR). Thus, the form of N fertilizer (along with other factors reported in Chapter 4) is also an important factor affecting the concentrations of NO_3^- and NH_4-N in xylem sap of cabbages. Whether N fertilizer form effects petiole sap N and P levels is not known.

The above results suggest that there should be a separate calibration for form of N fertilizer in the determination of a critical sap NO_3-N concentration in xylem sap of cabbages. When high rates of the ammoniacal form of N (i.e., AmS) were applied to cabbages the final yields were severely reduced yet the sap NO_3-N concentrations were as high as in plants treated with the nitrate-N form of N (i.e., KNO_3) which achieved maximum yield. Thus, the critical sap NO_3-N concentration for

maximum yield may vary between the form of fertilizer N. In NH_4^+ fed cabbages significant N nutrition may be derived by NH_4^+ uptake which is not accounted for in the sap test. In this case high N uptake led to yield reductions whereas sap NO_3-N concentrations did not indicate that N nutrition was above the maximum level.

In terms of agronomic effectiveness under glasshouse conditions, N/PAPR and N/MCP products made with either urea or KNO_3, at equal rates of N application, are equally effective N and P sources for winter cabbages grown in a recent alluvial soil with low P retention capacity. Comparison among the different N/P products suggests that at higher application rates AmS/PAPR and AmS/MCP are the least efficient products in terms of all the parameters studied. The poorer performance of the plants fertilized with high rates of these N/P products can be attributed to initial high salt concentrations in the soils, intense soil acidification and accumulation of toxic levels of NH_4-N in the soils and plants.

In a limited evaluation in the field, Urea/PAPR was found not to be as agronomically effective N fertilizer as the readily soluble N fertilizer forms (Urea/Super and CAN/Super) as starter fertilizers for winter cabbages. This is in contradiction to earlier findings obtained in the glasshouse. Further assessment in the field is required to validate this result. Cabbage growth response to phosphate was negligible, under these circumstances P uptake from N/PAPR type fertilizers applied at 200 kg N/ha, was lower than P uptake from N/Super fertilizer. This lower N uptake rather than P uptake, however, appeared to be a significant factor in the lower yields obtained with PAPR type fertilizers.

CHAPTER 6

PREDICTING NITROGEN FERTILIZER REQUIREMENTS OF WINTER CABBAGES BY PLANT (SAP) AND SOIL TESTS

6.1 INTRODUCTION

Sap NO_3 measurements have been used successfully in the UK as a predictor of N requirement of several vegetable crops i.e., brussels sprouts, carrot, leek, lettuce, onion and spinach (Scaife and Turner, 1984) but cabbages were not included in the evaluation. Emphasis has been on the use of petiole sap measurements for assessing the requirement for sidedressing N in addition to assessing the adequacy of the initial N fertilizer application at seedling establishment.

The current general N fertilizer recommendation for winter grown cabbages in NZ is to apply 350 kg N ha^{-1} (MAF, 1986). Such recommendation is, however, very general and does not cater for differences in locations and soils. Fertilizer N recommendations would vary from field to field as a consequence of differences in the amounts of residual mineral N at planting time, variations in N mineralisation rate during the subsequent growing season and differences in weather conditions.

The majority of growers split this amount of N fertilizer into two dressings; half the N is applied as a base dressing at planting, along with phosphate and potassium, and half, just prior to heading, as a sidedressing. Split N applications offer the opportunity for growers to employ a diagnostic test during crop growth that can provide an objective measure to indicate whether additional N fertilizer is required to optimize production.

By monitoring the soil and plant N status early in the growth of cabbage it may be possible to adjust the time and amount of N used for the second dressing to provide optimum N supply to the plant. This strategy

may improve the efficiency of N fertilizer use as well as maximizing yields.

6.2 OBJECTIVE

The objective of this study was to assess the use of soil and plant (sap) tests for predicting the N fertilizer requirements of winter cabbages.

6.3 MATERIALS AND METHODS

To assess the utility of diagnostic tests for indicating the N fertilizer requirements of cabbages, a large field trial was used (Figure 6.1). The field experiment was conducted on a Karapoti fine sandy loam soil (coarse loamy mixed mesic Dystric Eutrochrept). Some characteristics of the soil are shown in Table 6.1.

Five different initial rates of calcium ammonium nitrate (CAN): 0 (N0); 100 (N1); 200 (N2); 300 (N3) and 400 (N4) kg N ha^{-1}; at transplanting and two levels of urea sidedressing (nil and 100 kg N ha^{-1}) were the main fertilizer treatments. Time of sidedressing (90 DAT) was planned on the basis of the physical appearance of the plants i.e., when they started to develop an aggregate of folded leaves (wrapper leaves). Sidedressing was carried out by broadcasting the fertilizer over the whole plot area.

Winter cabbages "Autumn pride" variety were transplanted in the field on 4 May 1988. Each fertilizer treatment was replicated 3 times using plots containing 30 plants with 50 x 80 cm spacing between plants. This spacing is a reflection of the average given by MAF (1984) for NZ conditions.

The plants were sampled sequentially from the middle rows of each plot at the following days after transplanting(DAT)- 50, 60, 80, 90, 100, 130 and 150 (days correspond to the various stages of cabbage growth). At 50 and 60 DAT, two plants per plot were sampled and then one plant per plot was

Figure 6.1 General view of the field experiment.

Table 6.1 Some initial properties of Karapoti fine sandy loam topsoil used in the field experiment.

		Reference (Measurement technique)
pH (water)	6.5	Blakemore et al., (1987)
0.5M $NaHCO_3$-soluble P	53 $\mu g/g$	Olsen et al., (1954)
NH_4OAc extractable K	1.16 me/100 g	Blakemore et al., (1987)
2M KCl extractable $NO_3^- + NH_4^+$-N	14 $\mu g/g$	Bremner (1965b)

taken at the successive dates. Fresh and dry weight yields of cabbages were recorded.

6.3.1 Sap Sampling Techniques

Sampling techniques for petiole and xylem sap collection at each sampling date were given in Chapter 3 (3.3.5.1 and 3.3.5.2).

To suppress microbial activity, the plant sap samples were diluted with 0.1M HCl before NO_3-N and NH_4-N concentrations were determined as described in Chapter 3.

For the purposes of assessing the immediate effect of sidedressing urea on petiole sap NO_3-N concentrations, sap samples were taken from guard row plants on a treatment where sidedressing would be likely to create a major effect on sap NO_3-N concentration i.e., plants initially fertilized with 100 kg N ha^{-1}.

6.3.2 Soil Measurements

Soils were collected from the field trial at the time of transplanting (4/5/88) then on the following DAT - 15, 20, 40, 50, 60, 80, 90, 100, 130 and 150. Soil samples were usually collected after the occurrence of heavy rain and/or close to the plant sampling dates in order to compare soil N and plant sap N concentrations.

At each sampling, three soil cores (0-60 cm) were taken randomly from within the fertilized area of each plot. Each core was cut into five sections (0-10, 10-20, 20-30, 30-45 and 45-60 cm) and the corresponding sections for the 3 cores taken at each sampling bulked for analysis.

The mineral N content of the soils was measured by breaking up the soil cores and extracting fresh subsamples by shaking for one hour with 2M

KCl solution (soil:solution ratio 1:10). The NH_4-N and NO_3-N concentrations in the extracts were measured as described in Chapter 3 (3.3.6).

6.3.3 N Depletion Zone Around the Roots of a Cabbage Plant

To assist in determining the effectiveness of the N fertilizer sidedressing to the whole plot, information on the N depletion zone around the roots of a cabbage plant is essential. To obtain such information, a concurrent trial which involved the collection of soils at different depths and distances from a cabbage plant (Figure 6.7) was done at 20 and 40 DAS. The distances of sampling were 0, 10, 20 and 40 cm away from the plant base. The depths of sampling were 0-10, 10-20 and 20-30 cm to account for the effective rooting depth of the crop. Soil samples were taken from plots with an initial dressing of 200 kg N ha^{-1}. Nitrate and NH_4-N concentrations in the soil samples were determined as described (6.3.2).

6.3.4 Meteorological Data

Records of daily rainfall and daily maximum and minimum temperature were obtained from the meteorological station at DSIR situated about 300 m from the experimental site.

6.4 RESULTS AND DISCUSSION

6.4.1 Meteorological Conditions

The total monthly rainfall during the 6-month experimental period relative to the average during that period for the previous 10 years is shown in Figure 6.2. In all months, a higher rainfall than average was received with July and September about 45% higher than average. Thus, the experiment is considered to have been conducted in a very wet year and

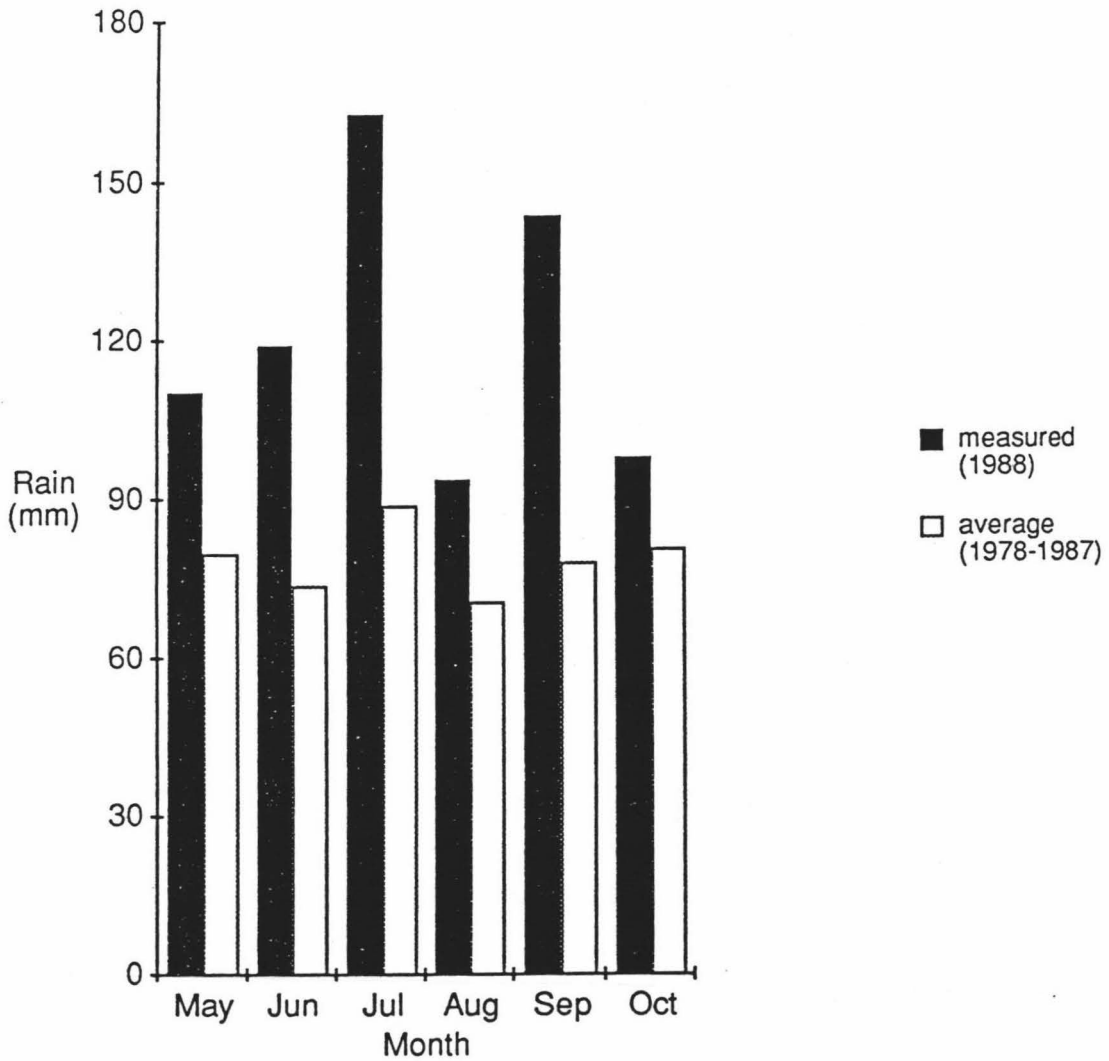

Figure 6.2 Total monthly rainfall during the conduct of the experiment relative to the 10-year average.

from the point of N leaching losses from the system, this situation could be considered almost the "worse case" scenario. From transplanting to final harvest time, total rainfall measured 673 mm and drainage (estimated from a water balance model similar to that of Scotter et al., 1979) was 448 mm.

As reported elsewhere (Scaife et al., 1972), the optimal rate of N application between growing seasons even on the same soil type may be expected to increase with increasing rainfall. Downward transport of NO_3^- is expected to be rapid under high rainfall conditions, thus, the efficiency of N fertilizer is reduced.

6.4.2 Effect of N Sidedressing on Xylem Sap NO_3-N

The effect of sidedressing N fertilizer on plant sap NO_3-N concentration will be mainly considered in this chapter as the effect of initial dressings of N on xylem and petiole sap NO_3-N concentrations with time of sampling (DAT) has been presented in Chapter 4 (see Figures 4.5a and 4.5b).

In all treatments, the NO_3-N concentrations in the xylem sap, 10 days after sidedressing (DAS), were significantly increased by N fertilizer sidedressing (Figure 6.3). Nitrate-N concentration in the N0 (0 kg N) treatment increased from 70 to 350 $\mu g\ ml^{-1}$; while the N4 (400 kg N) treatment had an increase of 240 to 450 $\mu g\ ml^{-1}$. At 130 and 150 DAT, plants that received N fertilizer sidedressing had higher xylem sap NO_3-N than those without sidedressing.

6.4.3 Effect of Sidedressing on Petiole Sap NO_3-N

Prior to N fertilizer sidedressing, NO_3-N concentrations in petiole sap of N0 and N2 (200 kg N) were very low (<20 $\mu g\ ml^{-1}$; Figure 6.4). Ten days after sidedressing, NO_3-N concentrations markedly increased up to 700 μg

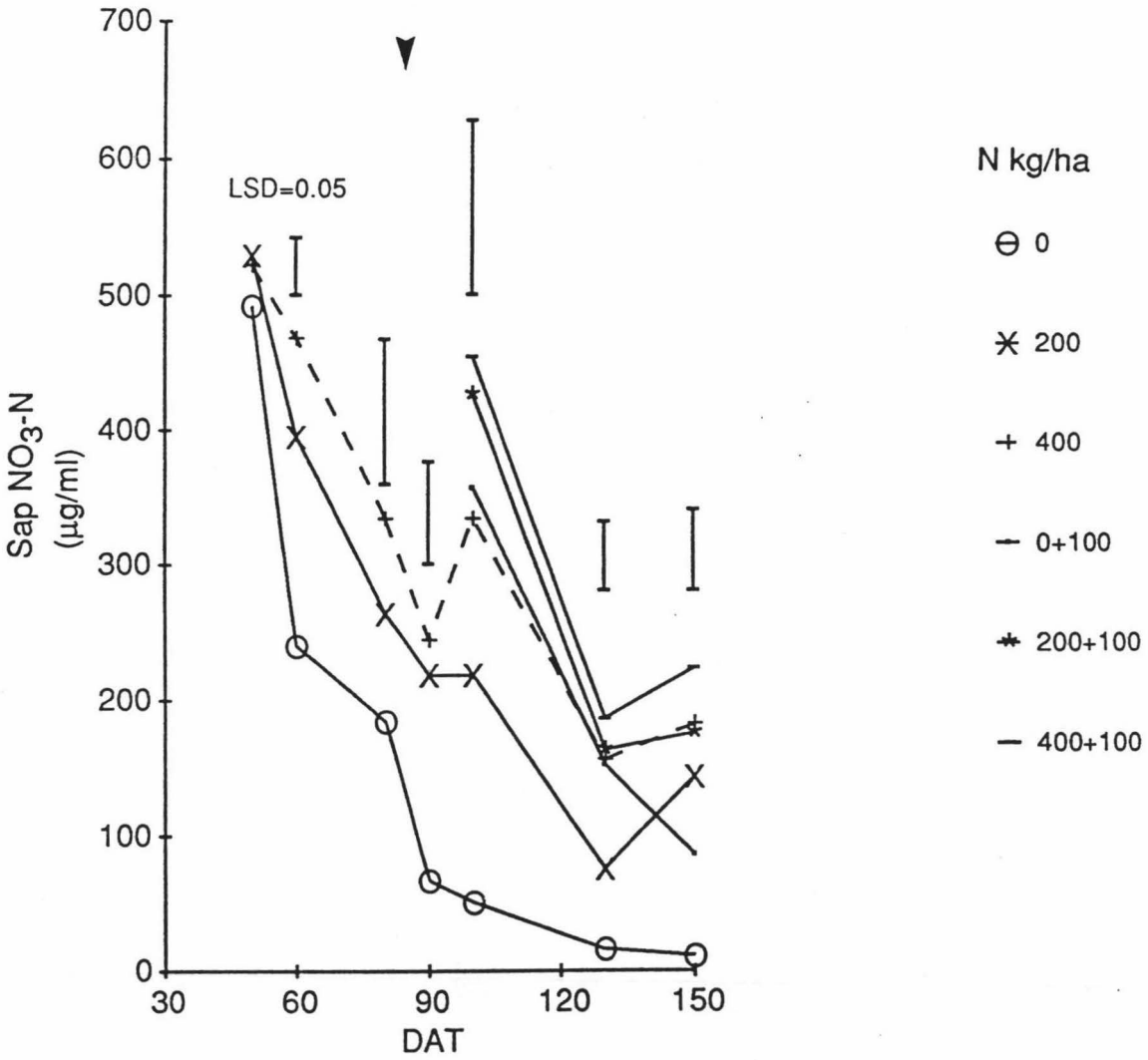

Figure 6.3 NO_3-N concentration in xylem sap of cabbages. (▼) indicates time of N fertilizer sidedressing.

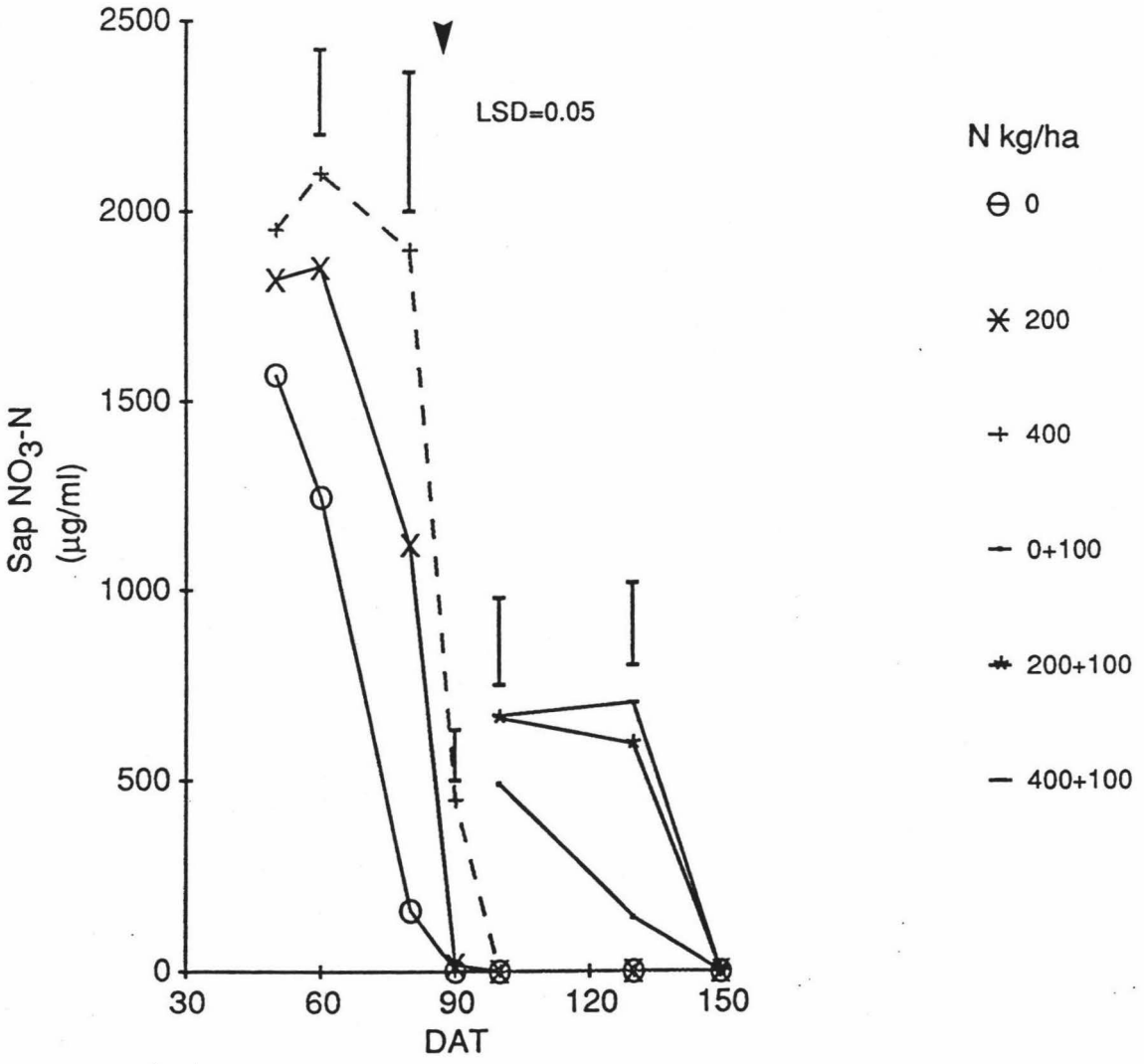

Figure 6.4 NO_3-N concentration in petiole sap of cabbages. (▼) indicates time of N fertilizer sidedressing.

ml^{-1}. The dramatic increases of NO_3-N concentrations in xylem or petiole sap after sidedressing illustrate their sensitivity to changes of N supply in the soil. At 130 DAT, NO_3-N concentration in petiole sap of N2 and N4 treatments were maintained above 600 μg ml^{-1} but these eventually declined as the other treatments did to nearly zero levels at 150 DAT.

Figure 6.5 illustrates the short term trend of NO_3 concentration in petiole sap after sidedressing. It can be seen that the NO_3-N concentrations markedly increased 7 DAS, from 100 to 500 μg ml^{-1}, with the concentration peaking at 10 DAS (650 μg ml^{-1}) and remaining at this level for only 3 days before dropping rapidly. In this study, treatment 200 kg N ha^{-1} (initial dressing) + 100 kg N ha^{-1} (sidedressing) gave similar maximum yield as with an initial application of 300 kg N ha^{-1} (Figure 6.12) suggesting that if 700 μg ml^{-1} NO_3-N concentration in petiole sap is reached after 10 days from sidedressing, then, maximum yield may be achieved. The increase in NO_3-N concentration at 7 DAS may have been caused by the light rain (about 20 mm) received at 5 DAS moving NO_3^- at the surface layer into a greater proportion of the root zone. The number of days from sidedressing to reach maximum sap NO_3-N levels, however, may vary and also the maximum level achieved may depend on the fate of urea in relation to weather conditions after application.

6.4.4 Soil NO_3^- and NH_4-N Concentrations

The concentrations of mineral (NO_3^- and NH_4^+)-N in the top 30-cm sampled depth (effective rooting depth for cabbages) for the selected treatments were significantly influenced by the initial N fertilizer rates (Figure 6.6a). The supply of N in the soil generally decreased with crop growth. This trend agrees closely with the decreasing concentration of NO_3-N in xylem (Figure 6.3) or petiole (Figure 6.4) sap with time. The levels of mineral N in the soils expectedly increased 10 DAS, thereafter, concentrations were as low as those in the non-sidedressed treatments.

Figure 6.6b shows that there was greater quantities of NO_3^- that have

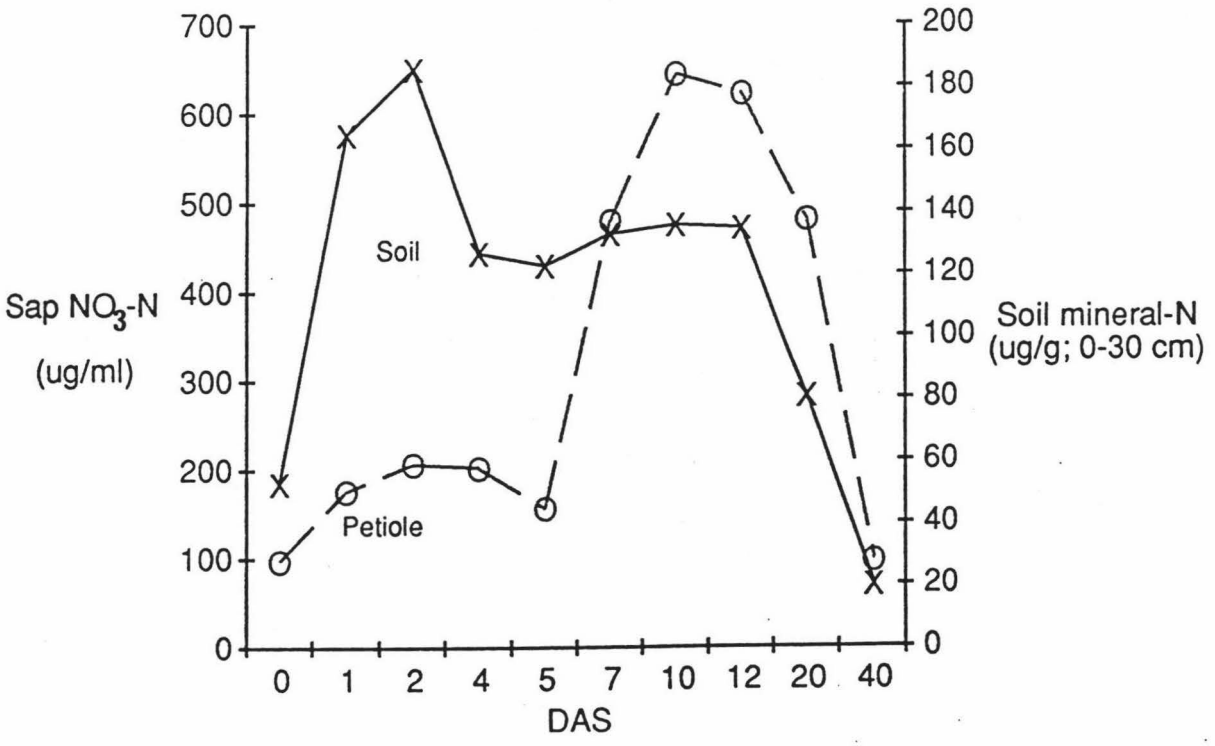

Figure 6.5 Petiole sap NO_3-N concentration in relation to soil N after N fertilizer sidedressing.

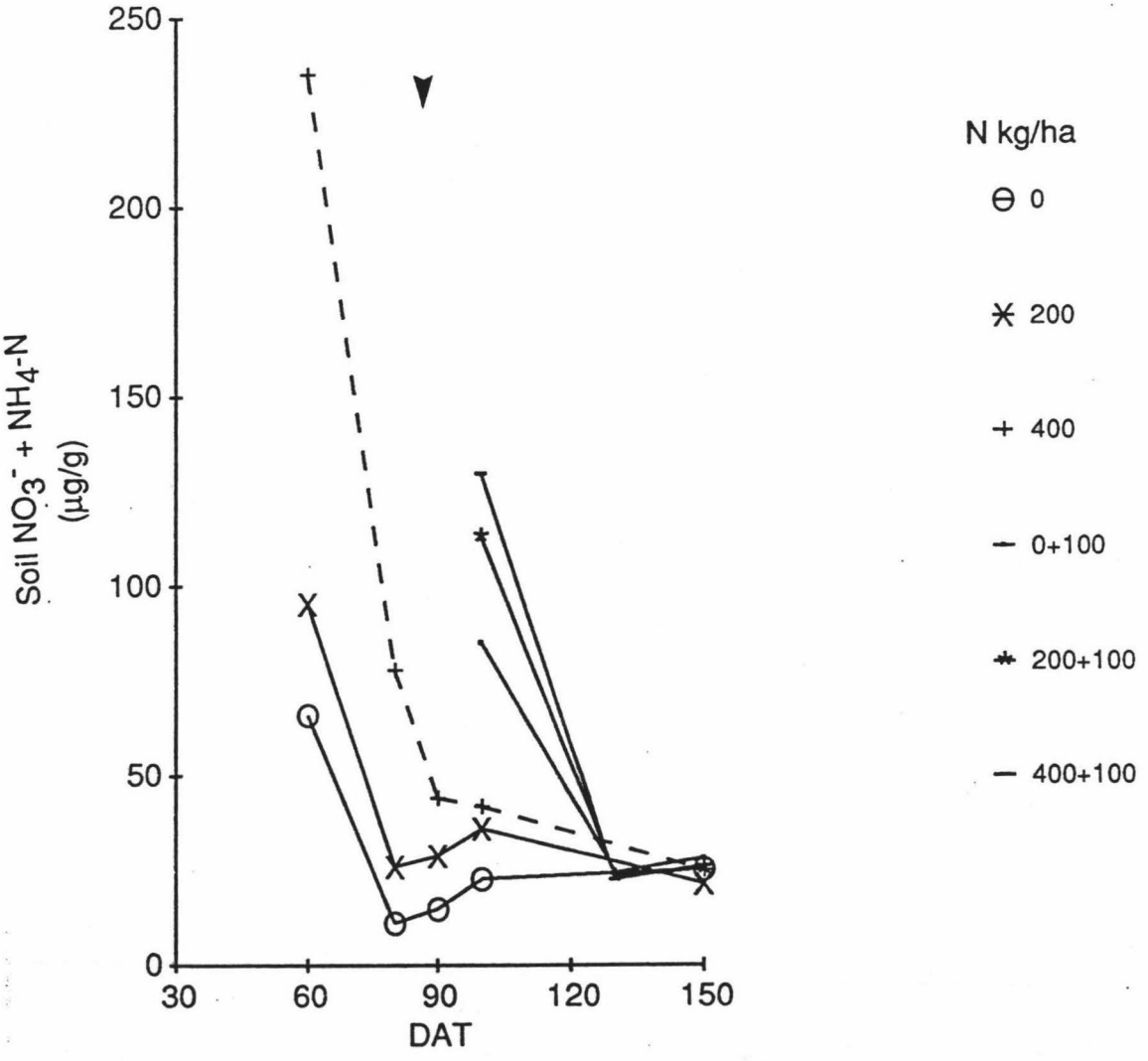

Figure 6.6a Soil NO_3^- + NH_4-N concentrations (0-30 cm depth) at each harvest. (▼) indicates time of N fertilizer sidedressing.

accumulated below 30 cm depth following N4 than N2 treatment. The difference is a reflection of higher fertilizer rates having the potential to leach greater amounts of NO_3^-; thus; the efficiency of fertilizer use at these rates is reduced (see Figure 6.14).

6.4.5 N Depletion Zone Around the Roots of a Cabbage Plant

At 20 DAS, the depletion zone of NO_3-N (Figure 6.7a) was at the distance of 0-20 cm away from the plant base at 10 cm depth. At this date, significant amounts of NO_3-N still remained at 40 cm distance at similar depth. At 40 DAS, the zone of NO_3-N depletion was no longer specific in distance and depth. In both samplings, the depletion zone for NH_4-N around the roots could not be clearly delineated (Figures 6.7b).

Although there were no other fertilizer placement methods considered in the study, the result of the work suggests that the efficiency of urea N fertilizer, as sidedressing, may be improved by applying the N fertilizer close to the root zone of the plant rather than broadcasting evenly over the surface. Where winter cabbages are widely spaced i.e., 80 cm x 50 cm (25000 plants ha^{-1}) N fertilizer, as sidedressing, can be surface broadcast along the planting rows to a distance of 20 cm away from the plant base.

6.4.6 Correlation of Soil and Sap Tests

At 4 sampling dates (50, 60, 80 and 90 DAT) and prior to sidedressing, the concentration of mineral N (NO_3^- + NH_4-N) in xylem and petiole sap were strongly correlated to extractable NO_3^- + NH_4-N in the soil to a depth of 30 cm (Figures 6.8a and 6.8b). The similar strong correlation between xylem and petiole sap NO_3-N concentrations with soil N levels contradicts the expected better correlation of xylem sap for reasons mentioned in Chapter 2 (section 2.2.2.3). Other workers have also found good relationships between soil mineral N and stem NO_3-N in winter wheat (Darby et al., 1986); in young corn stalks (Iversen et al., 1985) and in

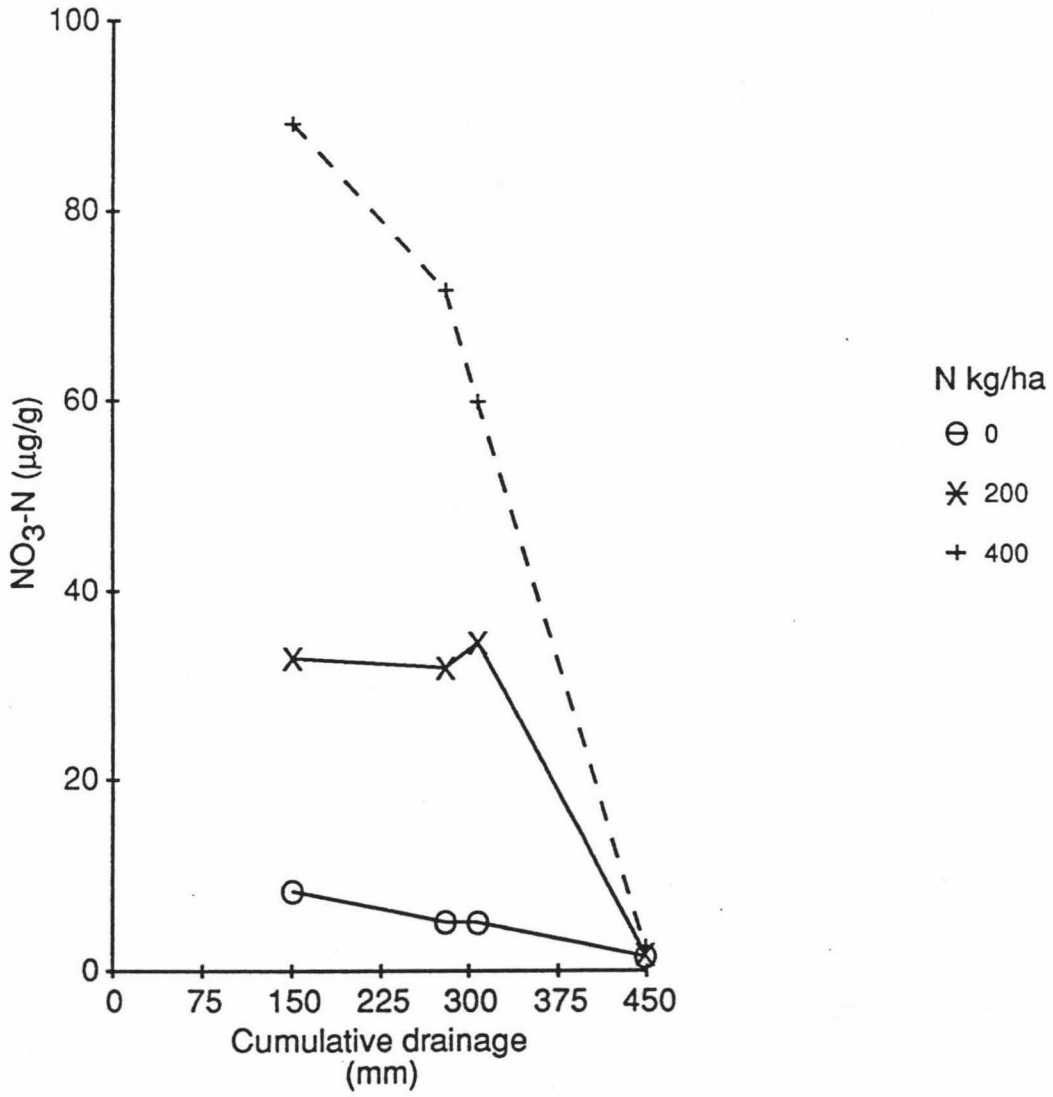

Figure 6.6b Soil NO_3-N concentrations (>30 cm depth) in relation to cumulative drainage.

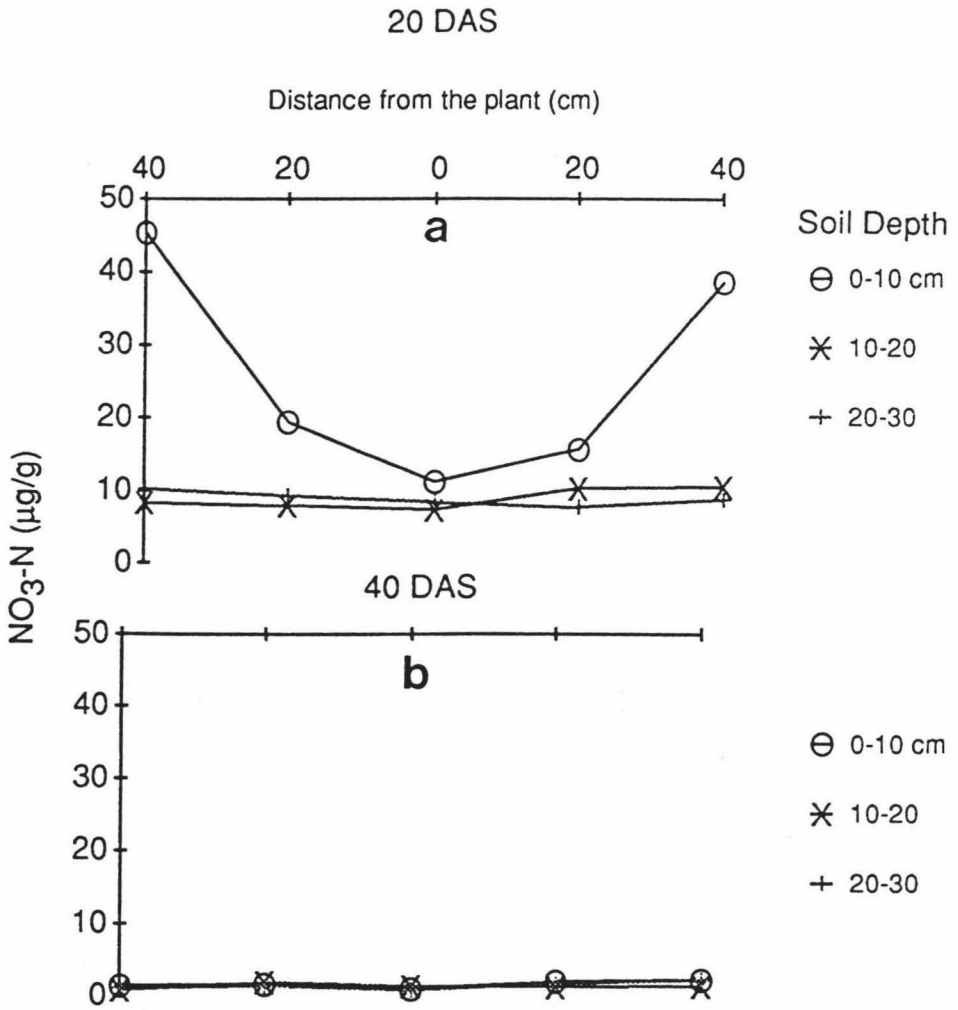

Figure 6.7a NO_3-N depletion zone around cabbage roots at (a) 20 and (b) 40 DAS.

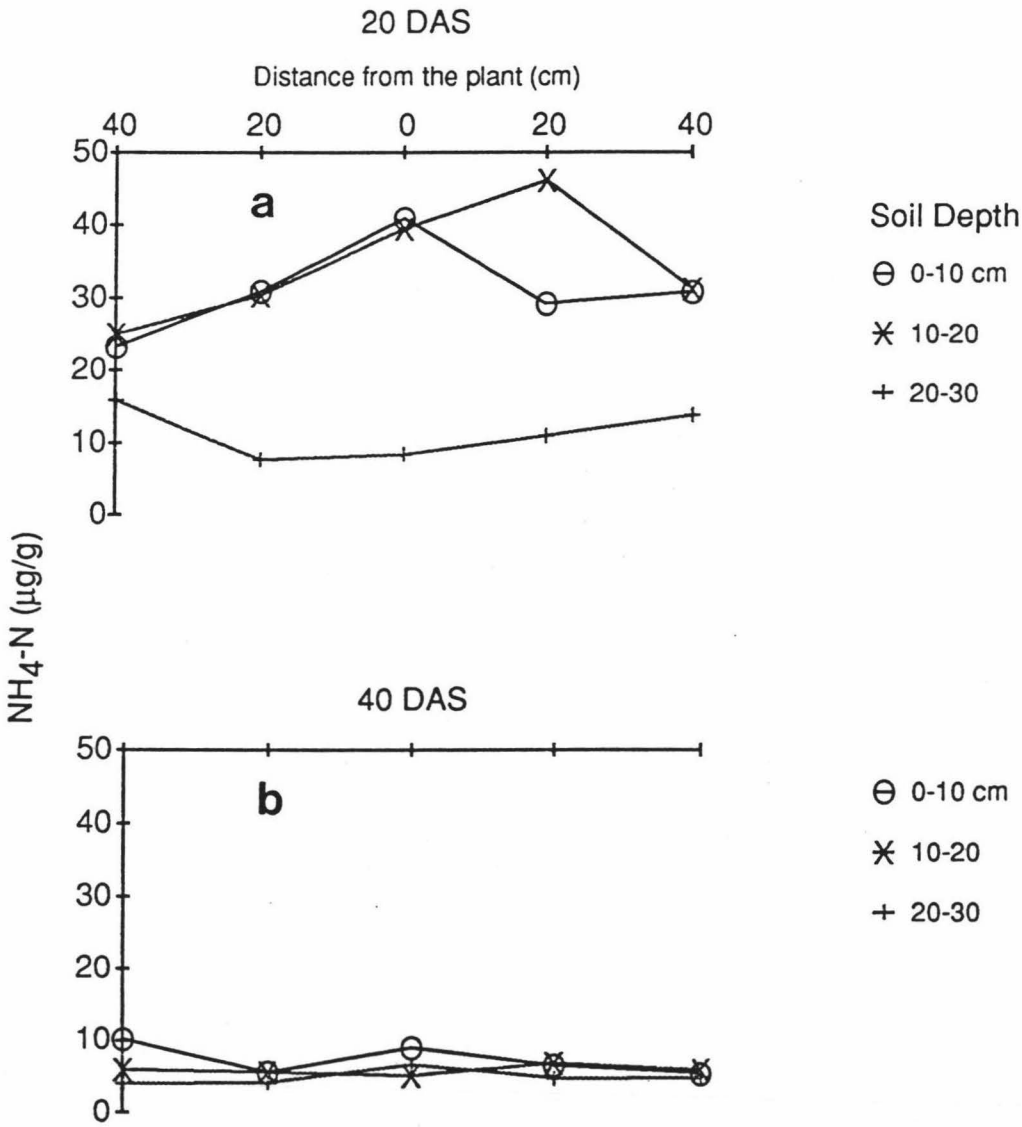

Figure 6.7b NH_4-N depletion zone around cabbage roots at (a) 20 and (b) 40 DAS.

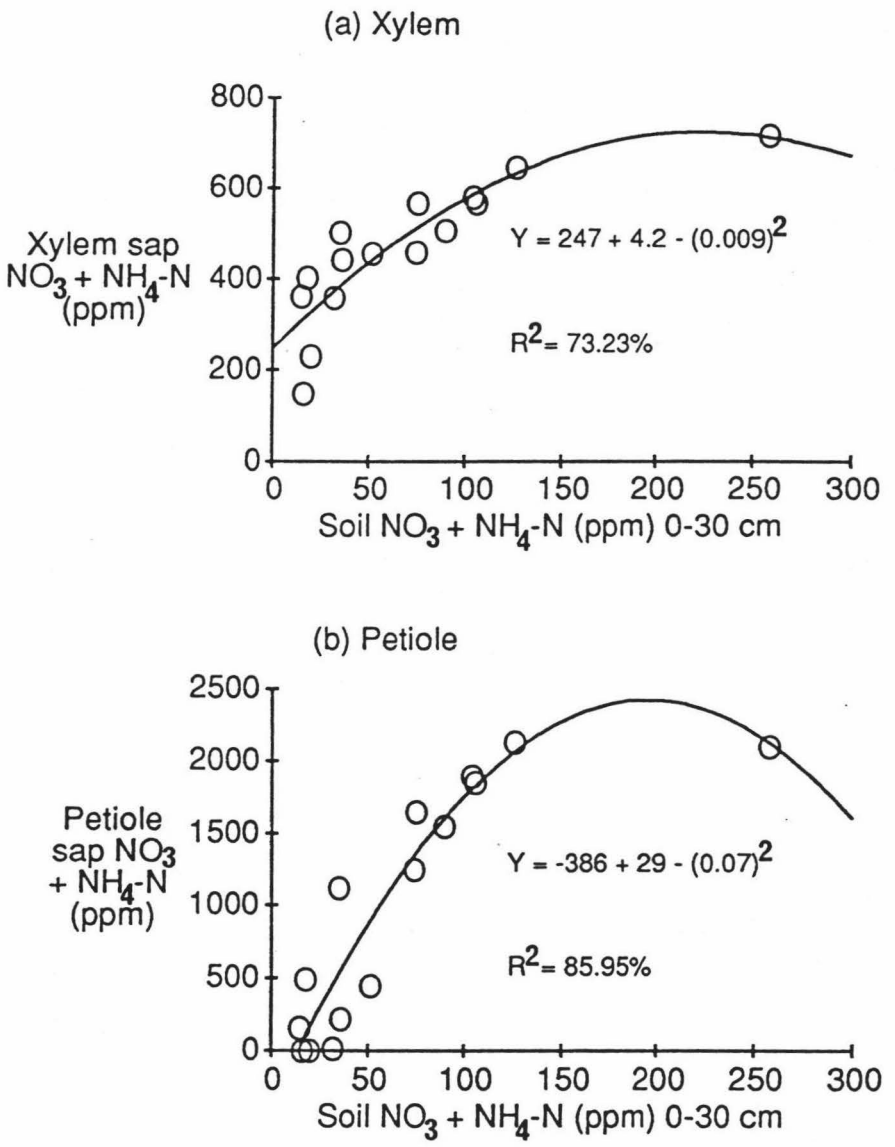

Figure 6.8 Correlation between soil and sap tests.

petioles of potatoes (Westermann and Kleinkopf, 1985) but xylem sap was not studied.

The result of the present study suggests that sap NO_3^- and NH_4-N can be used as indices of N supply in the soil at the time of sampling. During wet conditions, when soil sampling is not feasible, plant sap tests for cabbages could be used for diagnostic purposes when normally soil tests are used.

6.4.7 Relationship Between Sap N Concentration and Harvestable Fresh Head Yield

The relationships between sap NO_3^- and NH_4-N concentrations measured at each sampling and harvestable fresh head yield were examined for prognostic purposes. In most cases, the relationship was found to be curvilinear, and was adequately described by a quadratic equation.

Concentrations of NO_3-N in xylem sap at 60 and 80 DAT and in petiole sap at 50, 60 and 80 DAT were good predictors of harvestable fresh head yield (Figures 6.9a and 6.9b). The NH_4-N concentrations in sap samples at 50, 60 and 80 DAT and sap NO_3-N concentrations after 80 DAT were poor predictors of harvestable fresh head yield (not presented).

Petiole sap NO_3-N concentration measured at different sampling dates (each date corresponded to a specific stage of growth) by Merck strip test has also been successfully correlated with final yields of beans, carrots, celery, potato, rock melon, squash, sweet corn and tomato (Prasad and Spiers, 1984a); brussels sprouts, carrot, leek, lettuce, onion and spinach (Scaife and Turner, 1984) and tomatoes (Prasad and Spiers, 1985; Huett and Rose, 1988 and Coltman, 1988).

The results from this experiment suggest that the most suitable time for assessing the current N status of winter cabbages is any time during the cabbage-head development phases (60-80 DAT) because the differences in

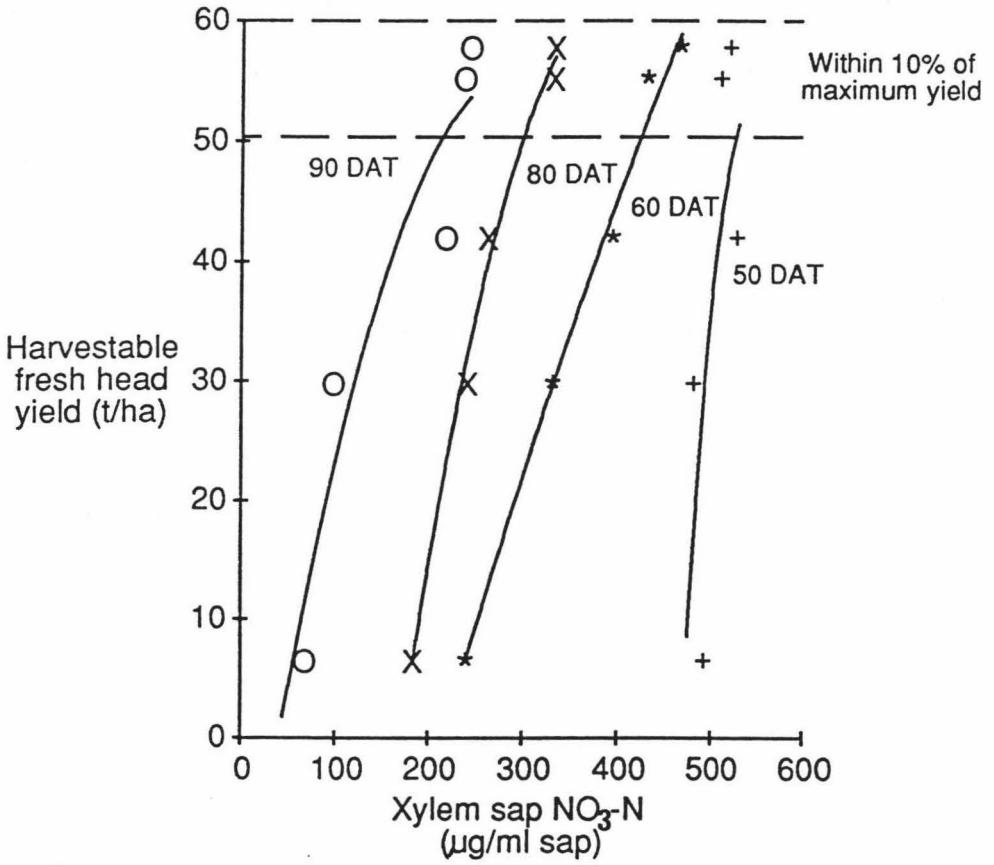

Figure 6.9a Harvestable fresh head yield vs. xylem sap NO_3-N measured at various sampling dates.

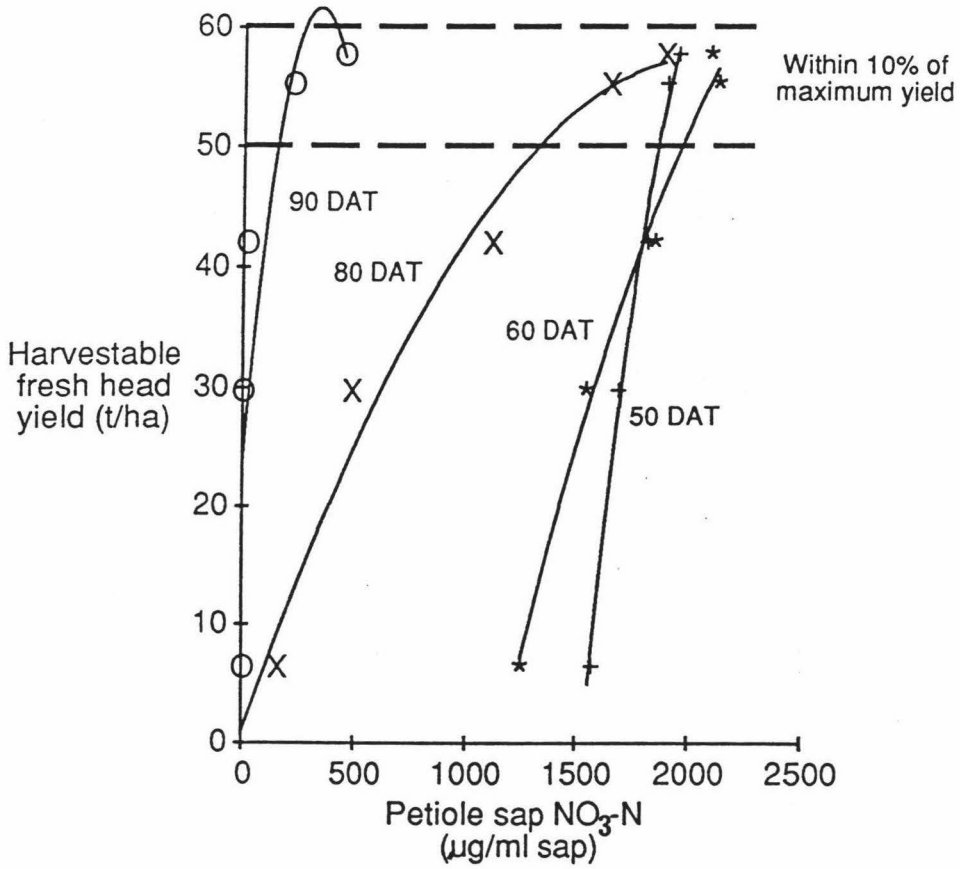

Figure 6.9b Harvestable fresh head yield vs. petiole sap NO_3-N measured at various sampling dates.

plant sap NO_3-N concentrations were largest at these plant ages.

6.4.8 Critical Plant Sap NO_3-N Concentrations

Approaches for determining the critical concentration in plant sap as presented in Chapter 2 (section 2.2.4) for diagnostic and prognostic purposes were compared in this study.

Applying the conventional method, at heading (80 DAT), on the 300 kg N ha^{-1} treatment, xylem sap concentration was 333 $\pm$ 21 μg NO_3-N ml^{-1}, 1651 $\pm$ 134 μg NO_3-N ml^{-1} in the petiole sap and 75 $\pm$ 7 kg N ha^{-1} soil mineral N (30 cm depth). This critical value for petiole sap is higher than that (1300 μg NO_3-N ml^{-1}) recently reported by Huett and Rose (1989) for sand culture grown cabbages. There has been no reported critical xylem sap NO_3-N concentration for cabbages.

As explained by Homenauth et al., (1986), in actual practice, critical values for sap should not be regarded as physiological critical values which must be maintained under all circumstances to allow maximum growth of a crop. In this study, NO_3-N concentrations below 1651 μg ml^{-1} in petiole sap and below 333 μg ml^{-1} in xylem sap at heading (80 DAT) should indicate that N supply from the soil was not sufficient at that stage and that N fertilizer sidedressing was required to maximize yield. An initial application of 300 kg N ha^{-1} was sufficient to maximize yield under the conditions of this experiment and showed petiole sap NO_3-N concentration within the critical level (1651 μg/ml) at heading.

An alternative approach, using a simple simulation model (Scaife, 1988) for brussels sprouts, to determine critical sap NO_3-N concentration was applied to the results of the present study. Using this approach, k_1 and k_2 coefficients in Equation (2.1) in Chapter 2 (section 2.2.2.4) were first determined. As illustrated in Figure 6.11 the growth pattern of a cabbage plant can be divided into 2 phases (1) the slow growth phase i.e., from transplanting to heading; and (2) the rapid growth phase i.e., from heading

to maturity. Thus, it would be essential to find out the k_1 and k_2 values for the respective growth phases. To determine these values, the estimated plant dry weights on the 300 kg N ha^{-1} treatment (i.e., the treatment where N was not limiting) were fitted to Equation (2.1). Values obtained for k_1 (intercept of log relative growth rate (RGR)-plant weight relationship) were -3.05 and -2.62 and for k_2 (slope of the relationship) were -0.0033 and -0.0036 for the respective growth phases. These values were used in the simulation model, the results of which are summarized in Table 6.2 (using xylem sap data) and Table 6.3 (using petiole sap data).

The relationships between S (potential/actual growth rate) and NO_3-N concentrations in plant sap suggest that in order to maintain cabbage growth rate within 95% of its potential value, sap NO_3-N concentration should not fall below 300 μg ml^{-1} in xylem sap (Figure 6.10a) and 500 μg ml^{-1} in petiole sap (Figure 6.10b). For brussels sprouts, Scaife (1988) determined 380 μg ml^{-1} as the critical sap NO_3-N concentration in petiole sap of the middle leaf in order to maintain growth within 95% of its potential growth rate. Xylem sap was not evaluated in his study.

According to Scaife (1988) the measure of success with the simulation model in determining S relies on the degree of agreement between measured and predicted plant weights. The model assumes that crop growth (plant dry weights) is simply a function of plant weight at planting and tissue nutrient concentration. Additionally, it assumes that the growth pattern of the crop is linearly related with time.

In the present study, provided the appropriate k_1 and k_2 values for each growth phase of cabbages were used, there was a general close agreement between the measured and predicted plant dry weights using xylem sap data (Table 6.2) and petiole sap data (Table 6.3). Thus, the calculated S values are considered to be accurate for this trial situation. Thus, as with brussels sprouts (Scaife, 1988), the simulation model has the potential to be successfully used for cabbages to derive a critical plant sap NO_3 concentration for achieving a growth rate close to potential value. However the practicality of using this approach to diagnose N status in

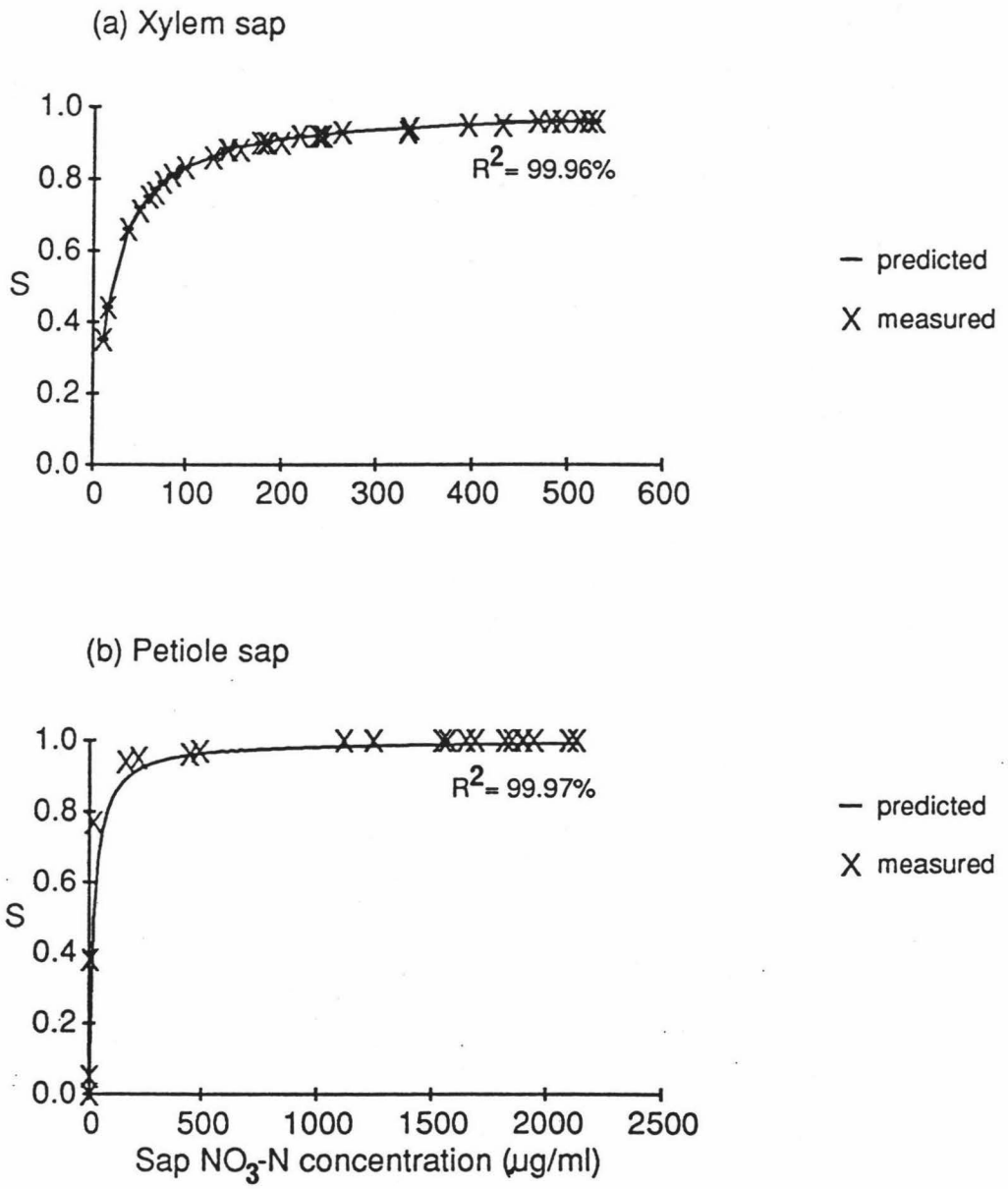

Figure 6.10 The relationship between S and nitrate concentration in (a) xylem sap and (b) petiole sap.

Table 6.2 Cabbage data and simulation results using xylem sap.

Treatment[1] kg N ha^{-1}	DAT	Measured DW/plant (g)	Simulated DW/plant (g)	Xylem sap NO_3-N	AGRPOT[2]	S[3]
0	50	3.7	7	492	0.32	0.96
	60	4.5	11	240	0.49	0.92
	80	12.1	25	184	1.08	0.90
	90	18.4	36	67	1.51	0.77
	100	23.9	50	51	2.00	0.72
	130	52.4	103	16	3.44	0.44
	150	86.3	139	11	4.12	0.35
100	50	5.9	7	482	0.32	0.96
	60	9.1	11	332	0.50	0.94
	80	17.7	25	242	1.10	0.92
	90	25.4	37	98	1.55	0.83
	100	40.5	53	84	2.09	0.81
	130	78.0	122	38	3.83	0.66
	150	163.5	191	60	4.75	0.75
200	50	6.0	7	529	0.32	0.96
	60	11.4	11	395	0.50	0.95
	80	23.3	25	263	1.10	0.93
	90	39.9	38	218	1.58	0.92
	100	55.2	55	142	2.16	0.88
	130	118.4	136	75	4.08	0.79
	150	210.5	218	143	4.95	0.88
300	50	6.2	7	512	0.32	0.96
	60	13.3	11	432	0.50	0.96
	80	27.1	26	333	1.11	0.94
	90	46.3	38	238	1.59	0.92
	100	62.3	56	199	2.19	0.91
	130	127.5	146	127	4.18	0.86
	150	220.7	232	177	5.01	0.90
400	50	8.1	7	522	0.32	0.96
	60	12.0	11	468	0.50	0.96
	80	26.7	26	334	1.11	0.94
	90	46.3	38	244	1.59	0.92
	100	63.1	56	240	2.19	0.92
	130	149.1	146	156	4.22	0.89
	150	251.1	232	182	5.03	0.90

[1]Initial applications
[2]AGRPOT = potential absolute growth rate
[3]S = actual/potential growth rate

Table 6.3 Cabbage data and simulation results using petiole sap.

Treatment[1] kg N ha^{-1}	DAT	Measured DW/plant (g)	Simulated DW/plant (g)	Petiole sap NO_3-N	AGRPOT[2]	S[3]
0	50	3.7	7	1570	0.32	1.00
	60	4.5	11	1247	0.50	1.00
	80	12.1	26	159	1.13	0.97
	90	18.4	39	3	1.59	0.38
	100	23.9	43	0	1.72	0.02
	130	52.4	110	0	5.54	0.00
	150	86.3	110	0	5.54	0.00
100	50	5.9	7	1691	0.32	1.00
	60	9.1	11	1547	0.50	1.00
	80	17.7	27	491	1.14	0.99
	90	25.4	40	3	1.62	0.38
	100	40.5	44	0	1.77	0.06
	130	78.0	115	0	6.02	0.00
	150	163.5	127	0	6.02	0.00
200	50	6.0	7	1820	0.32	1.00
	60	11.4	11	1853	0.50	1.00
	80	23.3	27	1120	1.14	1.00
	90	39.9	40	17	1.64	0.77
	100	55.2	51	0	1.99	0.06
	130	118.4	134	0	6.52	0.00
	150	210.5	147	0	6.52	0.00
300	50	6.2	7	1902	0.32	1.00
	60	13.3	11	2132	0.50	1.00
	80	27.1	27	1651	1.14	1.00
	90	46.3	40	218	1.64	0.98
	100	62.3	58	1	2.22	0.12
	130	127.5	147	0	7.25	0.00
	150	220.7	187	0	7.25	0.00
400	50	8.1	7	1950	0.32	1.00
	60	12.0	11	2098	0.50	1.00
	80	26.7	27	1897	1.14	1.00
	90	46.3	40	447	1.64	0.99
	100	63.1	59	1	2.24	0.12
	130	149.1	148	1	7.80	0.00
	150	251.1	271	0	7.93	0.00

[1]Initial applications
[2]AGRPOT = potential absolute growth rate
[3]S = actual/potential growth rate

cabbages under field conditions is unclear as continual monitoring would be required which is unlikely in practice.

6.4.9 Effect of N Rates on Cabbage Yield and N Uptake

The effects of added N on dry matter yield at different harvest dates are shown in Figure 6.11. Except at 50 DAT, yield generally increased with increasing rate of N application but there was no further significant increase above 300 kg N ha^{-1}.

The relationship between cabbage head yield and rate of N application was best described by a second-degree polynomial function (Figure 6.12). As the application rate of N increased, yield increased but at a diminishing rate. Maximum head yield (55.3 $\pm$ 5.0 t ha^{-1}) was achieved with an application of CAN at 300 kg N ha^{-1} at transplanting (Figure 6.12) and a growing period of 150 days in a growth period which had 448 mm estimated drainage. On a dry matter yield basis, this maximum head yield was equivalent to 5.5 $\pm$ 0.3 t ha^{-1} which surprisingly is in accordance with the findings of Greenwood et al., (1980b) who obtained 5.1 t ha^{-1} of dry matter (average value from series of field experiments between years in the UK) with the optimum N level (281 kg N ha^{-1}) applied to winter cabbages grown on a sandy loam soil.

Whether the yield of 55.3 t ha^{-1} from one field trial is the true maximum for the site is unknown as yields of cabbages from comparable sites are difficult to obtain from growers. At least, soil N status is not likely to be the limiting factor as responses ceased at 300 kg N and 400 kg N gave no further increase. In the present study the maximum yield was obtained under a growing season characterized by above-normal rainfall (42% higher than normal). Excessive rainfall can induce soil moisture conditions near saturation for long periods of time and may create a physical condition which may limit growth. Additionally, owing to the limited number of replications and plant samples measured at each harvest the variability of the trial must also be considered in assessing maximum yield. For

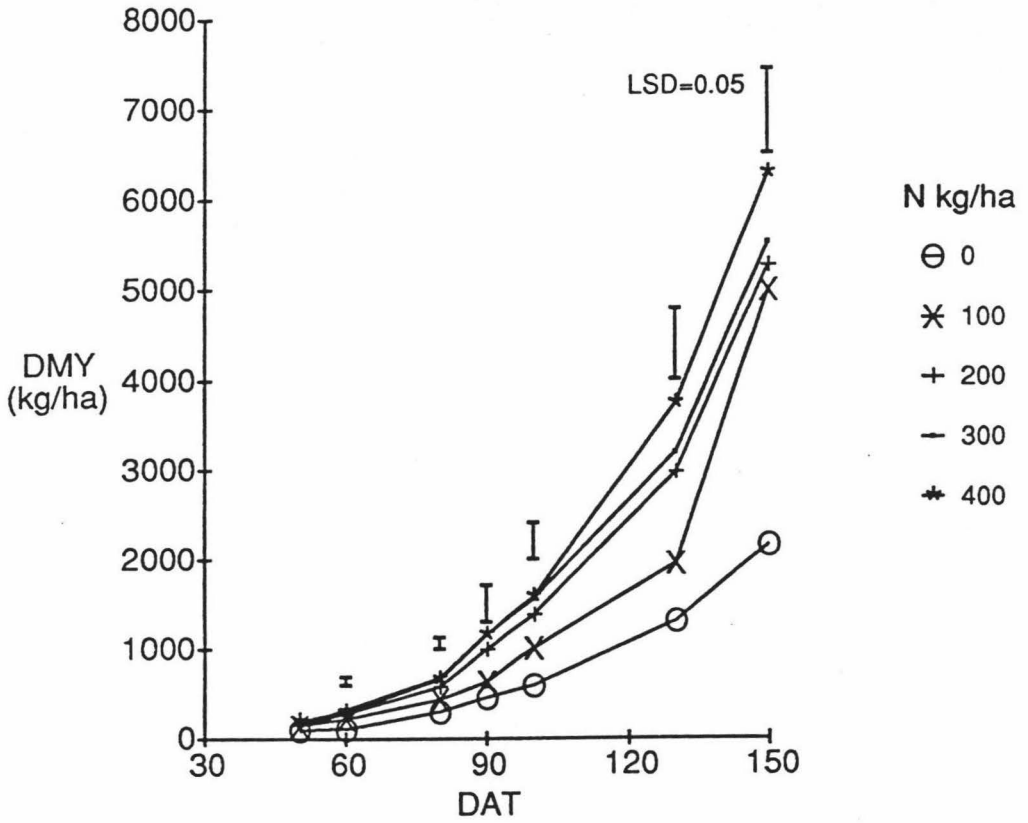

Figure 6.11 The effect of N additions on dry matter yield of cabbages.

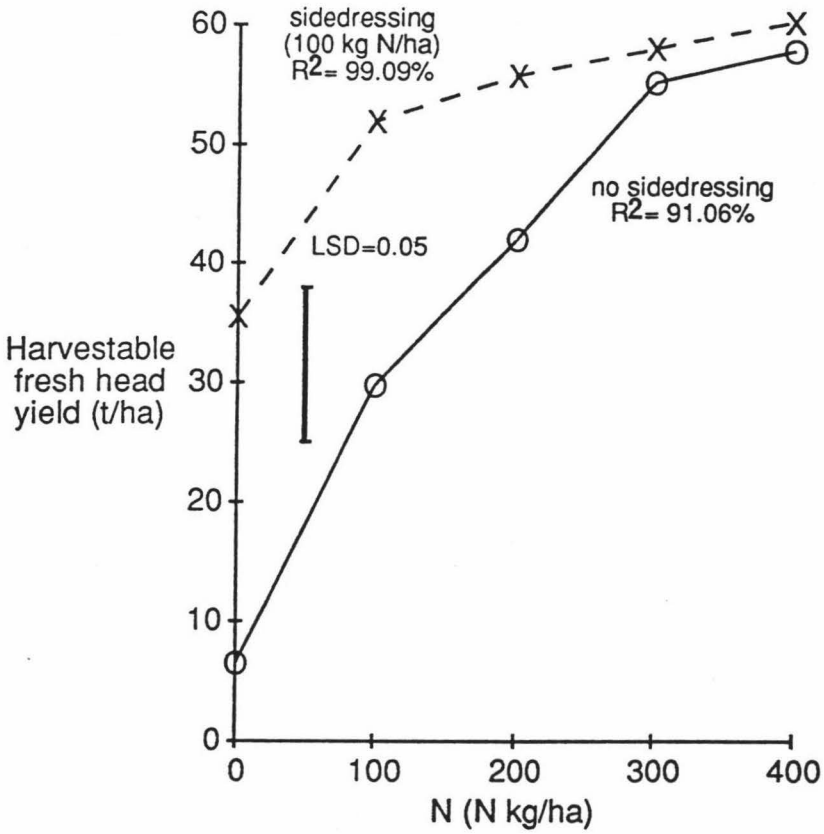

Figure 6.12 The effect of N additions on harvestable fresh head yield.

example a relatively high coefficient of variation (16.2%) was associated with fresh head yield measurement and therefore values determined for maximum yields are not precise but are considered adequate for the purpose of determining N fertilizer requirements of winter cabbages where an estimate of yield is required.

In general, N plant uptake (Figure 6.13) increased (log linear) with increasing application of N fertilizer. In this study, the associated N plant uptake (above ground parts) with the maximum yield was 170 kg N ha^{-1} while Greenwood et al., (1980b) obtained an almost similar value (160 kg N ha^{-1}) for their maximum yield.

The apparent recovery (Figure 6.14) of applied N fertilizer as initial dressings (calculated by difference method) (see section 2.4.1) declined linearly with increasing rate of N applied. The decreasing trend of fertilizer recovery can be related to the greater leaching losses of fertilizer N at higher application rates (see Figure 6.6b). Recoveries ranged from 40-63%. For the treatment giving maximum yield in this study, recovery was 45% while Greenwood et al., (1980b) measured a similar recovery level (38%) for their optimum rate.

The recoveries of applied N fertilizer as sidedressing for the different initial N applications were: 114% (control); 63% (100); 56% (200); 46% (300) and 32% (400). The reason for less than 100% recovery, where N initially applied, may be due to lack of cabbage roots in 50% of the area broadcast with N fertilizer. The depletion zone around a cabbage plant (section 6.4.5) suggests that up to 50% of the ground area fertilized would not contain cabbage roots although some N especially as NO_3^- will move to plant roots by mass flow.

The mean plant recovery of mineral soil N present at the time of sidedressing (heading) was found to be 70% averaged over all rates with little difference between rates (58-78%). These values relate well to plant recovery of fertilizer N applied as a sidedressing (Welch et al., 1971; Riga et al., 1988). The 70% mean recovery will be used as an input in the

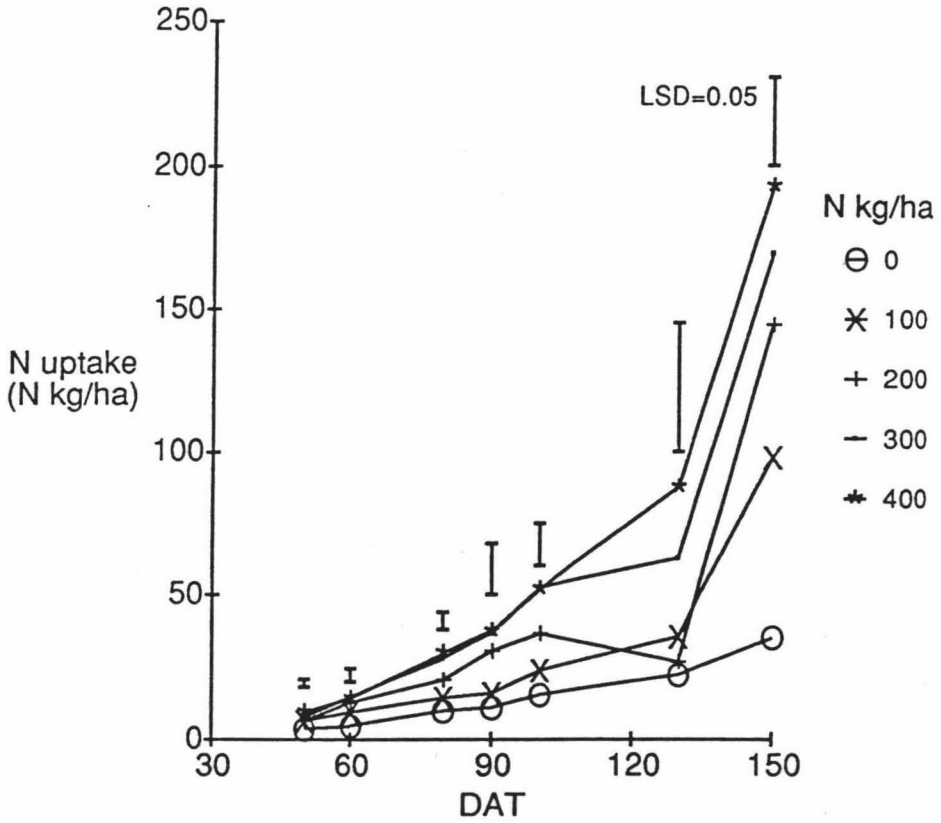

Figure 6.13 The effect of N additions on N uptake by cabbages.

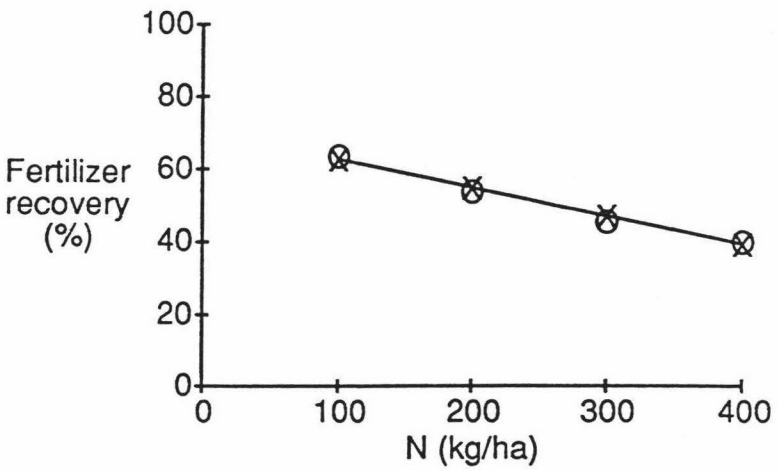

Figure 6.14 Percent recovery of fertilizer N.

model to be developed later (Chapter 8).

6.4.10 Effect of Sidedressing on Marketable Fresh Head Yield

Sidedressing initial applications of 0, 100 and 200 kg N ha^{-1} with 100 kg N ha^{-1} as urea was required to achieve similar maximum yields as found with an initial application of 300 kg N ha^{-1} as CAN. As shown in Figure 6.12, treatments 0, 100 and 200 kg N ha^{-1} (having sap concentrations below the critical level of 1651 μg NO_3-N ml^{-1} at heading; Figures 6.9a and 6.9b) benefited from the N sidedressing. With sidedressing, yields in these treatments were increased by 29, 22 and 14 t ha^{-1}; respectively. The control, however, failed to achieve maximum yield at final harvest even with sidedressing of 100 kg N/ha. Separate studies (Burns, 1987) have shown that a nutritional setback in early growth, such as that caused by temporary N stress, can depress the final yields of some crops, even when the stress is subsequently relieved through sidedressing.

The results for the other two treatments (100 and 200 kg N) indicate the utility of sap nitrate testing for determining the need to sidedress winter cabbages with N fertilizer at heading. Sap test results, however, do not provide information on the amounts of N fertilizer required as a sidedressing to maximise crop yields. Scaife and Turner (1984) have provided sidedressing recommendations (rates of application) for some UK grown vegetable crops but not cabbages, where sap concentrations were below the critical level, but the recommendations were admitted to be speculative and not based on sound scientific evidence.

6.5 CONCLUSION

The plant sap and soil N indices measured at heading in this field study showed whether or not initial N status was adequate to achieve maximum fresh head yield. The maximum fresh head yield (55 t/ha) was obtained with an initial N application of 300 kg N ha^{-1} as CAN. At heading (80

DAT), in the 300 kg N ha^{-1} treatment, xylem sap concentration was 333 μg NO_3-N ml^{-1}, 1651 μg NO_3-N ml^{-1} in the petiole sap and there was 75 kg N ha^{-1} soil mineral N (30 cm depth). This critical value for petiole sap is higher than that reported in the literature for cabbages. When petiole sap concentration was below 1651 μg NO_3-N ml^{-1} in the petiole sap at heading sidedressing with 100 kg N ha^{-1} as urea was required to achieve a similar yield as found with an initial application of 300 kg N ha^{-1}.

The above critical plant sap test levels were determined by the normally advocated method i.e., by plotting the final yield against the various plant sap test results measured at different times. The alternative method using a simple simulation model proposed by Scaife (1988) proved also satisfactory in determining critical sap nitrate concentrations in cabbages. Using this simulation model, it is suggested that a single critical sap NO_3 concentration of 300 μg NO_3-N ml^{-1} in xylem sap and 500 μg NO_3-N ml^{-1} in petiole sap, be maintained at all growth stages in order to achieve a growth rate within 95% of the potential value. From a practical viewpoint, the use of the latter approach would be difficult to implement.

The sap NO_3 test, which can be easily carried out in the field at heading, also determined whether N sidedressing is required or not by winter cabbages. The strong correlation between soil and sap test results suggests that during wet conditions, when soil sampling is not feasible, sap testing can be employed to evaluate the current N status of cabbages. At these times sap testing is more convenient to use than soil testing. Additionally sap testing (with the use of the "Merckoquant" test strips) gives immediate results overcoming the potential problem of delayed results of soil tests. This is particularly important when there is a short interval between sampling and the appropriate time of sidedressing N if additional N is necessary.

Since the trial was conducted on only one soil type at one location and under 1988 climatic conditions, more widespread calibration and assessment will be required to have full confidence in the use of sap tests for

determining the N status of winter cabbages.

CHAPTER 7

EFFICIENCY OF ^{15}N LABELLED UREA FERTILIZER APPLIED AS A SIDEDRESSING TO WINTER CABBAGES

7.1 INTRODUCTION

It was determined in Chapter 6 that a sidedressing with urea (100 kg N ha^{-1}) at heading was required by treatments with 100 and 200 kg N ha^{-1} (having sap concentrations below the critical level at heading) to achieve the maximum yield of an initial application of 300 kg N ha^{-1} as calcium ammonium nitrate. The efficiency (about 60%) of the sidedressed N fertilizer on the above treatments, however, could only be estimated by the difference method as unlabelled urea was used. As indicated in Chapter 2 (section 2.4.1), the difference method often overestimates N fertilizer efficiency. Since an efficiency factor is to be used as an input in the model to be developed (Chapter 8) designed for determining N fertilizer requirements of winter cabbages, it is essential to have an accurate determination of N fertilizer efficiency added as a sidedressing.

7.2 OBJECTIVE

The objective of the study was to determine the efficiency of ^{15}N labelled urea fertilizer applied as a sidedressing at the heading stage of growth of winter cabbages.

7.3 MATERIALS AND METHODS

An area adjacent to the main field experiment described in Chapter 6 (6.3) was used for this study. Four plots (3.2 x 3.0 m^2 each) were established to accommodate 2 N sidedressing rates (100 and 200 kg N/ha) with 2 replications for each treatment.

Prior to transplanting cabbages into the plots, the plots were fertilized with 100 kg N ha^{-1} from CAN and 100 kg P ha^{-1} and 78 kg K ha^{-1} using 15% potassic superphosphate (0-9-7-10). Cabbages were planted 2 weeks later than the main trial (described in Chapter 6) as weather conditions prevented an earlier planting time. Plant spacing was between rows 80 and within rows 50 cm.

Four soil cylinders (40 cm diameter) were located in each plot by pressing the cylinders through the soil to a depth of 30 cm leaving the soil structure undisturbed (Figure 7.1). The cylinders served as microplots containing one transplanted cabbage plant which was sidedressed with ^{15}N urea (5.2 atom% excess ^{15}N) at heading stage. All other plants in the plot (26 in all) were sidedressed by broadcasting with unlabelled urea at 2 different rates. Fine sand was used as extender in applying the ^{15}N urea fertilizer.

A week before sidedressing, water suction samplers were placed in the soil within the cylinders (2 water samplers per cylinder) to 30 cm depth. The samplers were used to collect soil solutions after heavy rain falls between the time of sidedressing (27 August 1988) to final plant harvest (25 October 1988).

7.3.1 Sampling and Analytical Procedures

7.3.1.1 *Plant*

Whole plants (including roots) were sampled at the following dates: 15, 25, 35 and 60 days after sidedressing (DAS). At 15 DAS, one plant per treatment was sampled while two plants per treatment were obtained for the succeeding sampling dates. Fresh and dry weights of cabbages were recorded at each sampling. Nitrogen concentrations in plant parts (roots, outer leaves and inner leaves) were measured as described in Chapter 3 (3.3.5.4).

Figure 7.1 Showing the microplots used in the ^{15}N field experiment.

7.3.1.2 *Soil*

Soil cores (0-5, 5-10, 10-15, 15-20, 20-25 and 25-30 cm depth sections) were sampled on the following dates: 5, 10, 15, 20, 25, 30, 45 and 60 DAS. Two cores per cylinder were obtained and the corresponding sections for the 2 cores taken at each sampling bulked for analysis. The NO_3^- and NH_4-N concentrations in the soil extracts were measured as described in Chapter 3 (3.3.6).

7.3.1.3 *Soil solutions*

Soil solutions were collected from the suction samplers on the following dates: 10, 15, 30, 40, 45, 50, 55 and 60 DAS. Soil solutions were normally collected after the event of a heavy rain (schedule of water sample collection is indicated in Figure 7.6). Immediately after collection, the water samples were treated with few drops of toluene to suppress microbial activity and placed immediately in the freezer. The samples were filtered before analysis for NO_3^- and NH_4-N concentrations as described above (7.3.1.2).

7.3.1.4 *^{15}N analysis*

Both the plant and soil samples taken at 2 harvests (25 and 60 DAS) were analysed for total N and ^{15}N enrichment using a mass spectrometer (Bremner, 1965a; 1965c).

The percentage ^{15}N derived from the fertilizer in the plant and soil samples was calculated using the following formula (Hauck and Bremner, 1976).

$\%^{15}N$ recovery from fertilizer = $N_s(c-b)/R(a-b) \times 100$

where N_s is the total nitrogen content of the sample; a, b and c are respectively the ^{15}N abundance of the applied fertilizer, the ^{15}N abundance of the untreated sample (background value) and the ^{15}N abundance of the treated sample; and R is the rate of the applied fertilizer.

The percentage of N in the plant derived from the fertilizer (%Ndff) is calculated using the following formula:

$\%Ndff = (c-b)/(a-b) \times 100$

The percentage of N in the plant derived from the soil (%Ndfs) is made up by the difference:
$\%Ndfs = 100 - \%Ndff$

7.4 RESULTS AND DISCUSSION

7.4.1 Yield, N Concentrations and N Uptake

In this experiment, a sidedressing response to 100 and 200 kg N ha^{-1} could not be evaluated fully as no treatment existed to determine the effect of an initial 100 kg N ha^{-1} without sidedressing. However, in a similar adjacent experiment, reported in Chapter 6, sidedressing with 100 kg N ha^{-1} significantly increased the yield of treatments 0, 100 and 200 kg N ha^{-1} initial applications (see Figure 6.12). Although these yield results were not strictly comparable as fertilizer treatments were applied 2 weeks earlier than the ^{15}N trial, it is assumed that a sidedressing response would also had occurred at this site for the application of 100 and 200 to the 100 kg initial rate.

In the ^{15}N trial, the dry matter production of cabbages at different

sampling dates from the onset of heading up to maturity was not affected by the higher (200) rate of sidedressing (Figure 7.2). Likewise, there was no significant effect of the rates on harvestable fresh head yield (Table 7.1a).

At final harvest, the inner leaves (head) made up at least 50% of the total dry matter (Table 7.1b) while the other parts (outer leaves and roots) constituted the remaining dry matter production. This result agrees very well with the findings of Huett and Dettmann (1989) in sand culture study that the head of cabbages would contribute 49% of the total shoot dry weight. The roots in the present study accounted only for a small proportion (about 1%) of the total dry matter weight. This low proportion, of the total weight, in the roots is lower than values given to other *Cruciferae* crops which ranged from 5-15% (Magnifico et al., 1979; Wurr, 1981).

Like the dry matter yield results, there was no significant effect of sidedressing rate on the total N concentration in cabbages at any harvest date (Figure 7.3). As a consequence, the total N uptake by cabbages was not influenced by either of the two sidedressing treatments (Figure 7.4) although at early growth stages the mean level of 200 was higher. At final harvest, N plant uptake was 177 and 186 kg N ha^{-1} from the respective sidedressing rates including the common initial application of 100 kg N ha^{-1}.

7.4.2 Recovery of Labelled Fertilizer N in the Plant

The N recovered by the plant is derived from both the soil and the added fertilizer. Labelling the fertilizer applied as sidedressing with ^{15}N allowed the relative effectiveness of each sidedressing rate to be evaluated by measuring the content of ^{15}N in the plant. The amounts of N derived from the fertilizer (Ndff) and the amount of N derived from the soil (Ndfs) by the plant are presented in Table 7.2.

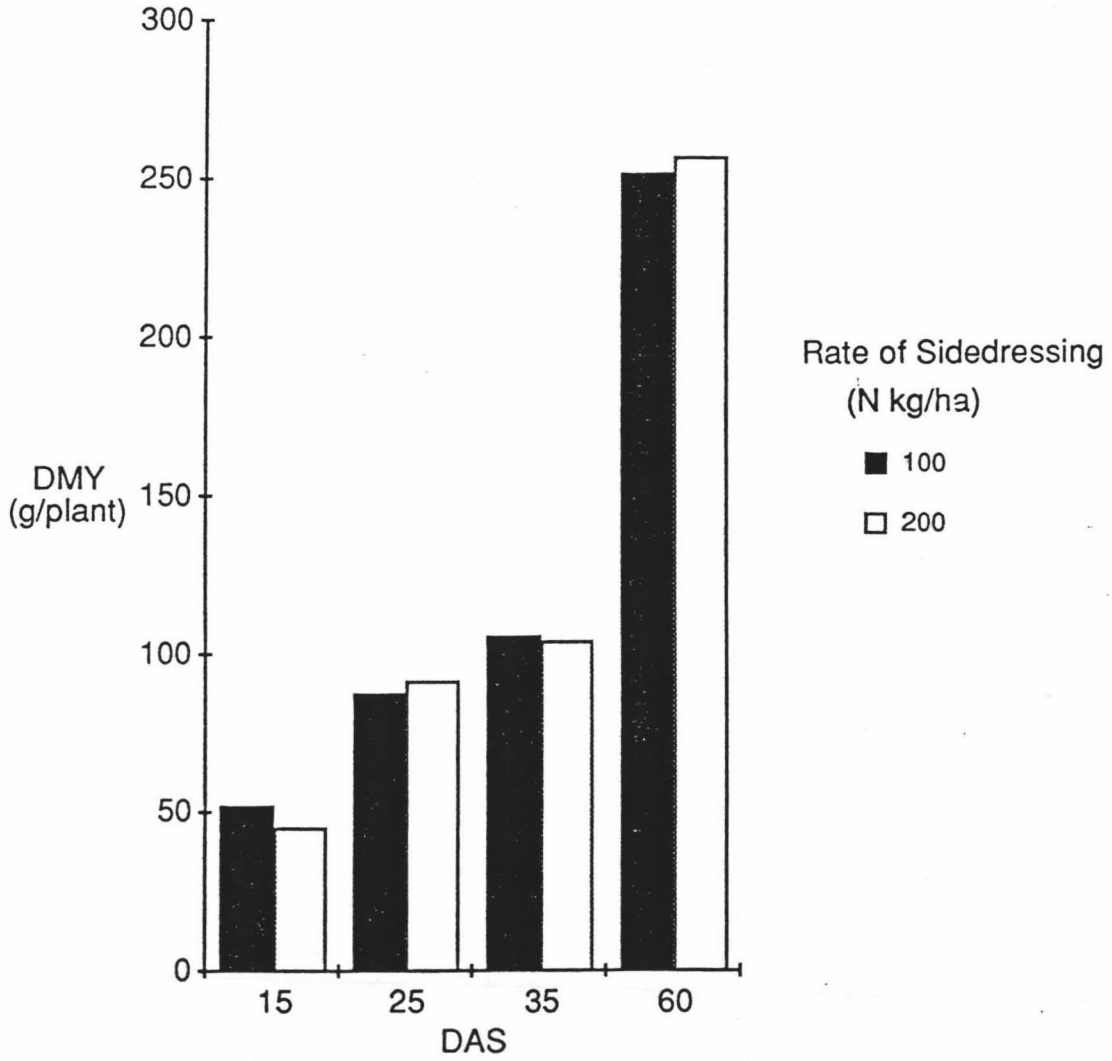

Figure 7.2 The effect of rate of N fertilizer sidedressing on total (roots + shoots) dry matter yield of cabbages.

Table 7.1a The effect of rate of N fertilizer sidedressing on harvestable fresh head yield (kg/plant) of cabbages.

Sidedressing N kg/ha	Fresh head yield (kg/plant)
100	1.948
200	2.065
$t_{.05}$ = 4.30	ns

ns = not significant

Table 7.1b The effect of rate of N fertilizer sidedressing on total dry matter yield (g/plant) of cabbages.

Sidedressing kg N ha^{-1}	Plant Position	Time of sampling (DAS) 15	25	35	60
100	inner leaves	14.2	25.6	33.0	142.6
	outer leaves	36.7	60.0	70.6	106.9
	roots	1.4	2.5	2.3	2.4
	Total	**52.3**	**88.1**	**105.9**	**251.9**
200	inner leaves	7.2	24.6	23.7	141.6
	outer leaves	37.0	65.0	78.2	112.6
	roots	1.3	2.2	2.5	2.6
	Total	**45.5**	**91.8**	**104.4**	**256.8**
$t_{.05}$(total yield)		ND	ns	ns	ns

ND = not determined
ns = not significant

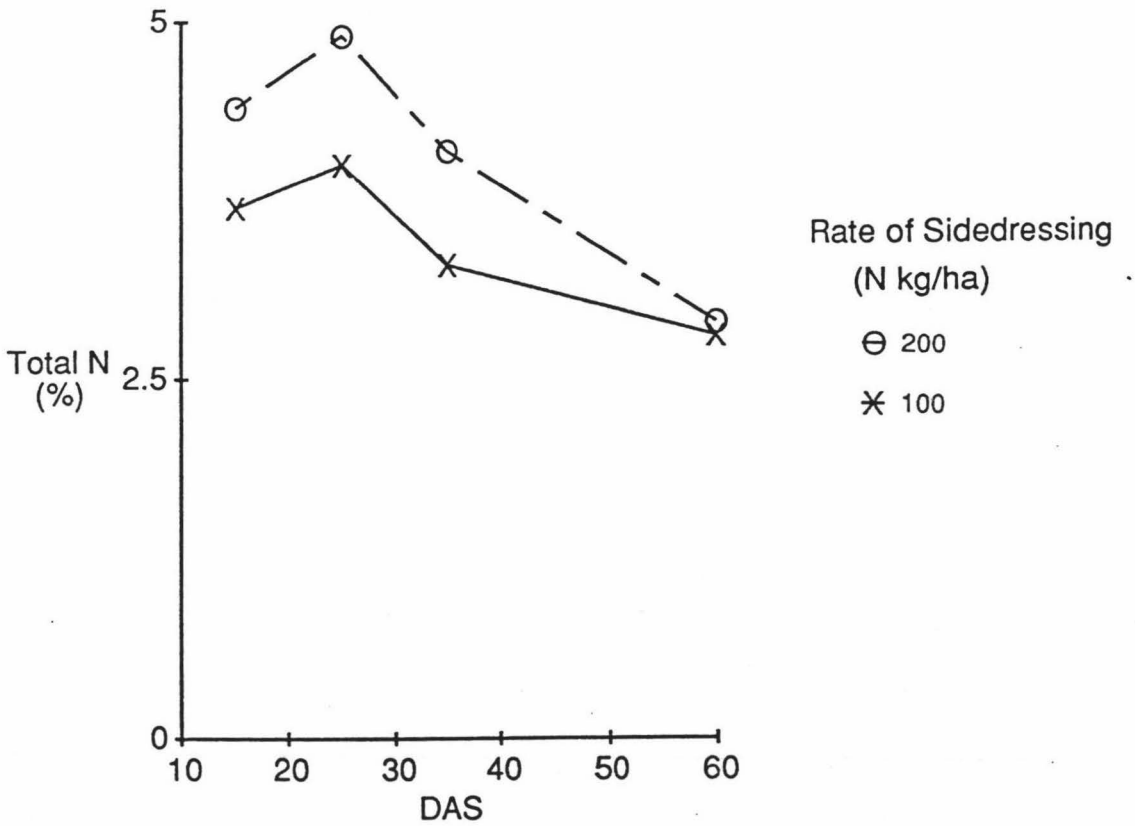

Figure 7.3 Total N concentrations in cabbages.

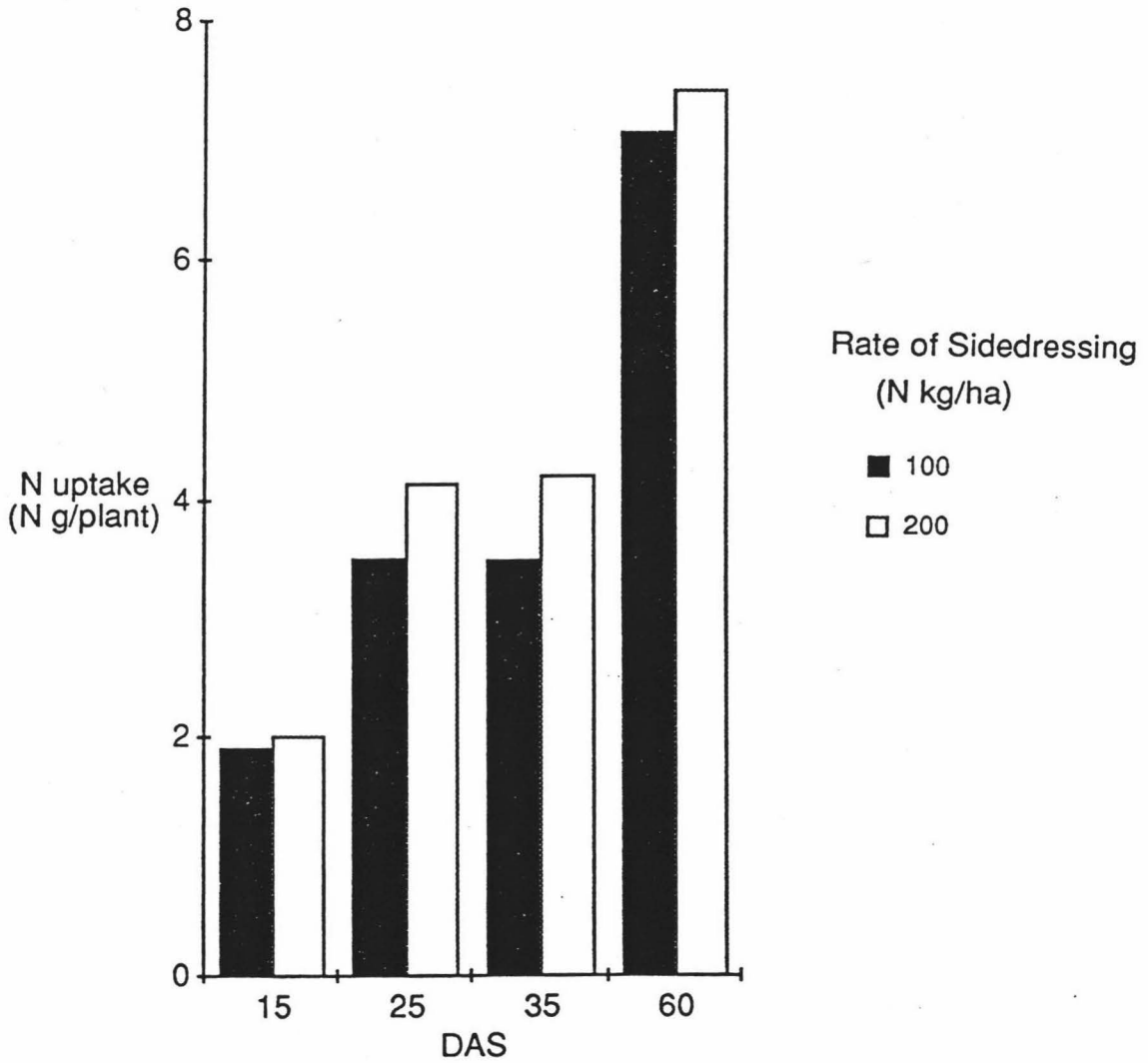

Figure 7.4 Total N uptake (roots + shoots) by cabbages.

At final harvest, the percent plant recovery of applied labelled fertilizer N was in the range of 62-65% for the two rates of sidedressing, respectively. These recovery values are in line with those reported in the literature (Welch et al., 1971; Stanford, 1973).

The recovery values were not significantly different suggesting that increasing the rate of sidedressing application did not result in less efficient use of sidedressed fertilizer N by the plants. The equal recovery of sidedressed ^{15}N at final harvest could be due to the presence of an active root system for absorbing the fertilizer N when it was applied at heading. Normally (see Chapter 2 section 2.5) for most crops, N uptake efficiency which ranges from 50-70% is inversely related to the initial N fertilizer application rate (Parr, 1973; Stanford, 1973; Greenwood et al., 1989c) but no published data appear to exist for the effect of fertilizer rate at sidedressing on fertilizer efficiency. The result in the present study, however, is rather restricted by the limited range of sidedressing rates.

At 25 DAS, however, the percent recovery of sidedressed fertilizer N by the plant was significantly higher (see Table 7.2) in the lower rate (52%) than in the higher rate (37%). The somewhat lower percentage of fertilizer N in plants treated with higher rate suggests the possibility of the capacity of the soil to readily immobilise the inorganic N and/or leach N.

Amounts of ^{15}N labelled fertilizer remaining in the top 30 cm soil at 25 DAS were 58 kg N on the lower rate (100) and 72 kg N on the higher rate (200). It would be expected that with the heavier rate of application there is likely to be a higher percentage of N as inorganic N, which is the major source of N plant uptake the excess of which is subject to immobilisation or leaching losses might occur.

The possibility of N being immobilised is suggested as Mohammed et al., (1984) investigating the short-term fate of urea applied to barley in a silt loam soil under a similar climate to that in this study, found that by day

Table 7.2 Recovery of labelled fertilizer N in the plant.

DAS	Sidedressing N kg/ha	Plant Position	At% ^{15}N excess	%Ndf	%Ndfs	Recovery (%)
25	100	inner leaves	3.51	67.6	32.4	23.2
		outer leaves	2.80	53.9	46.1	27.8
		roots	2.27	43.6	56.4	0.9
		Total				**51.9**
	200	inner leaves	3.84	74.5	25.5	13.9
		outer leaves	3.21	61.8	38.2	22.6
		roots	2.70	51.9	48.1	0.4
		Total				**36.9**
60	100	inner leaves	2.15	41.4	58.6	38.4
		outer leaves	1.64	31.7	68.3	26.3
		roots	1.47	28.3	71.7	0.4
		Total				**65.1**
	200	innerleaves	3.58	69.0	31.0	32.7
		outerleaves	3.36	64.7	35.3	28.9
		roots	2.64	50.9	49.1	0.4
		Total				**62.0**

25 after urea application, about 45% of the applied N was present in the organic form in the top 20 cm soil. Most of the immobilisation occurred between days 3 and 14. However, because labelled inorganic N was not able to be measured the amount of N immobilised in the present study could not be accurately determined.

In relation to leaching losses, Mohammed et al., (1984) found that at this period, 5% of the fertilizer N was leached from the normal lysimeters (drainage, totalling 28 $\pm$ 4 mm) and 11% from the wetter lysimeters (drainage, totalling 48 $\pm$ 4 mm). In the present study at 25 DAS, 2.5 kg N was lost by leaching (see Figure 7.7) on the higher rate (200 kg N). Thus, immobilisation is likely to be more important than leaching.

In the present study, the contribution of soil N to total plant N uptake from sidedressing to final harvest time cannot be accurately quantified under the condition of the experiment as only the fertilizer N sidedressings were labelled and not the initial fertilizer N applications. The unlabelled fertilizer N applied as an initial dressing contributed to N uptake along with soil N.

At final harvest, plant recovery of sidedressed ^{15}N labelled fertilizer N in cabbages was mostly by the harvested plant material i.e., inner leaves (about 50%) followed by the outer leaves, while the the amount in the roots was generally low (<1%). Thus, the exclusion of roots from N recovery measurements at final harvest in cabbages may not produce significant error.

7.4.3 Recovery of Labelled Fertilizer N in the Soil

The distribution and percent recoveries of labelled fertilizer N remaining in the soil (0-30 cm depth) at 25 and 60 DAS are shown in Table 7.3. Since the soils were analysed only for total N, the amounts of labelled fertilizer as organic or inorganic N could not be quantified separately. Although it may be assumed that at these times a greater proportion of the total N

Table 7.3 Recovery of labelled fertilizer N in the soil.

DAS	Sidedressing N kg/ha	Depth cm	%N	At% ^{15}N excess	%Ndff	Recovery (%)
25	100	0-5	0.29	0.64945	12.5	13.2
		5-10	0.28	0.37975	7.3	9.1
		10-15	0.24	0.37185	7.2	9.3
		15-20	0.25	0.37060	7.1	11.4
		20-25	0.20	0.37200	7.2	8.7
		25-30	0.14	0.37060	7.1	6.5
		Total				**58.2**
	200	0-5	0.32	1.10485	21.2	12.4
		5-10	0.25	0.46700	9.0	5.0
		10-15	0.26	0.37755	7.3	5.1
		15-20	0.26	0.37250	7.2	6.0
		20-25	0.18	0.37400	7.2	3.9
		25-30	0.16	0.37180	7.2	3.8
		Total				**36.2**
60	100	0-5	0.28	0.49620	9.5	9.7
		5-10	0.26	0.38185	7.3	8.4
		10-15	0.24	0.37230	7.2	7.8
		15-20	0.22	0.37040	7.1	8.4
		20-25	0.20	0.37160	7.1	8.6
		25-30	0.14	0.36960	7.1	6.5
		Total				**49.4**
	200	0-5	0.28	0.50155	9.6	4.9
		5-10	0.27	0.38370	7.4	4.4
		10-15	0.24	0.37175	7.1	4.6
		15-20	0.25	0.37215	7.2	5.8
		20-25	0.22	0.37310	7.2	4.8
		25-30	0.14	0.37120	7.1	3.2
		Total				**27.7**

was organic N in accordance to the findings of Mohammed et al., (1984) especially in the top 20 cm.

In the present study, greater amounts of labelled fertilizer N remained in the soil on the higher rate (200) of sidedressing in both samplings. Over the sampling time (25 to 60 DAS), the amount of residual fertilizer N in the soil decreased from 58 to 49 kg N ha^{-1} on the lower rate (100) and from 72 to 56 kg N ha^{-1} on the higher rate (200). The decreasing trend of the residual soil values with time indicates the possibility of NO_3^- leaching and/or remineralisation and plant uptake of the immobilised fertilizer N at this period. In this study, a fraction of the remineralised N may have become available for plant uptake as plant recoveries of fertilizer N increased with time (compare values of plant uptake in Table 7.2). Between 25 and 60 DAS, the increase in plant uptake of ^{15}N labelled fertilizer on the lower rate (100) was 7 kg N (decrease of ^{15}N levels in the soil was 8 kg N) while on the higher rate (200) the increase in N plant uptake was 50 kg N (soil ^{15}N levels decreased to 16 kg N).

7.4.4 Balance of Applied Labelled Fertilizer N

A balance sheet of sidedressed labelled fertilizer N in soil and plant is given in Table 7.4. At final harvest, fertilizer N recovery in plant and soil was 114.5% $\pm$ 0.9 of the applied fertilizer N for the lower rate and 89.7% $\pm$ 1.1 for the higher rate (Figure 7.5). At 25 DAS, total percent recovery of the sidedressed ^{15}N was 110 $\pm$ 0.5% for the lower rate and 73.1 $\pm$ 0.7% for the higher rate. A rather peculiar result in this study concerns the extra 40 kg N ha^{-1} that was accounted for in total recovery on the higher rate (200) at final harvest. This suggests that the ^{15}N that accumulated below 30 cm depth may have become available for plant uptake between 25 and 60 DAS.

The total N recovery values, with sidedressing, found in this study are high. Other workers have reported a wide range of total recovery results but only for initially applied fertilizer N. In studies involving winter

Table 7.4 Balance of applied labelled fertilizer N in the plant and soil.

	Sidedressing N kg/ha	Fertilizer N recovery (%) Plant	Soil	Total
25	100	51.9	58.2	110.1 ± 0.5
	200	36.9	36.2	73.1 ± 0.7
$t_{.05}$		*	*	*
60	100	65.1	49.4	114.5 ± 0.9
	200	62.0	27.7	89.7 ± 1.1
$t_{.05}$		ns	**	**

**, * = Significant at 1, 5%; ns = not significant
± SEM

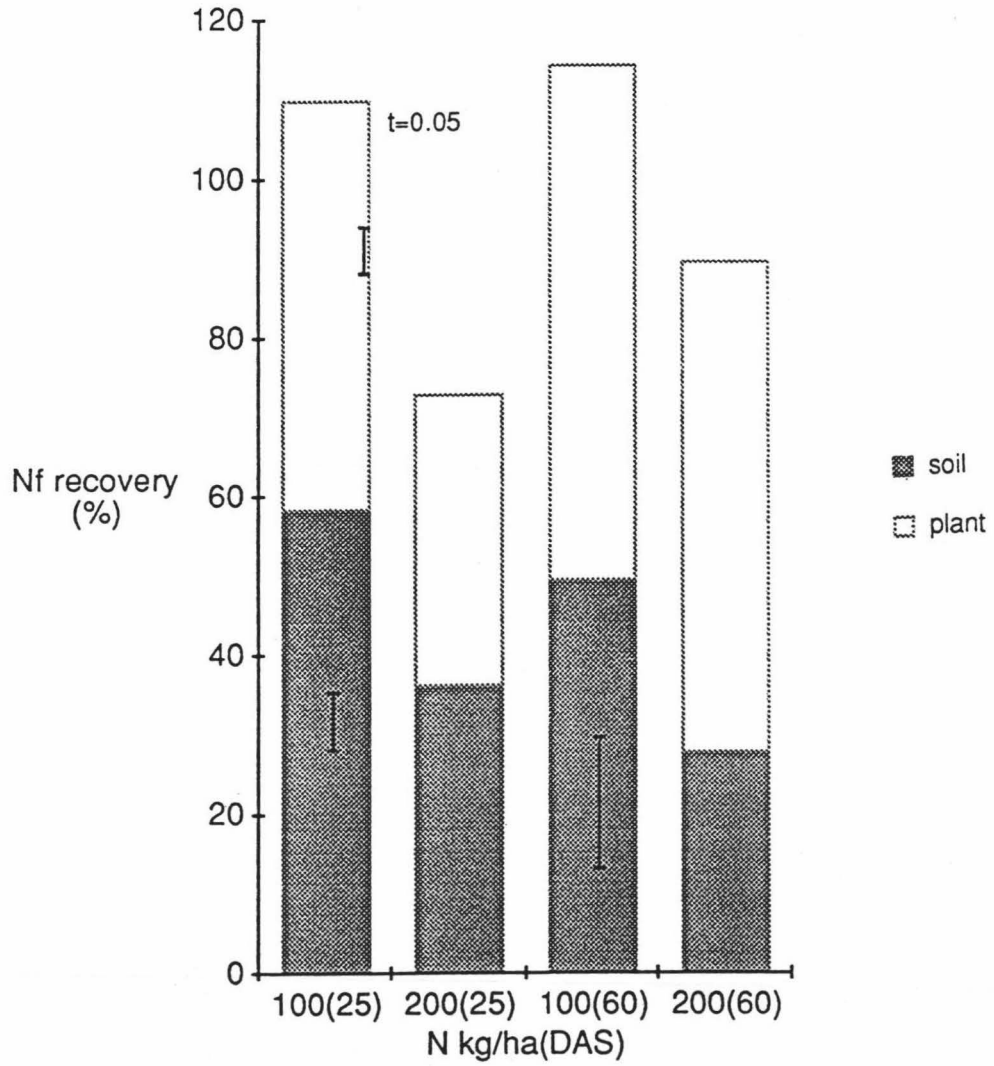

Figure 7.5 Balance of applied labelled fertilizer N in the plant and soil.

wheat, Olson et al., (1979) recorded an average 80% recovery of fertilizer N in plant and soil (50 cm depth) irrespective of N rates (50 and 100 kg ha^{-1}) as $(NH_4)_2SO_4$ solutions applied in autumn before planting and in spring as topdressing. They attributed the unaccounted fertilizer N (19-23%) mainly to gaseous losses rather than leaching since they found little evidence of fertilizer N moving below about 50 cm in the soil. In another study using a similar crop, Van Cleemput et al., (1981) measured 93% total recovery of initially added fertilizer in soil and plant and the unaccounted 7% was considered lost by both leaching and denitrification. The recovery results in the present study, however, need to be viewed with caution as they were based on a limited number of replicates and soil and plant samples.

In the present study, it is suggested that a major fraction of unaccounted 20 kg N on the higher rate (200) was mainly due to immobilisation at soil depths >30 cm rather than volatilisation and NO_3^- leaching. Immobilisation due to NH_4^+ fixation could have occurred at these depths considering that the soil used in this experiment (Karapoti fine sandy loam soil) contains appreciable amounts of illite which has the ability to retain NH_4^+ in nonexchangeable forms. The NH_4^+ fixing capacity of soils would vary with depth, usually higher in subsoil than in surface soil, the reasons for this difference between topsoil and subsoil are not known and information on the subject is meagre as indicated in a review by Nommik and Vahtras (1982).

The soil to which urea was applied as a sidedressing had a pH of 6.5 (see Table 6.1) and mean temperature of 12°C, so conditions were not favourable to significant volatilisation (Nelson, 1982). Despite the considerable quantity of drainage water estimated (total = 130 mm) from sidedressing to final harvest time and the event of 20 mm drainage 7 DAS (Figure 7.6), only 3 kg N was measured to have been leached on the higher rate. This amount of leached N was based on the cumulative NO_3-N concentrations in the water samples taken at 30 cm depth over 8 sampling times (Figure 7.7). The presence of an active root system for absorbing the fertilizer N at sidedressing time may have reduced leaching losses of

fertilizer N.

7.4.5 Extrapolation of Results from ^{15}N Plot to the Main Trial

Due to the high cost of ^{15}N, the ^{15}N plots were smaller and had less replications than the plots in the main trial. The ^{15}N plots were also planted 2 weeks later than the main trial. The relevance of the results obtained from the ^{15}N plots to the main trial results depends on how representative the ^{15}N plots are of the whole field. To test this, the means of fresh head yield and N uptake from the ^{15}N plots and main trial plots that received similar treatment (100 kg N ha^{-1} basal + 100 kg N ha^{-1} sidedressing) were compared.

Using the t-test, it is shown (Table 7.5) that the means of the yield results from the ^{15}N plots and from the main trial did not differ significantly. Thus, 2 weeks difference in time of planting made little difference to yield. Therefore it is concluded that in the main trial, if 200 kg N had been sidedressed on 100 kg N ha^{-1} treatment, recovery would have been 65%.

Percent recovery of the applied fertilizer N (100 kg N ha^{-1}) calculated in the ^{15}N plots (65%) was not significantly different from the value (63%) calculated by the difference method for the main trial.

7.5 CONCLUSION

At final harvest, plant recovery of sidedressed labelled fertilizer was 62-65% and did not differ between application rates which is in contrast to the expected result of decreasing efficiency of fertilizer utilisation with increasing application rates.

A balance sheet of sidedressed ^{15}N in the plant and soil indicates that

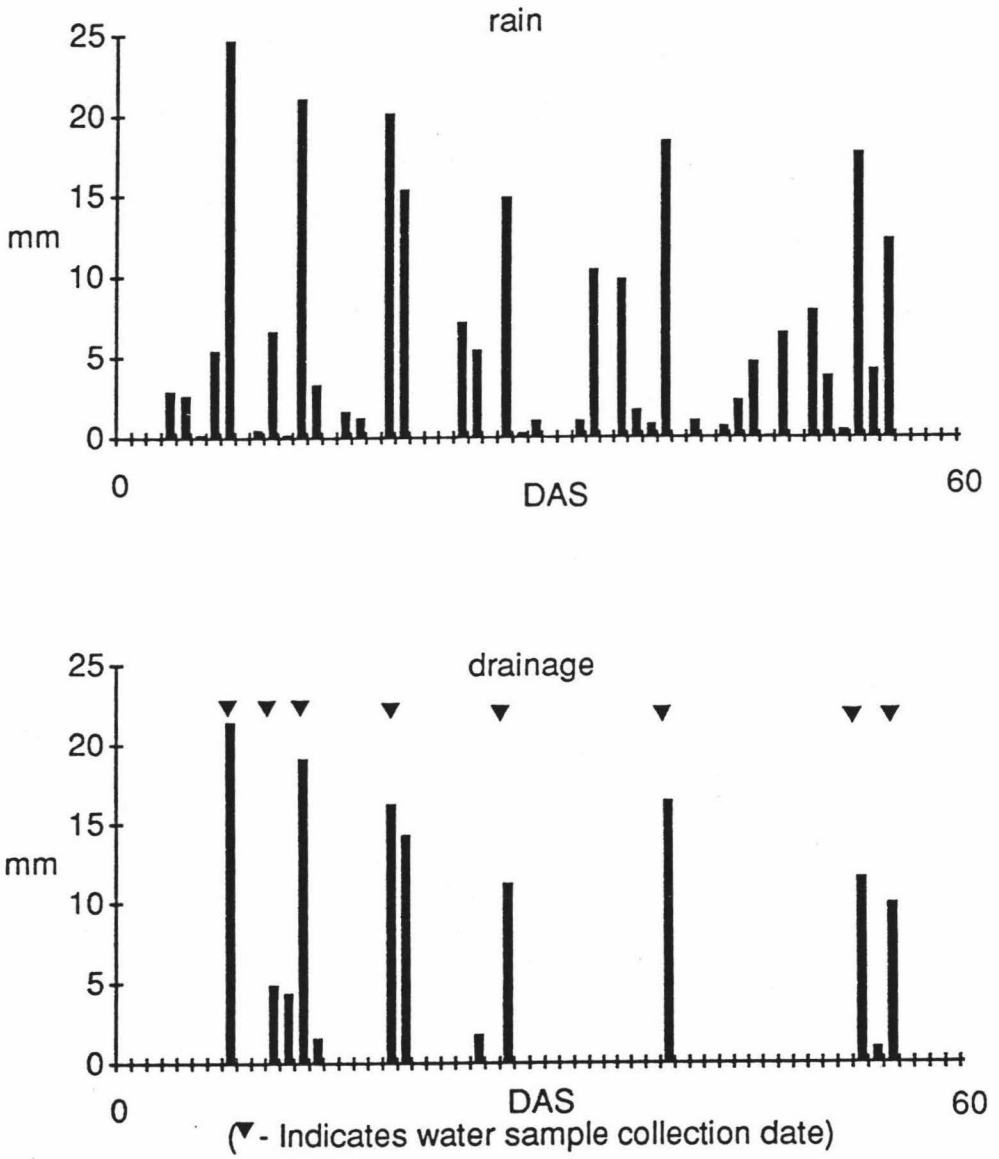

Figure 7.6 Daily rain and drainage data after sidedressing ^{15}N fertilizer.

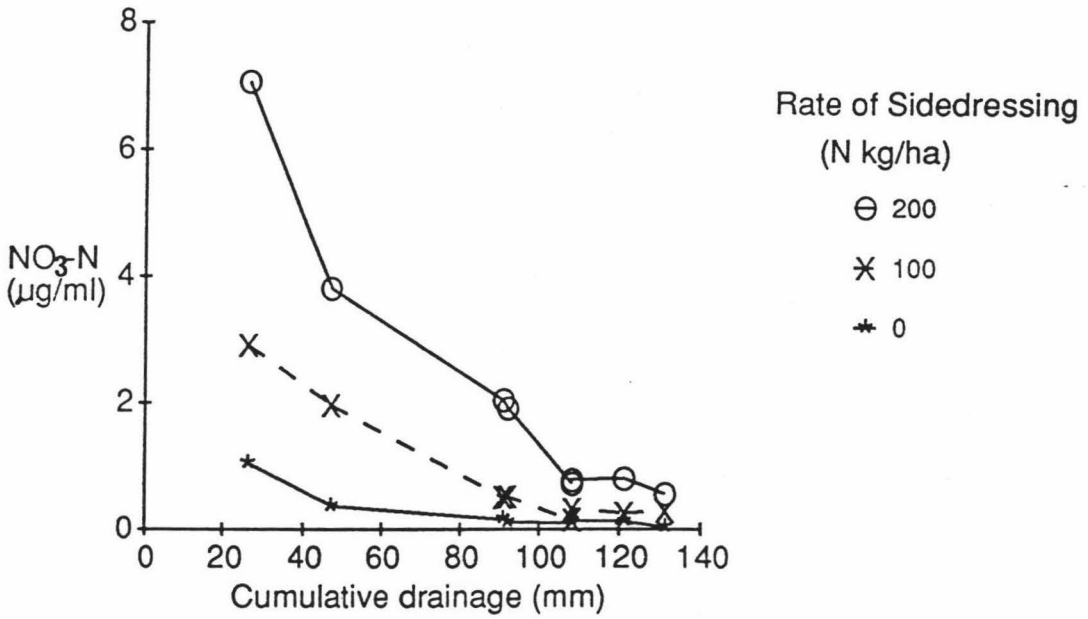

Figure 7.7 NO_3-N concentrations in water samples collected at 30 cm depth.

Table 7.5 Statistical analysis of fresh head yield and N uptake in the ^{15}N plot (A) and main trial (B).

		Replicates	Mean	$t_{.05}$
Fresh head yield	A	2	1.94	ns
(kg/plant)	B	3	2.08	
N uptake	A	2	7.0150	ns
(N g/plant)	B	3	6.3909	

ns = not significant

about 20 kg N was lost from the 200 kg N ha^{-1} treatment but no losses for the 100 kg N ha^{-1} application rate occurred. It is suggested that a major fraction of the unaccounted 20 kg N (10%) on the higher rate (200) was probably due to immobilisation at soil depths >30 cm rather than leaching.

Overall, total recovery of ^{15}N in the plant and soil at final harvest; 114 $\pm$ 0.9% and 90 $\pm$ 1.1%; for the respective sidedressing rates (100 and 200) are considered relatively high although there are no comparable data in the literature.

The difference method of determining N fertilizer efficiency at sidedressing gave a similar result to the ^{15}N method suggesting that the inadequacies ascribed to the difference method often used to determine the efficiency of fertilizer N applied at planting may not apply to sidedressing applications. This requires further validation.

CHAPTER 8

MODELLING THE NITROGEN FERTILIZER REQUIREMENTS OF WINTER CABBAGES

8.1 INTRODUCTION

Since a large number of soil, plant, environmental and management factors affect the fertilizer requirements of crops, N fertilizer requirements of cabbages are likely to vary from site to site. Up until recent years, N fertilizer requirements of horticultural crops have been determined from field trials but the site specific nature of field trials limits their applicability to other sites (Mohammed et al., 1984). Attempts to reduce this limitation of field trials have been the use of simple models developed from relevant information, from one site, which can be readily modified to apply to other sites.

Using data from other experiments in this study, this chapter reports on the development and validation of a simple model that is designed to predict the N fertilizer requirements of winter cabbages by assessing the adequacy of N status at heading.

8.2 GENERAL METHODOLOGY

As indicated in Chapter 6 (section 6.1) most growers of cabbages use split applications of N fertiliser. Assuming that the initial rates used to fertilise transplanted cabbages will be based on past grower practice and experiences, the model to be developed in the present study will specifically determine the amount of N fertiliser needed to be applied as a sidedressing at a critical time to obtain maximum yields. The time selected for assessing adequacy of N status is at heading as determined in Chapter 6 (see section 6.4.7).

In developing the model, termed a "sidedressing model", a component which indicates a plant N status at heading is required and also a component representing soil N availability between heading and final harvest. Where the sum of the two components at heading is less than plant optimum N status, then, fertilizer N is required to be added. The plant optimum N status, as a function of dry matter production and N concentrations in the plant, would depend largely on the supply of N in the soil throughout crop growth.

To obtain plant optimum N status, the 1988 field trial data (presented in Chapter 6) from the treatment where 300 kg N ha^{-1} was initially applied was used. This treatment was considered not to have been limited by N deficiency.

8.3 RESULTS AND DISCUSSION

8.3.1 The Sidedressing Model

The sidedressing model proposed includes the major components of N nutrition of crops. These are (1) demand for N by the crop; (2) the ability of the soil to supply available N; and (3) the efficiency of uptake of soil and fertilizer N by the crop. In concept, the model described here resembles Parr (1973) and Stanford's (1973) models but differs in purpose. The sidedressing model is designed to assess N fertilizer needs for sidedressing whereas that of Parr and Stanford's are designed to determine N fertilizer needs at establishment or at planting only.

The sidedressing model is given as:

$$N_f = N_y - [N_h + E_s(N_s + N_m)]/E_f \qquad (8.1)$$

where

N_f = amount of N fertilizer sidedressing requirement

N_y = crop uptake of N associated with maximum yield

N_h = N already in the crop at time of sidedressing

N_s = NO_3^- + NH_4-N in soil at time of sidedressing (0-30 cm)

N_m = N likely to be mineralised from sidedressing to maturity

E_s = efficiency of plant uptake of N_s and N_m

E_f = efficiency of plant uptake of applied N fertilizer

All terms except E_s(%) and E_f(%) are expressed in kg N/ha.

8.3.2 Development of the Model

8.3.2.1 *Nitrogen demand (N_y, N_h)*

To obtain N_y, both the maximum dry matter yield (DMY) and plant N concentrations, under optimum conditions at final harvest need to be determined. For the treatment receiving 300 kg N ha^{-1} in the 1988 field trial, total DMY (above-ground parts) was 5518 kg ha^{-1} (see Figure 6.11). Plant total N concentrations declined with crop growth from 4.9 to 3.1% but concentrations were fairly constant (3.1%) from heading up to final harvest. Thus, if 5.5 t DMY ha^{-1} is considered to be the maximum yield and 3.1% to be the average plant N concentration at final harvest under the experimental conditions, then, the maximum uptake of N (N_y) to obtain this maximum yield was about 170 kg N ha^{-1} (see Figure 6.13).

N_h in Equation (8.1) represents the amount of N already in the crop measured at heading. For treatment 300 kg N ha^{-1}, N_h was 36.5 kg N ha^{-1}.

8.3.2.2 *Nitrogen supply (N_s, N_m)*

The N supplied by the soil is the sum of soil mineral-N (N_s) in the root zone of the crop at sidedressing time plus N likely to be mineralised (N_m) from sidedressing to final harvest time. In Equation (8.1) N_s values are directly measured while N_m values are estimated. At sidedressing time (90 DAT), the amount of soil mineral-N at 0-30 cm depth in the treatment receiving 300 kg N ha^{-1} was 45 $\pm$ 5 kg N ha^{-1}.

To determine N_m, the method of Greenwood et al., (1987b) was used (see Equation 8.2). Apparent mineralisation rate (dN_m/dt), was based on measurements made on plots from which N-fertilizer had been withheld in 1988 i.e., control plots.

$$dN_m/dt = (dN_u + dN_s + dN_L)/dt \qquad (8.2)$$

where dN_u is the increase in N uptake by the above ground parts of the plant over the period, dt, which is from the time of sidedressing and that made shortly after harvest; dN_s is the change in inorganic N in soil to 30 cm depth over the period; and dN_L is the amount of NO_3^- estimated to be leached below 30 cm over the period.

In the present study, N uptake by roots was ignored as the contribution to the total plant N uptake was minimal (see Chapter 7; section 7.4.4). The value of dN_m/dt calculated, based from Equation (8.2), was 0.6 kg N ha^{-1} d^{-1}. For the 60-day period, covering sidedressing to final harvest time, this value is equal to 36 kg N/ha which is about 2.5 times the amount of N_s in the control treatment at sidedressing time. The mineralisation rate calculated is within the range of values (0.5-1.5 kg N ha^{-1} d^{-1}) that are reported in the literature (see Chapter 2; section 2.2.1) for many NZ soils under cropping.

For plots receiving 300 kg N ha^{-1}, the value of dN_m/dt was 2.1 kg N ha^{-1} d^{-1} equalling to 126 kg N ha^{-1} for the 60-day period. This N_m value of

the fertilised plot is about 3 times the amount of N_s at sidedressing time. The higher N_m value for the fertilised treatment may reflect the "priming effect" of N fertilizer additions on the mineralisation of native soil N (see Chapter 2; section 2.2.1) or exploitation of mineralised N by increased plant growth. Therefore, N_m for the control and fertilised plots was assumed to equal (N_s x 2.5) and (N_s x 3.0); respectively.

8.3.2.3 *Efficiency of plant uptake (E_s, E_f)*

Efficiency of plant uptake was calculated from a balance sheet approach using 1988 field trial results. The efficiency of plant uptake of N_s (E_s) measured from sidedressing to final harvest time was 70% (see Chapter 6; section 6.4.10) which was also assumed, like Parr (1973) and Stanford (1973), to apply to N_m efficiency. The mean plant recovery of urea-N fertilizer (E_f) as a sidedressing was assumed to be 63% as measured in the ^{15}N field trial (see Chapter 7; section 7.4.6).

8.3.3 Validation of the Sidedressing Model

Taking into account the above information and assumptions; and substituting them in Equation (8.1); the sidedressing model reads as:

$$N_f = 170 - [N_h + 0.7(N_s + N_m)]/0.63 \qquad (8.3)$$

For the purpose of initial validation of the model, 1988 data for two treatments i.e., 200 (initial) and 400 (initial) were used.

For treatment 200 (initial)

$N_f = 170 - [30.5 + 0.7(31.7 + 95.1)]/0.63$

$N_f = 80$ kg N ha^{-1}

For treatment 400 (initial)

$N_f = 170 - [37.3 + 0.7(51.3 + 153.9)]/0.63$
N_f = nil kg N ha^{-1}

The above calculations agree reasonably well with the measured response *data where the initial 200 kg N treatment responded to sidedressing (100 kg N) and 400 kg did not respond (see Figure 6.12). However, only one rate of sidedressing application was used which allows for only limited validation of the predicted 80 kg N ha^{-1} rate of application to the initial 200 kg N treatment. It would appear though that the sidedressing model (Equation 8.1) has potential for predicting the N sidedressing requirements of winter cabbages.

For the purpose of further validation of the sidedressing model, data from a large undergraduate student field trial on the same soil type, as the experiment reported in Chapter 6, but in the following year (1989), were used. Fertilizer treatments consisted of different initial rates of CAN: 0; 100; 150; 200; 250; and 300 kg N ha^{-1}. Winter cabbages "Wintercross" variety were transplanted in the field on 11 May 1989. Distance of planting and the number of replications per treatment were the same as for 1988 field trial but a different winter cabbage variety was used. The trial was replanted 15 DAT because most of the initial plants were severely damaged by birds and rabbits. The date of replanting was then taken as the time of trial commencement.

At sidedressing time (heading) or after accumulation of at least 700 heat units, plant and soil samples were measured for N plant uptake (N_h) and NO_3^- and NH_4-N levels (N_s); respectively. Using the sidedressing model (Equation 8.3), cabbages either not initially fertilized (control) or fertilised initially with 100 kg N were assessed to require N sidedressings (Table 8.1) at heading. Initial rates from 150-300 kg N ha^{-1} were estimated not to require sidedressing. It was expected that at final harvest the treatments given sidedressings would give similar maximum yield as those predicted to be under optimum N supply i.e., 150-300 kg N ha^{-1}. In the conduct of the

Table 8.1 Fertilizer N (N_f) sidedressing requirements of winter cabbages in the 1989 field trial.

Treatment	N_h	N_s	N_m[1]	N_f[2]	N_f[3]
	kg N ha^{-1}				
0	29 ± 5.3	31 ± 9	78	103	175
100	45 ± 2.7	36 ± 18	108	38	140
150	45 ± 2.7	52 ± 11	156	0	140
200	50 ± 6.8	61 ± 8	183	0	95
250	73 ± 5.3	122 ± 12	366	0	0
300	68 ±14.0	125 ± 14	375	0	0

[1] N_m = N_s x 2.5 (control); N_s x 3.0 (fertilized)
[2] N_f = Calculated following Equation (8.3)
[3] N_f = Students' sidedressing rates
± SEM

1989 student field trial, however, different rates of N_f were used from those estimated by the model (Table 8.1).

In the validation, only whether sidedressing was required or not can be assessed. Whether the estimated sidedressing rates applied to the control and 100 kg N are adequate or not was not fully evaluated as on these treatments a range of sidedressing rates would need to be applied.

On the basis of statistical analysis of treatment yields, the control plot, as predicted, responded to sidedressing (Figure 8.1). On the other hand, the difference (12.5 t ha^{-1}) between the yield of 100 kg N (initial) and 100 + 140 kg N (sidedressing) was almost significant at 5% (calculated $LSD_{0.05}$ = 14.1 t ha^{-1}). The lack of a significant difference between sidedressing and not sidedressing the initial rates of 150 and 200 further validates the estimations of nil N sidedressing requirements by the model. While sidedressing was not conducted at the high rates, the nature of the response curve for both sidedressing and initial rates suggests that no sidedressing response would result at higher rates which is also in line with predictions from the sidedressing model.

8.3.4 Discussion of Validation

Several assumptions have been made in validating the model. For instance, the N_y expected in 1989 would be approximately 170 kg N/ha associated with maximum dry matter yield. In 1989, maximum dry matter yield (8.5 t ha^{-1}) was obtained on 100 kg N ha^{-1} and this gave an N_y of 229 kg N ha^{-1} which is higher than N uptake at maximum yield in 1988. However, since no initial rates were applied <100 kg N it is unknown whether a lower rate of application would also give maximum dry matter yield with a lower N uptake value. In terms of fresh head yield, a similar maximum yield was achieved in 1989 (52 t ha^{-1}) as in 1988 (55 t ha^{-1}) despite large differences in climatic conditions (Table 8.2). From a practical viewpoint, weight of cabbages at various stages of growth may be better expressed as fresh weight which is more meaningful to a grower. Overall, the

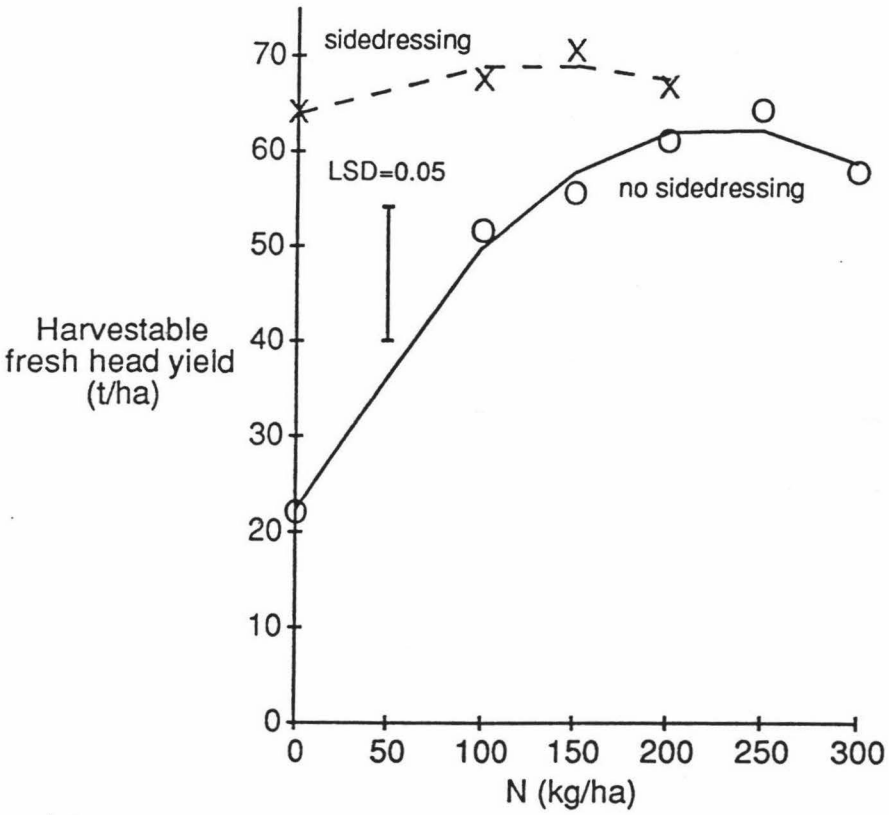

Figure 8.1 The effect of N additions on harvestable fresh head yield of cabbages in the 1989 field trial.

assumption that N_y would be similar in both years appears realistic on this soil type at least. Obviously a more widespread evaluation of N_y is required to assess soil and region specificity.

Another assumption made was that the efficiency of plant uptake of N_s and N_m between heading and maturity would be about 70%. In the 1989 trial, much higher recovery values (as high as 100%) were recorded. The higher efficiencies in 1989 could be related to more favourable climatic conditions for plant uptake of N_s and N_m (Table 8.2). Unlike conditions in 1988, there was virtually no drainage water in the months of August to October (heading to final harvest) in 1989 which could have limited the leaching losses of N in the soil and enhanced plant recovery of N_s and N_m. Therefore, it would appear that the efficiency of plant uptake of N_s and N_m is not a constant value but could range from a minimum of 70 to 100% depending on climatic conditions. This is a large weakness of any model dependent on climatic conditions as one cannot predict the weather. For instance if one chooses 70% to be the E_s and E_f value and little leaching occurs between heading and maturity then N requirements are overestimated. On the other hand, if 100% is chosen to be the E_s and E_f value and a wet winter occurs then N requirements are underestimated. Since 70% efficiency was associated with a growing season where the high rainfall measured between heading and final harvest would only occur 1 in 10 years then the use of 70% efficiency would create a very low risk of underestimating optimum N requirements. But this level of efficiency would on average create inefficient use of N fertilizer and could create an environmental problem in respect to N concentrations in edible parts. An average efficiency of 85% would be a compromise but in wet years would probably influence yield detrimentally.

It was also assumed that N_m from heading to final harvest is related to N_s at heading i.e., $N_m = N_s \times 2.5$ (control) and $N_m = N_s \times 3.0$ (fertilised). These assumptions were found to be reasonable in 1989 (Table 8.3) particularly on the low N rate treatments (0-200 kg N) but not on the high rates (250-300 kg N) where predicted values were much higher than the measured values. This suggests a lower mineralisation rate on the plots

Table 8.2 Monthly rainfall and drainage during the conduct of the field trials.

Month	Rainfall (mm) 1988	1989	Drainage (mm) 1988	1989
May (Transplanting)[1]	110.3	43.8	38.3	1.6
June	119.2	88.2	85.5	72.5
July	163.0	53.4	142.3	40.6
August (Heading)	93.8	53.1	59.8	2.7
September	144.0	25.3	90.8	nil
October (Harvest)[2]	42.7	108.3	31.3	14.6
Total	**673.0**	**372.1**	**448.0**	**132.0**

[1]Transplanting dates: 4 May 1988; 11 May 1989
[2]Harvesting dates: 6 October 1988; 26 October 1989

Table 8.3 Measured and predicted N_m (N kg/ha) from heading to final harvest in the 1989 field trial.

kg N/ha[1]	Measured	Predicted[2]
0	61	78
100	159	108
150	181	156
200	221	183
250	168	366
300	99	375

[1]Initial applications
[2]As indicated in Table 8.1

that received higher N fertilizer rates. This may be due to decreased plant activity because of root alterations. It has been found (Drew, 1975) that the proliferation of plant roots is markedly reduced when there is high concentrations of NO_3^- or NH_4^+ within the rooting zone. Thus, the assumption that the amount of N to be mineralised is linearly related with the amounts of N_s at heading, is incorrect in this particular year.

The dN_m/dt values (using Equation 8.2) for the control plot in 1989 was higher (0.9 kg N ha^{-1} d^{-1}) than in 1988 (0.6 kg N ha^{-1} d^{-1}). For the plots fertilised at a lower rate (100 kg N) in 1989 mineralisation rate (2.3 kg N ha^{-1} d^{-1}) was comparable to that in 1988 (2.1 kg N ha^{-1} d^{-1}).

As discussed earlier, the objective of the sidedressing model of determining the actual rate of sidedressing was only partially validated as a range of sidedressing rates at any one initial application rate was not available to test model predictions of sidedressing rate. Further validation is therefore required to determine the N fertilizer rate predictions of the model. Unless actual rate of sidedressing can be successfully predicted, the model provides no more information than the sap test method reported earlier.

In Chapter 6 (6.4.8), it was determined that plants having petiole sap concentration <1600 μg NO_3-N ml^{-1} at heading would respond to N sidedressing. In the 1989 trial (Table 8.4) the control and treatment 100 kg N ha^{-1} (initial) had sap NO_3-N concentrations below this critical level hence a response to sidedressing was expected (see Figure 8.1) which is in line with predictions from the sidedressing model.

The above result contradicts an earlier conclusion of Homenauth et al., (1986) that the critical concentration for maximum growth and yield of a crop would vary at different sites and seasons. Furthermore, the result contrasts with the findings of Scaife and Turner (1987) that the sap test, although easily carried out in the field, was not capable of predicting the responses of brussels sprouts to N sidedressing when mineralisation rate was higher than expected. However, cabbages were not examined in their work.

Table 8.4 NO_3-N concentrations (μg/ml) in petiole sap (YML) of winter cabbages at two sampling growth stages in the 1989 field trial.

kg N/ha[1]	Sampling stage	1988	1989
0	Pre-heading	1570	616
	Heading	159	143
100	Pre-heading	1691	368
	Heading	491	1367
200	Pre-heading	1820	966
	Heading	1120	2070
300	Pre-heading	1902	1027
	Heading	1651	2966

[1]Initial applications

8.3.5 Possibilities for Improving the Model

Like most models, the sidedressing model has a degree of site and season specificity and several measurements are required. To extend the utility of the model to other situations and reduce actual measurements, it is necessary to develop simple submodels to predict its components, particularly, N_h and N_s. The component, N_y, is considered to be fixed for this site (i.e., 170 kg N/ha) as mentioned in section (8.3.4) but may differ from site to site.

8.3.5.1 *Predicting N_h*

The term N_h gives a measure of N already accumulated by the crop at heading. To obtain N_h, both the DMY and N concentrations in the plant, need to be predicted.

The initial step in determining N_h would be to predict DMY at heading. Various approaches could be used to predict DMY. The ability of the crop growth model of Greenwood et al., (1977), as given in Equation 2.4 (see Chapter 2 section 2.5), to predict DMY on the control and 300 kg N ha^{-1} (initial) treatments for 1989 field trial was examined. These two treatments represent a limiting and non-limiting N supply situation, respectively.

To predict DMY, a growth rate coefficient (k_2) for the period 50 DAT to heading (90 DAT) was calculated using Equation 2.5 (see Chapter 2 section 2.5) and the data from the control and 300 kg N/ha treatments for the 1988 field trial. The k_2 values were 0.005 and 0.083 t ha^{-1} d^{-1} for the respective treatments. The latter value compares very well with the average value (0.095 t ha^{-1} d^{-1}) reported by Greenwood et al., (1977) for winter cabbages that have been grown under optimum N supply for two separate years in the UK.

By substituting the k_2 values in Equation (2.4), the increases in plant dry weights (dW's) between two sampling periods, 30 DAT (W_o) to heading (90-100 DAT; W_h) were predicted for 1989 field trial (Table 8.5).

On the 300 kg N treatment there was, in general, a good agreement between the measured and predicted dW's using the model of Greenwood et al., (1977). Between years (1988-1989), the k_2 values did not vary much (0.072 in 1989) supporting earlier findings of Greenwood et al., (1985b) that the k_2 value, under optimum N supply, in Equation (2.4) would not vary by more than 25% as a result of soil type and/or inter-year variation in weather. In fact, in other studies, Greenwood et al., (1985b; 1987b) assumed k_2 to be a constant value for a particular crop species.

The growth model of Greenwood et al., (1977), however, underestimated the plant dry weight increases of the control treatment at 80 and 100 DAT and overestimated at 50 DAT. The discrepancy is due to the inappropriate k_2 (growth rate coefficient) value used in the prediction. The overall growth rate of cabbages in 1989 was much higher than that in 1988. For instance, the DMY on the control treatment at heading was 780 kg/ha while it was only 460 kg/ha in 1988. The reason for this difference is probably due to different N status of the control treatments between years. The amounts of N_s in the top 30 cm were about 2 times as high in 1989 than in 1988 (see Table 8.12) at heading. Thus, the k_2 value was much higher in 1989 (0.054) than in 1988. It appeared that the k_2 value for N limited plants will vary depending on the rate of growth of the plant which in turn depends on the rate of supply of N in the soil (mainly from mineralisation of soil N).

The above results suggest that the growth model of Greenwood et al., (1977) for predicting DMY is of limited use where soil N status is below optimum at heading but if at optimum is a good predictor of DMY.

Another approach considered to predict DMY is the simulation model of Scaife (1988). It was shown in Chapter 6 (section 6.4.8) that the model showed good predictions of DMY at heading and final harvest in 1988

Table 8.5 Measured and predicted increases in plant dry weights (dW, t/ha) of winter cabbages in the 1989 field trial.[a]

kg N/ha	DAT	Measured	Predicted[a]
0	50	0.01 ± 0.006	0.04
	80	0.33 ± 0.013	0.10
	90-100 (Heading)	0.40 ± 0.140	0.14
300	50	0.03 ± 0.013	0.03
	80	0.49 ± 0.060	0.37
	90-100 (Heading)	1.08 ± 0.243	0.91

[a]Using Equation (2.5) with W_o = 0.04 t/ha (control) and 0.06 t/ha (300 kg N); t_o = 30 DAT
±SEM

irrespective of the N status in the soil. Using the same growth rate coefficients the model of Scaife also showed reasonable predictions of DMY at heading in 1989 field trial for all N rates particularly on the control treatment (Table 8.6). Thus, the model of Scaife may have more utility than the Greenwood's growth model in predicting DMY under a range of different soil N status. The limitation of Scaife's model is that it does not have a component that predicts %N in plants which is also required in predicting N_h, but could be modified to do this as shown later (see Table 8.8).

In the present study, the procedure of Greenwood (1986) in predicting %N in the plants was adopted using the data on the control and 300 kg N treatments for 1988 field trial. The %N data on these treatments were plotted against the dry matter yield at intervals during growth. The data were fitted into a curve defined by the equations shown in Figure 8.2. It is shown in the figure that %N in the fertilized cabbages fell on one curve and %N in cabbages from which N fertilizer had been withheld fell on another. The differences between the two curves would indicate the increase in %N in the plants brought about by applying N fertilizer. Further, it is shown that the decline in %N is determined largely by DMY as earlier reported by Greenwood (1986).

In this study, the 2 equations shown in Figure 8.2 and Greenwood's model (Equation 2.6 in Chapter 2 section 2.5) were used to predict %N in cabbages for the selected treatments in the 1989 field trial. Additionally, a modified form of Equation (2.6) designed by Greenwood et al., (1989b) for situations where N is limiting was used. Results are summarised in Table 8.7.

On the control treatment, the equation (for the control) in Figure 8.2 and the modified form of Equation 2.6 (Greenwood et al., 1989b) did not give good agreement between the measured and predicted %N at heading. On the 300 kg N treatment, Greenwood's (1986) model gave better predictions than the equation, for the 300 kg N treatment, shown in Figure 8.2.

Table 8.6 Measured and predicted dry matter yield of winter cabbages (g/plant) in the 1989 field trial (after Scaife's simulation model).

N kg/ha[1]	DAT[2]	Measured	Predicted
0	30	1.6 ± 0.1	2
	50	2.0 ± 0.4	5
	80	15.0 ± 0.7	16
	90-100	31.2 ± 5.1	35
100	30	2.0 ± 0.2	2
	50	3.9 ± 0.5	5
	80	20.0 ± 2.1	17
	90-100	48.6 ± 2.4	61
150	30	2.0 ± 0.3	2
	50	3.6 ± 0.5	5
	80	21.7 ± 0.4	7
	90-100	47.4 ± 2.9	73
200	30	2.4 ± 0.2	2
	50	5.0 ± 0.4	5
	80	20.0 ± 0.3	17
	90-100	49.8 ± 5.9	83
250	30	2.7 ± 0.3	2
	50	6.7 ± 2.0	5
	80	27.9 ± 1.4	17
	90-100	73.0 ± 7.2	91
300	30	2.5 ± 0.4	2
	50	3.6 ± 0.7	5
	80	23.2 ± 4.1	7
	90-100	66.3 ±15.4	86

[1]Initial applications
[2]Heading at 90-100 DAT
± SEM

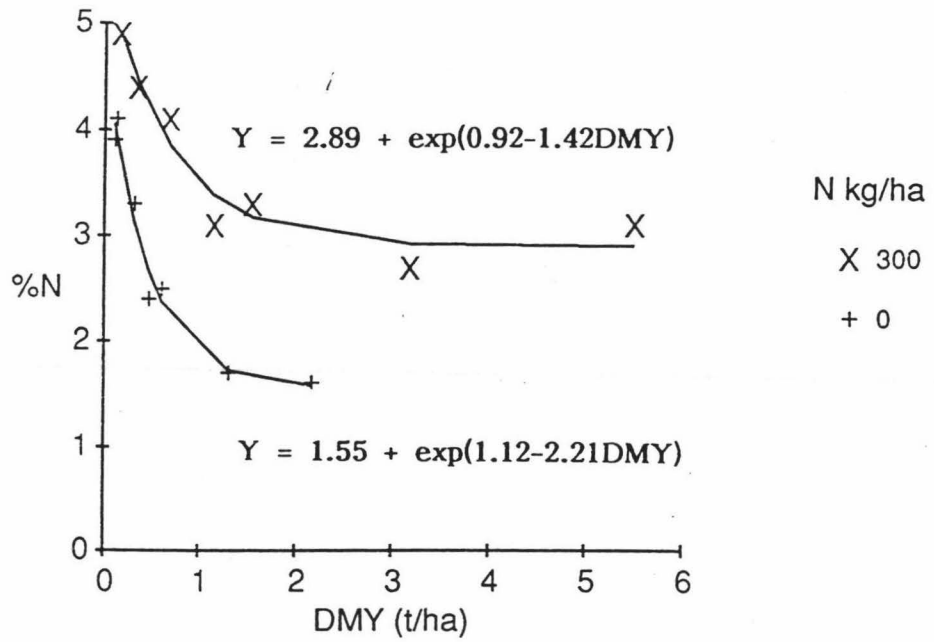

Figure 8.2 The %N in the dry matter yield (above ground parts of cabbages plotted against their dry matter yield measured at intervals during growth on treatments (x) 300 and (+) 0 kg N/ha in the 1988 field trial.

Table 8.7 Measured and predicted %N in cabbage plants for the 1989 field trial.

N kg/ha	DAT	Measured	Predicted	
0	50	4.1 ± 0.2	4.3[a]	3.1[b]
	80	3.7 ± 0.1	2.9	2.9
	90-100 (Heading)	3.8 ± 0.1	1.7	2.7
300	50	4.9 ± 0.2	5.1[a]	5.3[c]
	80	4.4 ± 0.1	3.4	4.8
	90-100 Heading)	4.1 ± 0.1	3.1	4.0

Predicted using [a]Equations shown in Figure 8.2; [b]Greenwood et al., (1989b) and [c]Greenwod (1986)
± SEM

Since the 300 kg N treatment was assumed to have achieved maximum yield in the 1988 study, the %N needed for maximum growth rate of cabbages at heading can be deduced, graphically. The predicted %N (4.0%) at heading was in very close agreement with that measured (4.1%) in accordance to Equation (2.6). Thus, this latter equation has potential to define the relationship between the minimum %N needed for maximum growth rate of winter cabbages at heading. The equation has been used successfully for other crops like potatoes, winter wheat and a variety of vegetable crops including winter cabbages (Greenwood et al., 1985b; 1987b; 1989b) provided they were grown at optimum soil N status.

In the sidedressing model the information on N uptake at heading (N_h), is required for a range of soil N status. Hence, a model that predicts N_h for all N fertilizer rates initially used (i.e., different soil N status situation) is needed to determine N_h and ultimately the amount of N fertilizer required for sidedressing.

The good predictions of dry matter yield and %N by Greenwood's models (1977; 1986) on the 300 kg N treatment consequently resulted in a very close agreement between the measured and predicted N uptake (Table 8.8). For instance, the measured (68 kg N/ha) N uptake by cabbages on this treatment at heading was very close to the predicted (66 kg N/ha) N uptake.

On the other hand, Greenwood's models for dry matter yield and %N proved unsatisfactory for the control treatment. Therefore, it appears that the previously derived equations of Greenwood et al., (1977) and Greenwood (1986) may only be used to predict N uptake by cabbages at heading (N_h) provided non-limiting conditions prevail at this stage. A combination of Scaife's model (for DMY) and Greenwood's model (for %N) to predict N_h slightly improved the agreement between the measured and predicted N uptake values (Table 8.8) for the control treatment for 80 and 90-100 DAT only.

Table 8.8 Measured and predicted N uptake (N kg/ha) by winter cabbages (above ground parts) in the 1989 field trial.

N kg/ha	DAT	Measured	Predicted	
0	50	2.1 ± 0.6	1.6[a]	3.8[b]
	80	13.9 ± 0.5	10.9	11.6
	90-100 (Heading)	29.6 ± 5.3	21.1	23.6
300	50	4.4 ± 1.4	4.8	
	80	25.5 ± 7.6	27.8	
	90-100 (Heading)	68.0 ±14.0	66.3	

[a]Predicted by Greenwood's model
[b]Predicted by Scaife's model (for DMY) and Greenwood's model (for %N)
± SEM

The evaluation of whether conditions are non-limiting or not at heading could be achieved either by using plant sap tests or having information on which N_s + N_h levels provide critical amount of N below which maximum yield is not reached. For 1988, N_h and N_s on the non-limiting treatment were 36 $\pm$ 10 and 45 $\pm$ 5 kg N/ha, respectively and in 1989 it was 45 $\pm$ 2.7 and 36 $\pm$ 18 kg N/ha, respectively. Given the large difference in climatic conditions between the 2 years, the sum of the mean values are surprisingly similar between years. Further trial data are needed to substantiate whether these values represent optimum levels for achieving maximum yield.

An alternative approach of predicting N plant uptake, under a range of N supply, is by using a model which is driven by growing degree days (GDD) or accumulated heat units (H_u). Several experiments have shown that the growth and yield of vegetable crops such as winter heading cauliflower (Wurr et al., 1981); potato, onion, garlic and hybrid squash (Buwalda and Freeman, 1987) and broccoli (Marshall and Thompson, 1987) are directly related to GDD or H_u. The growth rate of NZ sown crops studied by Buwalda and Freeman (1987) correlated closely with H_u and was described using low-order polynomial regressions. If dry matter yield can be related to accumulated H_u's, and also to N uptake, then it may be possible to predict N_h from H_u's accumulated between transplanting and heading. In addition, as indicated in Chapter 2 (section 2.5), to reduce the problem of site and season specificity of field trials the concept of using H_u has much potential. Additionally, the use of H_u would assist in eliminating or reducing the uncertainty of visual assessment of the heading stage of growth of cabbages (the critical time to apply N fertilizer as a sidedressing) which is quite arbitrary.

To apply the concept of GDD or H_u to predicting N plant uptake (including N_h) in the present study, the base temperature suitable for winter cabbages was first determined because no data were available in the literature. A quadratic function was fitted to the plant DMY data of treatment 300 kg N ha^{-1} for the 1988 field trial against the heat unit summation time scale. A number of base temperatures (0 to 10°C) were

tried and 2°C yielding the highest R^2 (with the least error mean square) was considered to be the most appropriate. For other vegetable crops, minimum temperature for growth was assumed to be 2°C for potato (MacKerron and Waister, 1985), 0°C for onions and garlic (Buwalda, 1986), and 10°C for hybrid squash (Slack and Hand, 1983). Accumulated H_u's were calculated in the present study from transplanting up to final harvest using 2°C base temperature following earlier equations (see Chapter 2 section 2.5) written in a computer spreadsheet programme (Multiplan 4.1). Inputs to the programme are the daily maximum and minimum air temperature.

Figure 8.3a shows the predicted cumulative N uptake curves of winter cabbages fertilised with various initial rates of N application using accumulated heat units as a time base in the 1988 field trial. The experimental data was fitted best by using an exponential relationship:

$$Y = A+B*\exp(C*X) \qquad \text{MODEL 1} \qquad (8.4)$$

where Y is the cumulative N uptake (kg N/ha) at the time of sampling; A was a constant (A = 0.12 kg N/ha) which refers to the amount of N already in the cabbage transplants at transplanting; B is a constant reflecting the linear component of increase in N uptake (kg N/H_u); C is a dimensionless constant reflecting the crop response coefficient and X refers to cumulative H_u's at the time of sampling.

Equation (8.4), Model 1, predicted well the N uptake values throughout crop growth with R^2 values ranging from 91.04-99.39% (Figure 8.3b). It could be noted (Appendix x) from the predicted curves that the C values did not vary much (mean value = 0.00285) between N treatments. Thus, the C coefficient can be regarded as a constant value, in the same way that, Greenwood et al., (1987b) assumed a constant k_2 (growth rate coefficient) value for predicting DMY of crops.

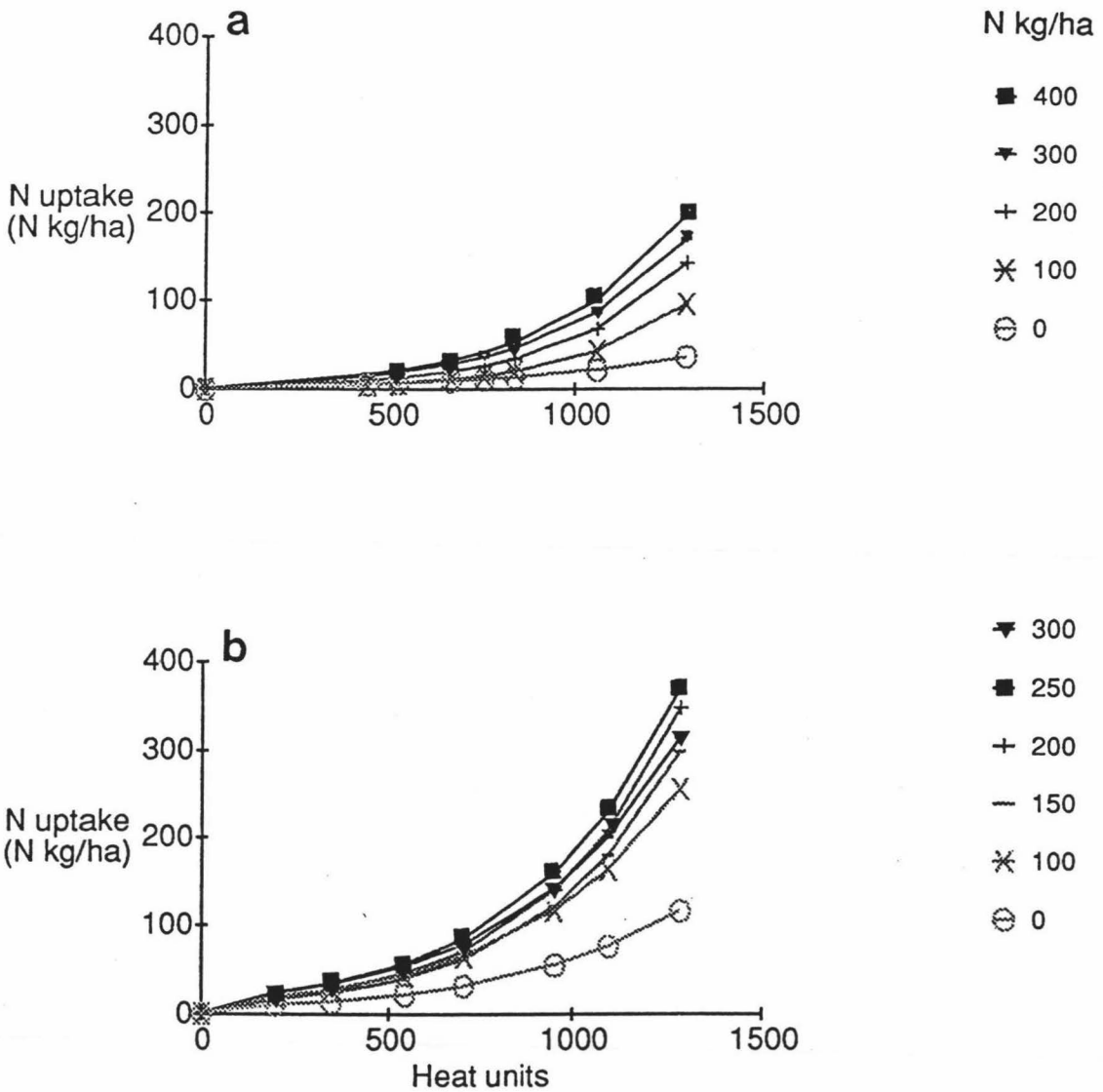

Figure 8.3 Predicted N uptake (N kg/ha) by winter cabbages (above ground parts) against heat units in the (a) 1988 and (b) 1989 field trial.

The constancy of a C value justified a modification of the exponential equation, this time, with A and C coefficients constant. This equation (Model 2) is in the form:

$$Y = 0.12+B*\exp(0.00285*X) \qquad \text{MODEL 2} \qquad (8.5)$$

The above equation produced a similar range of R^2 values (90.32-99.48%) as that of Model 1. This means that the predictive ability of Model 1 was not modified by holding A and C constant.

Using Model 2, from the predicted N uptake curves, the B values for the different N treatments were derived (see Appendix x). It will be noted from Appendix x that the B values varied (range = 0.94-4.79). For the 1988 field trial, the highest N uptake (192 kg N/ha) was associated with a B value of 4.79 kg N/H_a, hence, this value could be regarded as the Bmax. By relating the B values of the other N treatments with the Bmax (B/Bmax), then, the current N uptake status of any cabbage plant at any one time can be assessed. A value of 1.0 would indicate a 100% of the N uptake maximum at heading or any other time. There was a good relationship using a logistic function (R^2 = 0.9479) between B/Bmax and petiole sap NO_3-N concentrations for all rates of N fertilizer added (1988 data). Thus, the equation given in Figure 8.4a can be a predictor of B values which then can be used to predict N uptake at heading (N_h) which is the required information in the sidedressing model.

Using the B values (see Table 8.9) derived from the equation given in Figure 8.4a, another equation (Model 3) was established as:

$$Y = 0.12+B*\exp(0.00285*X) \qquad \text{MODEL 3} \qquad (8.6)$$

where $B = Bmax[1.06/(1+4.39*\exp(-0.0019*P_{sap})]$

Using Equation (8.6), the N uptake by cabbages at heading (N_h) were predicted in the 1989 field trial (Table 8.9). In all N rates, the predicted values were much lower than the measured values. This is not surprising

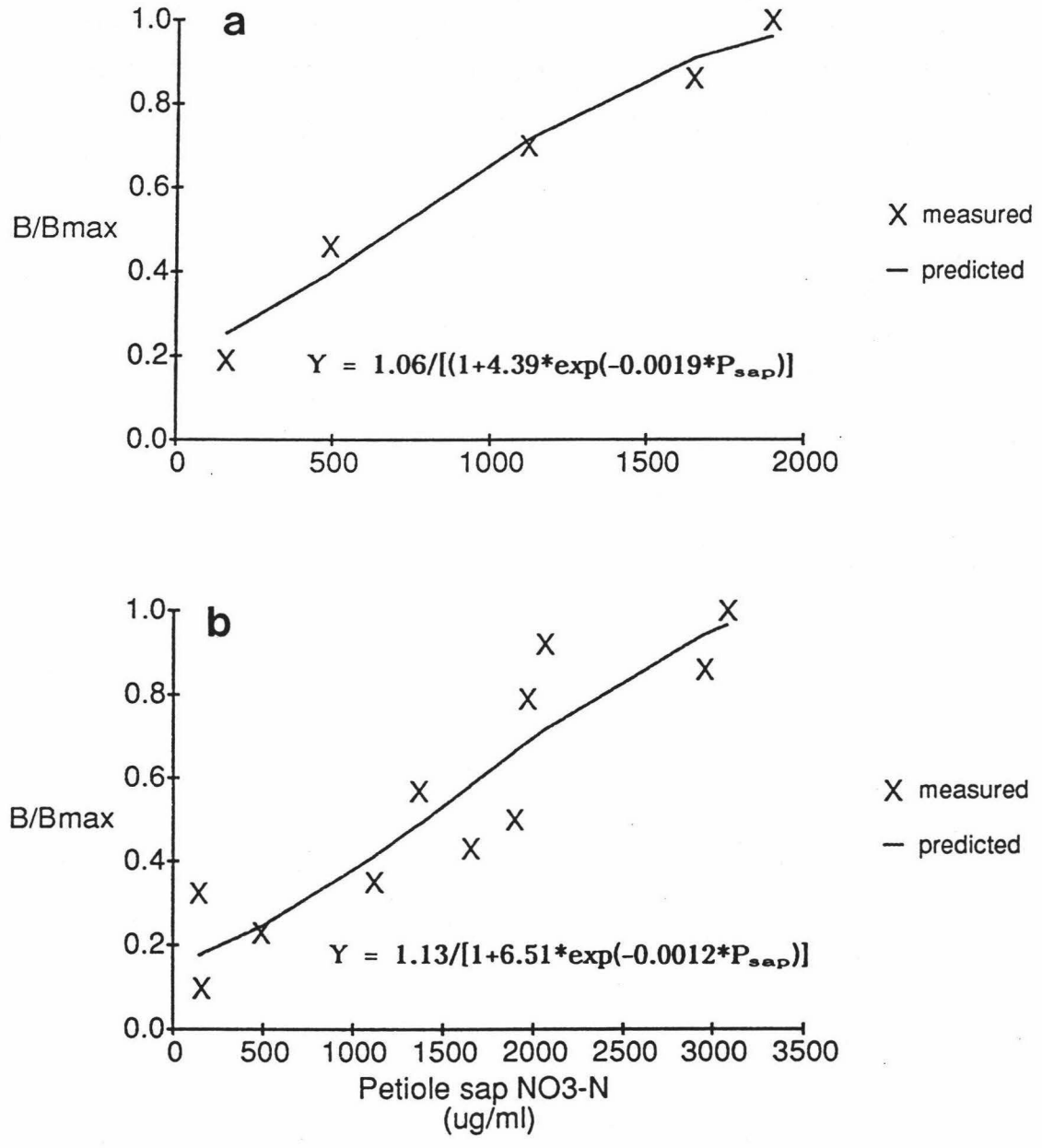

Figure 8.4 The relationship between B/Bmax and petiole sap NO3-N concentrations at heading in the (a) 1988 and (b) 1988 + 1989 field trials.

Table 8.9 Measured and predicted N uptake (N kg/ha) by winter cabbages (above ground parts) at heading in the 1989 field trial.

Treatment N kg/ha	Sap NO_3-N (μg/ml)	B[c]	N uptake[a] Measured	N uptake[a] Predicted	Model3[b] R^2
0	143	1.18	29.60	8.84	0.1957
100	1367	3.95	45.00	29.32	0.5998
150	1969	4.68	45.00	34.72	0.7086
200	2070	4.74	49.80	35.60	0.5990
250	3090	5.03	73.00	37.31	0.5484
300	2966	5.02	68.00	37.24	0.6367

[a]Measured at heading (700-800 H_u's)
[b]Y = 0.12+B*exp(0.00285*X); B values are given in the above table
[c]B = Bmax[(1.06/(1+4.39*exp(-0.002*X)]; where Bmax=4.79 (Appendix x)

because the overall growth rate of cabbages in 1989 was much higher than in 1988 as they were grown under a more favourable growing conditions (see Table 8.2) and higher overall soil N status (see Table 8.12).

However, the 2-year field trials data generated a wide range of N_h values (10-70 kg N/ha) and soil available N levels (15-125 kg N/ha). These ranges in values would probably relate to the range of values in regions where winter cabbages are grown. Thus, combining the data for 2 years would provide a preliminary model to assess **B** and **C** coefficients using Equation (8.4). This approach also increases the utility of the model (i.e., Equation 8.6) to predict N_h under contrasting growing conditions.

The N uptake by cabbages in all N rates for the 1989 field trial was found to be closely related with the accumulated heat units at the time of sampling (Figure 8.3b). The **B** and **C** values of the fitted equations are summarised in Appendix xi. The mean value of **C** for the 2-year field trials (0.00267) was used to run Equation (8.5), the modified form of the equation is given as:

$$Y = 0.12+B*\exp(0.00267*X) \qquad \text{MODEL 4} \qquad (8.7)$$

The **B** values for 1989 field trial data were, as expected, much higher (3-12 kg N/H_u) than in 1988. The highest N uptake (340 kg N/ha) in 1989 was associated with a B value of 12.14 kg N/H_u. Hence, this value could be regarded as the Bmax for the 2-year field trials.

The relationship (R^2 = 0.7958) of **B/Bmax** and petiole sap NO_3-N concentrations at heading for all N rates in the 2-year field trials using a logistic function is shown in Figure 8.4b. The relationship can be considered reasonable considering the fact that the data used in the regression represented two contrasting seasons. In relation to the long term rainfall average in the region, the 1988 growing condition could be regarded a "worse case" scenario which would only occur 1 in 10 years. Thus, the equation given in Figure 8.4b can be a predictor of **B** values which then can be used to predict N uptake at heading (N_h) which is the

required information in the sidedressing model.

By taking into account the new values for C and B, then, the modified form of Equation (8.7) is:

$Y = 0.12+B*\exp(0.00267*X)$ MODEL 5 (8.8)

where $B = Bmax[1.13/1+6.51*\exp(-0.0012*P_{sap})]$

Using Equation (8.8), the N uptake by cabbages in all N rates for the 2-year field trials were predicted (Table 8.10). In general there was a reasonable agreement between measured and predicted N uptake by the fertilised plants. In 1988, this includes initial rates (100 and 200 kg N) of fertilisation which ultimately gave below optimum yields and suggests that there is a potential in using this model (Equation 8.8) for N limiting situations although the agreement with control plot N uptake was not good particularly in 1989. This latter result, however, may not be of practical significance as cabbages are normally fertilised with N at transplanting.

The above results suggest that by simply measuring the NO_3-N concentration in the petiole sap of winter cabbages at heading (or after accumulation of 700-800 H_u's), then, the N uptake of the plants can be assessed from Equation (8.8) for predicting N_h in the sidedressing model.

Equation (8.8) was also found to predict well the N uptake by the fertilised cabbages at final harvest (or after the accumulation of 1200-1300 H_u's) i.e., N_y as determined in the sidedressing model is predicted (Table 8.11). This ability (prognosis) of the model to predict N_y may be of use if a model for determining fertilizer requirements needs a prediction of N_y. Although N_y is considered to be a fixed value in the sidedressing model (i.e., 170 kg N/ha for a horticultural soil type) a different N_y value may be required for other markedly different soil types and localities. At other sites, although N_y values should be determined experimentally, the heat unit model may provide an initial estimate of N_y achieved with a particular N_h at heading. Growers actual yields could then be related to

Table 8.10 Measured and predicted N uptake (N kg/ha) by winter cabbages (above ground parts) at heading in the 1988 and 1989 field trials.

Treatment N kg/ha		Sap NO_3-N (μg/ml)	B[d]	N uptake[a] Measured	N uptake[a] Predicted	Model4[b] R^2	Model5[c] R^2
1988	0	159	2.16	11.83	16.14	0.9416	0.6312
	100	491	3.24	15.84	22.06	0.9570	0.9573
	200	1120	5.31	30.50	37.12	0.9806	0.9342
	300	1651	7.05	36.63	52.59	0.9916	0.7670
	400	1897	7.86	37.34	59.85	0.9800	0.7970
1989	0	143	2.11	29.60	13.94	0.9180	0.5368
	100	1367	6.12	45.00	38.76	0.9028	0.7569
	150	1969	8.09	45.00	54.33	0.9660	0.9407
	200	2070	8.42	49.80	56.84	0.9630	0.8882
	250	3090	11.77	73.00	76.49	0.9498	0.9549
	300	2966	11.36	68.00	74.66	0.9131	0.9118

[a]Measured at 700-800 H_u's; N uptake predicted by Model 5
[b]Y = 0.12+B*exp(0.00267*X); B values are given in Appendix xi
[c]Y = 0.12+B*exp(0.00267*X); B values are given in the above table
[d]B = Bmax[(1.13/6.51*exp(-0.0012*X)]; where Bmax=12.14 (Appendix xi)

Table 8.11 Measured and predicted N uptake (N kg/ha) by winter cabbages (above ground parts) at final harvest in the 1988 and 1989 field trials.

Year	Treatment N kg/ha	Sap NO_3-N (μg/ml)	B[d]	N uptake[a] Measured	N uptake[a] Predicted	Model4[b] R^2	Model5[c] R^2
1988	0	159	2.16	35.23	68.90	0.9416	0.6408
	100	491	3.25	97.79	103.29	0.9570	0.9199
	200	1120	5.31	144.08	169.19	0.9806	0.8788
	300	1651	7.05	169.14	224.62	0.9916	0.7703
	400	1897	7.86	192.48	250.29	0.9800	0.8302
1989	0	143	2.11	105.70	65.08	0.9180	0.5314
	100	1367	6.12	229.10	188.73	0.9028	0.7789
	150	1969	8.09	284.20	249.55	0.9660	0.9292
	200	2070	8.42	329.60	259.75	0.9630	0.8690
	250	3090	11.77	340.90	362.79	0.9498	0.9554
	300	2966	11.36	281.10	350.27	0.9131	0.9140

[a]Measured at 1200-1300 H_u's; N uptake predicted by Model 5
[b]Y = 0.12+B*exp(0.00267*X); B values are given in Appendix xi
[c]Y = 0.12+B*exp(0.00267*X); B values are given in the above table
[d]B = Bmax[(1.13/6.51*exp(-0.0012*X)]; where Bmax=12.14 (Appendix xi)

them and tentative N_y values established for a particular soil or range of soils.

For the 2-year field trial data, it is evident that different values of N_y were obtained for a range of initial soil N status (Figure 8.5) i.e., different rate of N fertilizer at transplanting. It is shown that on this particular soil type there was a sharp initial response to N, then, as more N was applied a turning point was reached beyond which yield changed little. It is suggested from the fitted response curve (after a modified Mitscherlich growth model) that the amount of N required to obtain 90% within the maximum yield is about 170-180 kg N/ha at final harvest. Any N_y value higher than these values may represent an inefficient use of fertilizer N, hence, a waste of economic resources for the grower.

In the short term, a cabbage grower may apply N in excess of that required to ensure that a maximum yield is achieved. In the long term, however, repeated applications of excess N could result in serious threats to the quality of the environment (i.e., ground water pollution by high NO_3 levels) and the product (i.e., accumulation of excessive NO_3 levels). For instance, where N_y values were >200 kg N/ha, cabbages had petiole sap NO_3-N concentrations >1000 μg ml^{-1} at final harvest. Therefore growers and environmental administrators could be alerted to these potential problems by using the N_y prediction from Equation (8.8).

The relationship between yield and N_y plus the model developed in Equation (8.8) will be useful for assessing the levels of N that should be applied to give marketable cabbage yield while maximizing the input of N into the winter cabbage system.

8.3.5.2 *Predicting N_s*

In Chapter 6 (see Figure 6.8b) the concentrations of NO_3^- + NH_4-N in petiole sap (P_{sap}) of cabbages have been shown to relate well to the concentrations of soil NO_3^- + NH_4-N (N_s) to a depth of 30 cm for all

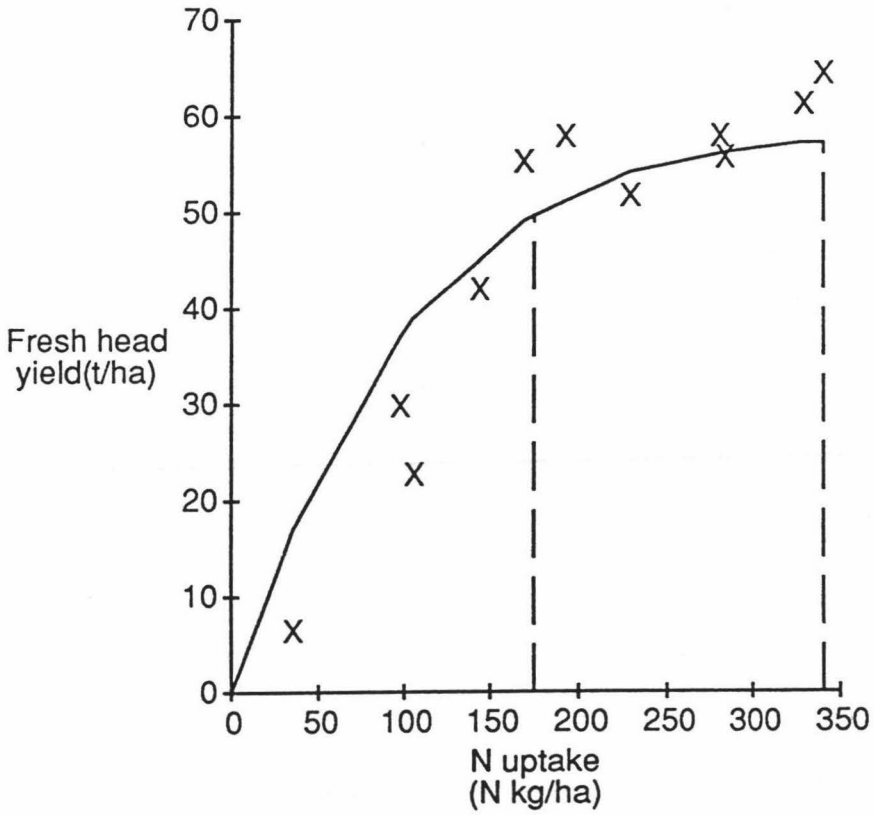

Figure 8.5 The relationship between fresh head yield (t/ha) and N uptake (N kg/ha) by cabbages at final harvest for the 1988 and 1989 field trials (pooled data).

sampling dates. Other workers (Iversen et al., 1985; Darby et al., 1986) have also found satisfactory relationship between the two but no predictive equations were established. Hence, N_s in the sidedressing model may be predicted using P_{sap} N concentrations. Using 1988 field trial data, the relationship between P_{sap} N concentrations and N_s measured prior to and at heading was best described by a simple linear equation as:

$$N_s = 15.3 + 0.05P_{sap} \qquad (8.9)$$
$$R^2 = 0.8206 \ (n=15)$$

where N_s is the soil available N at 0-30 cm depth (kg N/ha); P_{sap} is the concentration of NO_3-N (μg/ml) in petiole sap of cabbages.

At heading, the agreement between the measured and predicted N_s was reasonable particularly on the control and high N rates (Figure 8.6). Thus, Equation (8.9) can predict N_s at heading which is the required information in the sidedressing model. The predicted values on some treatments, however, tended to be much higher than the measured N_s. This may have resulted from the unexpectedly high P_{sap} N concentrations (2-3 times higher) in 1989 than in 1988 (see Table 8.4). Normally, P_{sap} N concentrations would decrease with plant age irrespective of initial rate of N application for reasons mentioned earlier (see Chapter 4 section 4.4.4). This was, however, not observed in 1989 where P_{sap} N concentrations in all N treatments excluding control and 100 kg N were maintained at a very high level (>1000 μg/ml) until the final harvest. The higher P_{sap} N concentrations in the fertilised plants in 1989 at heading were associated with higher N_s levels than in 1988 (Table 8.12).

Prior to heading, the levels of measured N_s were much higher than the predicted N_s (Table 8.12) although P_{sap} N concentrations in some treatments were low. It is possible that in 1989 a greater proportion of the mineral N on these treatments remained in the top 30 cm depth prior to heading as drainage events were low which could have reduced the leaching losses of N (see Table 8.2). The high levels of N_s, however, were not associated with increases in P_{sap} N concentrations. It was relatively

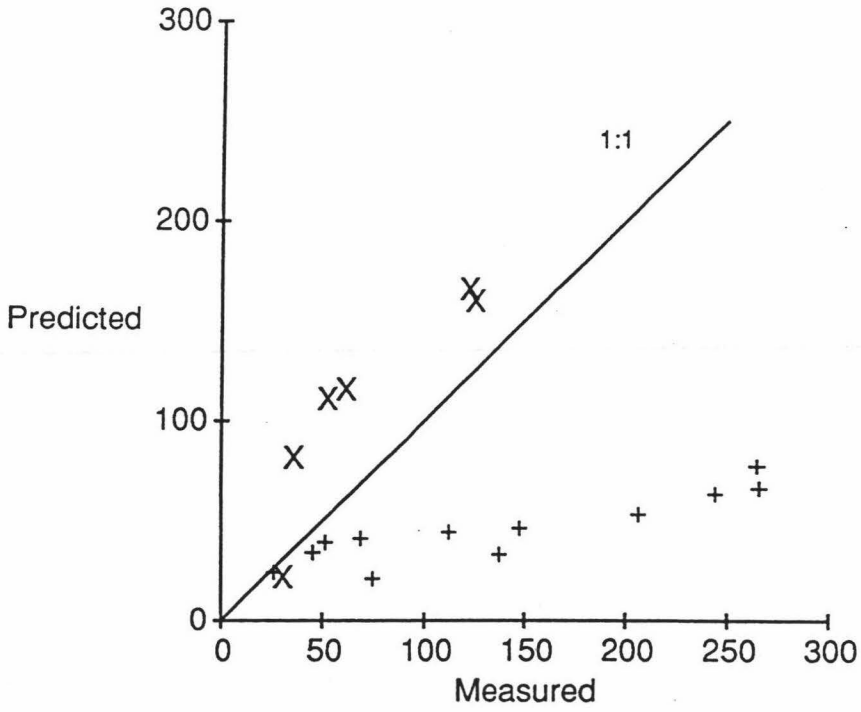

Figure 8.6 Measured and predicted soil N levels (N kg/ha) prior to (+) and at heading (x) in the 1989 field trial.

Table 8.12 Measured (1988 and 1989) and predicted (1989) N_s (N kg/ha) at two sampling growth stages using petiole sap N concentrations as the predictor in the linear model.

N kg/ha[1]	Sampling stage	Measured 1988	Measured 1989	Predicted 1989
0	Pre-heading	74 ± 6	74 ± 8	21
	Heading	15 ± 1	31 ± 9	22
100	Pre-heading	90 ±23	137 ±12	33
	Heading	20 ± 2	36 ±18	82
200	Pre-heading	106 ±22	244 ±30	62
	Heading	32 ±11	61 ± 8	116
300	Pre-heading	125 ±12	265 ±48	65
	Heading	45 ± 5	125 ±14	160

[1]Initial applications
± SEM

dry during this period (see Table 8.2), hence, soil moisture conditions were probably limiting the uptake of N by the plants.

It would appear that in order to develop a transferable predictive equation, more widespread soil and sap testing is needed to cover a wide range of soil N status and growing conditions than experienced in this study.

An alternative approach for determining N_s would be to develop a mechanistic model similar in principle to the one of Mohammed et al., (1987a) for predicting the fate of fertilizer N in barley fertilised with urea-N at sowing. This latter model required daily inputs of rainfall (irrigation), mean air temperature, short-wave radiation, and crop height and included the effect of drainage events following initial fertilizer application. One output of the model was to predict values of soil inorganic N at any time during the barley crop growth. They found that there was a considerable temporal variation in the measured data of soil inorganic N, and in both years of study, the agreement between predicted and measured values was poor. The discrepancy was attributed to native soil N mineralising at a more rapid rate than that predicted by the model.

Due to insufficient information, the approach of Mohammed et al., (1987a), could not be applied in the present study. For instance, data on evapotranspiration (E_t) could not be accurately calculated because of the varying proportion of uncovered ground area with growth stage of cabbages. The model of Mohammed et al., (1987a) considered a full-cover crop situation which did not occur in the present study.

Although at transplanting the two soils had similar amounts of initial extractable soil NO_3^- + NH_4-N (14 kg N/ha), the 1989 control soil was assessed to have more potentially mineralisable N (7 μg N/g soil) than the 1988 control soil (4 μg N/g soil) based on an anaerobic incubation study using the method of Waring and Bremner (1964). A contradictory result, however, was observed in the field between transplanting and heading where the 1988 control soil was mineralising at a faster rate and more available soil N was produced over the first 20 DAT (Figure 8.7) than for

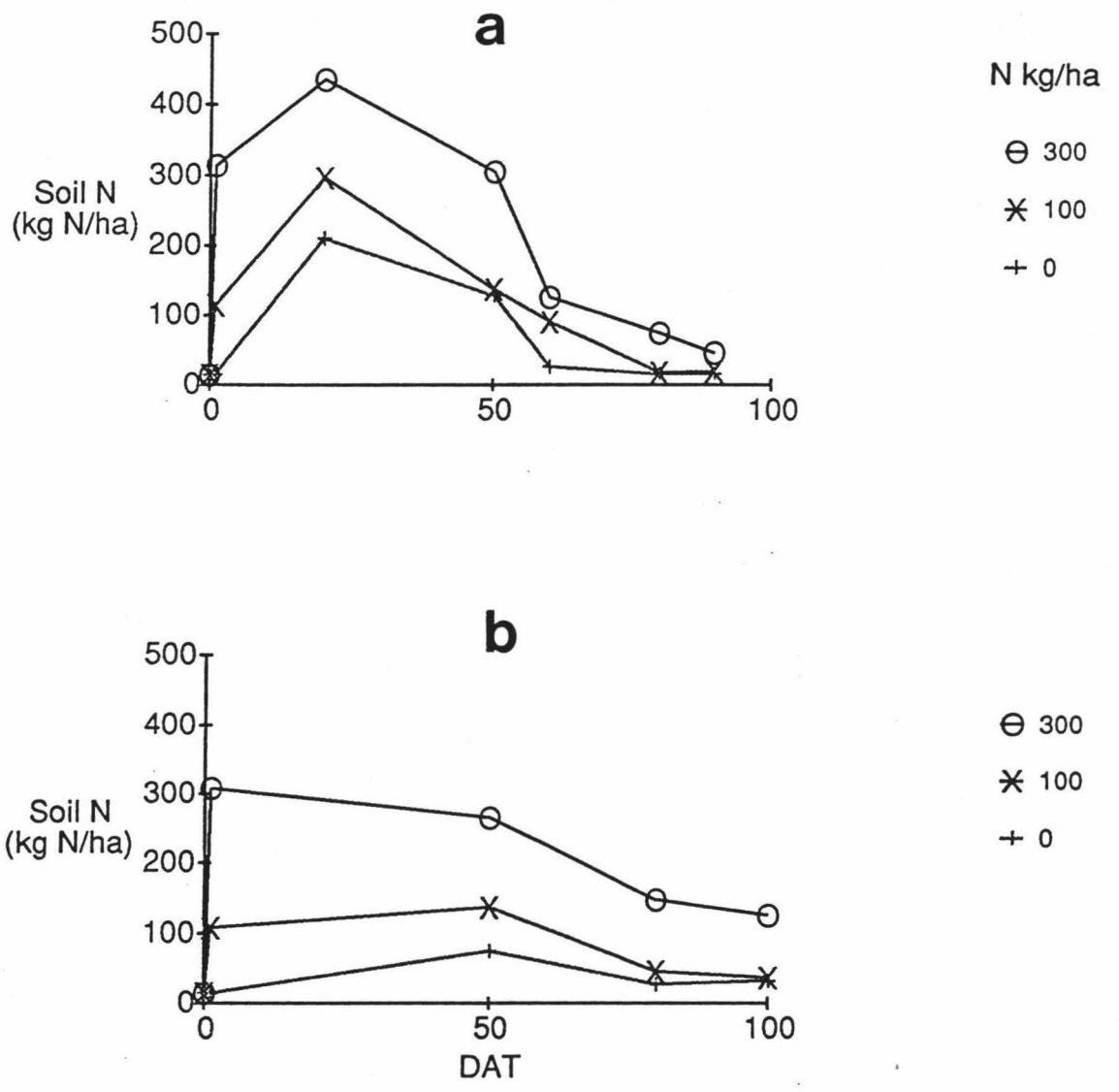

Figure 8.7 Available N (NO3- + NH4-N) in the soils (0-30 cm depth) from transplanting to heading in (a) 1988 and (b) 1989 field trial.

the 1989 control soil. This result, however, is not be very conclusive because limited soil samplings were done during the initial part of each study. The large flush of N mineralisation which led to the high soil NO_3^- and NH_4^+ concentrations measured at 20 DAT is difficult to predict, not only because laboratory measurements of the amounts of soil mineralisable N did not predict the differences observed between years, but that this flush, caused presumably by cultivation, will be dependent upon the method and extent of cultivation. Therefore, more work is needed to develop a model for predicting N_s in the sidedressing model. Future models should include a component which assesses the rate of soil N mineralisation for a range of soil N status and soil preparation conditions.

8.4 CONCLUSION

The sidedressing model shows some potential in determining the rate of N fertilizer required by winter cabbages as a sidedressing at heading in order to achieve maximum yield. The limitation of the model of being site and season specific can be reduced to some extent by applying a simple submodel to predict the component which assesses N in cabbages at heading (N_h). The N_h component could be accurately predicted by using some models available in the literature or by using a model which is driven by H_u's for situations where soil N status is not too limiting but for situation where N status was very limiting, N_h, was more difficult to predict.

Alternatively, rather than using the original sidedressing model to determine rate required at sidedressing, it would be feasible to create an alternative model which for any one N situation the amount applied at sidedressing would represent the difference between the predicted N_y and N_y for maximum yield and would include a fertilizer efficiency factor.

Overall, the sidedressing model requires additional validation over a further range of soil and climatic conditions. It would also have greater utility if the other parameters like N_s (soil available N at heading) were able to be

predicted. To this end, it would appear that there would be advantages if the effects of initial N fertilizer application was included in the model. Prediction of the efficiency components of fertilizer N (E_f) and soil N (E_s) remain elusive as they are weather dependent.

Like all biological systems subject to perturbations of climate, accurate prediction of N requirements for winter cabbages is elusive. The model development utilised data from an experiment conducted in a very wet year. From the point of view of N losses from the system, this situation could be considered the "worse case" scenario. Validation was conducted using data derived in a very favourable growth season and N losses appeared to be minimal. Despite these differences between growing seasons, the sidedressing model shows promise as a means of predicting N fertilizer requirements at heading for winter cabbage production.

CHAPTER 9

SUMMARY

The literature review (Chapter 2) has indicated that there is much uncertainty about the N fertilizer requirements of vegetable crops in both NZ and overseas. Current N fertilizer recommendations in NZ have generally been determined from rate type field experiments where a fixed fertilizer rate is derived for a particular crop. Elsewhere (e.g., in the UK) dynamic models have recently been developed and validated experimentally to predict responses of crops, including a range of vegetables, to N fertilizers. The limitation of these models is that they do not predict what N fertilizer rate is needed to meet optimum crop N requirements under a range of situations varying in N status. In NZ, models for determining the N fertilizer requirements have not been developed.

This study was conducted with the general objective of assessing the N fertilizer requirements of winter cabbages, a typical example of a head type leaf vegetable.

Results of a glasshouse evaluation (Chapter 3) on sap nitrate testing indicated that the rapid test, which makes use of "Merckoquant" test strips, accurately measured the NO_3-N concentration in petiole sap of cabbages over a range of concentrations likely to be found in practice. The rapid test was strongly correlated with the standard methods of measuring NO_3-N in plants namely: acetic acid extraction (standard procedures for most horticultural crops including vegetables in the USA) and the autoanalyser method.

A series of preliminary experiments to examine some factors affecting NO_3 and NH_4-N concentrations in the xylem and petiole sap of cabbages were evaluated in the glasshouse and field (Chapter 4). Results indicated that leaf position, time of day, sample storage time and plant age are important criteria for relating plant sap N concentration to N status of

cabbages.

Leaf position within the plant influenced sap NO_3-N concentration. The effect was dependent on the rate of N supply i.e., at lower rates of N application, concentrations were similar in both leaf petioles but at higher rates, petioles of young mature leaves (YML) had significantly higher concentrations of NO_3-N than wrapper leaves (WL). Petioles of YML, compared with WL, are the preferable leaves to sample for sap nitrate analysis due to lower variability in NO_3-N concentration and for more sampling convenience.

Nitrate-N concentration in xylem sap gradually decreased with time of the day but concentration in petiole sap was fairly stable within the sampling period. Concentrations of NO_3 and NH_4-N in xylem sap decreased significantly when sap samples were not placed in the freezer within 36-hr after collection. For more accurate measurement of sap NO_3 and NH_4-N concentrations it is preferable to place sap samples in the freezer immediately after collection.

Expectedly, NO_3-N concentrations in petiole and xylem sap decreased with plant age as a result of greater N assimilation rate than N uptake during the later stages of crop growth.

The effect of fertilizer forms (N, P and N/P) on NO_3^- and NH_4-N and PO_4-P concentrations in xylem sap and on growth and yield of winter cabbages was investigated in the glasshouse and field (Chapter 5). Nitrogen fertilizers were either nitrate-N (KNO_3) or ammonium-N (AmS or urea) and P fertilizers were either readily soluble P (MCP), 50% soluble P (PAPR) or slowly soluble P (NCPR).

Form of N fertilizer markedly influenced concentrations of NO_3^- and NH_4-N but not PO_4-P in xylem sap. Higher NO_3-N concentrations were measured when N was in the nitrate form while ammoniacal form of N produced higher NH_4-N concentrations in the sap. The readily soluble P (MCP) and 50% soluble P (PAPR) in combination with ammoniacal form of

N resulted in higher NO_3^- and NH_4-N concentrations than the slowly soluble P (NCPR). The predominance of NO_3^- over NH_4^+ in xylem sap points out that NO_3^- is the major form of transport of N into cabbages. When both ions are present in soil solution, NO_3^- is preferentially utilised by cabbages over NH_4^+. There is little NO_3 reductase activity in the roots of cabbages.

In terms of agronomic effectiveness evaluated in the glasshouse, N/PAPR and N/MCP products made with either Urea or KNO_3 at equal rate of application, are equally effective N and P sources for winter cabbages grown in a recent alluvial soil with low P retention capacity. Comparison among the different N/P products suggests that at higher application rates, AmS/PAPR and AmS/MCP are the least efficient products. This could be due to initial high salt concentrations in the soils, intense soil acidification and accumulation of toxic levels of NH_4-N in the soils.

In a limited evaluation in the field, Urea/PAPR was found not to be as agronomically effective N fertilizer as the readily soluble N fertilizer forms (Urea/Super and CAN/Super) as starter fertilizers for winter cabbages. Further assessment in the field is required to validate this result.

To assess the utility of plant sap and soil nitrogen indices for indicating the N fertilizer sidedressing requirements of winter cabbages, a large field trial (Chapter 6) was conducted with various rates of calcium ammonium nitrate (0-400 kg N/ha) and two levels of urea sidedressing (nil and 100 kg N/ha) at heading as the main treatments. At 4 sampling dates (50, 60, 80 and 90 DAT) and prior to sidedressing xylem (R^2 = 0.73**) and petiole (R^2 = 0.86**) sap NO_3-N and NH_4-N concentrations were strongly correlated to extractable NO_3-N and NH_4-N in the soil to a depth of 30 cm. Nitrate-N levels in xylem sap at 60 and 80 DAT and petiole sap at 50, 60 and 80 DAT were good predictors of harvestable fresh head yield. Maximum marketable yield (55 t/ha) was achieved with an initial application of 300 kg N/ha over a growing period of 150 days in which 448 mm of drainage was measured. At heading, on the 300 kg N/ha treatment, soil mineral N

levels were 75 ± 7 kg N/ha, xylem sap concentration was 333 ± 21 μg/ml NO_3-N and 1651 ± 134 μg/ml NO_3-N in the petiole sap. The critical value for petiole sap is higher than that reported in the literature for cabbages. At petiole sap levels below the critical value at heading, sidedressing with 100 kg N/ha as urea was required to achieve similar yield as found with an initial application of 300 kg N/ha as CAN.

The efficiency of ^{15}N labelled urea-N fertilizer applied as a sidedressing at heading stage of growth of winter grown cabbages was assessed in a field trial (Chapter 7). At final harvest, plant recovery of sidedressed ^{15}N did not differ between rates (62-65%) which is in contrast to the expected result of decreasing efficiency of fertilizer utilization with increasing initial application rates. Total recovery of ^{15}N in the plant and soil were high (114 ± 0.9% and 90 ± 1.1% for the respective rates).

Assuming that the initial rate used to fertilise transplanted cabbages will be based on past grower practice and experiences, a simple model termed a "sidedressing model" was developed (Chapter 8). The model is designed to determine the amount of N fertilizer needed to be applied as a sidedressing at heading to obtain maximum yield. In a rather limited validation, only whether a sidedressing is required or not was successfully predicted from the model. Thus, further validation is required to determine the N fertilizer rate predictions of the model. Unless actual rate of sidedressing can be accurately predicted, the model provides no more information than the sap test method.

The limitation of the sidedressing model of being site and season specific could be reduced to some extent by applying simple submodels to predict the component which measures N in cabbage at heading (N_h). The N_h component could be predicted by using some models available in the literature or by using a model which is driven by heat units (H_u's) for situation where soil N status is not too limiting. For situations, where N status was very limiting, N_h, was more difficult to predict. The other components of the model which include soil N status at heading (N_s) and the efficiency of plant uptake of fertilizer N (E_f) and soil N (E_s) from

heading to maturity could not be accurately predicted due to insufficient data and/or contrasting climatic conditions between the growing seasons. Despite the differences between growing conditions associated with the validation data, the model shows promise as a means of predicting N fertilizer requirements at heading for winter cabbage production. Overall, further validation is required to improve the sidedressing model particularly on a wide range of soil and climatic conditions.

The use of the heat unit model, developed from 2-year trial data, to predict N_h also provided a prediction of N_y. Although not able to be validated in the present study, this model which utilises sap test, has potential for assessing the levels of N that should be applied at heading to give marketable cabbage yield. The fact that the model can predict N_y may be of use to environmental administrators in predicting the likely effects of various growers' practices in relation to identifying problems associated with NO_3-N in drinking water quality and in edible cabbage heads.

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Appendix i

The effect of N fertilizer form on NO_3-N concentrations (μg/ml) in xylem sap of cabbages.

Form	g N/P pot^{-1}	Time of sampling (DAT) 40	60	160
Control		456	99	15
Urea	1.0	631	338	13
	2.0	708	380	39
	4.0	778	590	86
AmS	1.0	559	365	8
	2.0	553	403	10
	4.0	580	333	6
KNO_3	1.0	716	861	37
	2.0	599	935	25
	4.0	393	2575	702
$LSD_{.05}$		575	622	145

The effect of N fertilizer form on NH_4-N concentrations (μg/ml) in xylem sap of cabbages.

Form	g N pot^{-1}	Time of sampling (DAT) 40	60	160
Control		54	55	107
Urea	1.0	67	50	74
	2.0	111	148	71
	4.0	440	217	99
AmS	1.0	113	89	62
	2.0	232	195	87
	4.0	432	310	973
KNO_3	1.0	77	80	62
	2.0	61	87	70
	4.0	389	63	63
$LSD_{.05}$		180	115	145

Appendix ii

The effect of P fertilizer form on NO_3-N concentrations (μg/ml) in xylem sap of cabbages. The levels of NO_3^- in the soils are given in parentheses. Trace amounts (<1 μg/g) of NO_3^- were measured in all treatments at 160 DAT.

Form	g N/P pot^{-1}	Time of sampling (DAT) 40	60	160
Control		456 (39)	99 (9)	15
Ams/Control	2.0/0	553 (83)	403 (71)	10
	4.0/0	579 (80)	332(111)	6
AmS/MCP	2.0/1.9	604(100)	350 (51)	9
	4.0/3.9	1096(132)	546 (81)	13
AmS/PAPR	2.0/2.1	881 (85)	417 (86)	14
	4.0/4.2	1081(117)	940 (95)	21
AmS/NCPR	2.0/2.0	598 (82)	ND	11
	4.0/4.1	769(102)	ND	10
$LSD_{.05}$		268	159[a]	16

[a]Excluding AmS/NCPR
ND = not determined

The effect of P fertilizer form on NH_4-N concentrations (μg/ml) in xylem sap of cabbages. The levels of NH_4^+ in the soils are given in Table 5.8.

Form	g N/P pot^{-1}	Time of sampling (DAT) 40	60	160
Control		54	55	107
Ams/Control	2.0/0	232	195	62
	4.0/0	432	310	87
AmS/MCP	2.0/1.9	294	109	61
	4.0/3.9	702	187	225
AmS/PAPR	2.0/2.1	265	171	95
	4.0/4.2	734	377	118
AmS/NCPR	2.0/2.0	157	ND	82
	4.0/4.1	383	ND	84
$LSD_{.05}$		157	89[a]	88

[a]Excluding AmS/NCPR
ND = not determined

Appendix iii

The effect of N fertilizer form on PO_4-P concentrations (μg/ml) in xylem sap of cabbages.

Form	g N/P pot^{-1}	Time of sampling (DAT) 40	60	160
Control		42	60	149
AmS/Control	1.0/0	103	80	202
	2.0/0	87	64	163
	4.0/0	99	200	63
AmS/MCP	1.0/0.9	148	125	256
	2.0/1.9	203	196	258
	4.0/3.9	526	324	392
KNO_3/MCP	1.0/1.1	160	115	91
	2.0/2.2	295	217	189
	4.0/4.4	558	373	270
$LSD_{.05}$		116	115	45

Appendix iv

The results of regression analysis for the effect of N and P application rate as Urea/P on NO_3-N concentration in xylem sap of cabbages.

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	492932.48	492932.48	22.74*
N*N	1	59684.96	59684.96	2.75^{ns}
P (water)	1	1163.50	1163.50	0.05^{ns}
P*P	1	12420.28	12420.28	0.57^{ns}

The results of regression analysis for the effect of N and P application rate as Urea/P on NH_4-N concentration in xylem sap of cabbages.

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	90298.37	90298.36	30.72*
N*N	1	2853.01	2853.01	0.97^{ns}
P (water)	1	6477.56	6477.56	2.20^{ns}
P*P	1	433.81	433.81	0.15^{ns}

The results of regression analysis for the effect of N and P application rate as Urea/P on P concentration in xylem sap cabbages.

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	85269.89	85269.89	37.40*
N*N	1	1.04	1.04	0.00^{ns}
P (water)	1	7663.03	7663.03	3.36^{ns}
P*P	1	1085.80	1085.80	0.48^{ns}

* = Significant at 5%; ns = not sigificant

Appendix v

The results of regression analysis for the effect of N and P application rate as AmS/P on NO_3-N concentration in xylem sap of cabbages.

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	838260.33	838260.33	145.76**
N*N	1	50793.22	50793.22	8.83ns
P (water)	1	37269.03	37269.03	6.48ns
P*P	1	66600.77	66600.77	11.58ns

The results of regression analysis for the effect of N and P application rate as AmS/P on NH_4-N concentration in xylem sap of cabbages.

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	404826.17	404826.17	121.89**
N*N	1	49595.38	49595.38	14.93ns
P (water)	1	34227.61	34227.61	10.31ns
P*P	1	5461.24	5461.24	1.64ns

The results of regression analysis for the effect of N and P application rate as AmS/P on P concentration in xylem sap of cabbages.

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	24458.32	24458.31	6.42ns
N*N	1	25.45	25.45	0.01ns
P (water)	1	8332.98	8332.98	2.19ns
P*P	1	51.05	51.05	0.01ns

** = Significant at 1%; ns = not significant

Appendix vi

The results of regression analysis for the effect of N and P application rate as KNO_3/P on NO_3-N concentration in xylem sap of cabbages.

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	756472.56	1756472.56	58.57*
N*N	1	53.39	53.39	0.00^{ns}
P (water)	1	4158.84	4158.84	0.14^{ns}
P*P	1	62869.46	62869.46	2.10^{ns}

The results of regression analysis for the effect of N and P application rate as KNO_3/P on NH_4-N concentration in xylem sap of cabbages.

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	7885.03	7885.03	23.42^{ns}
N*N	1	823.02	823.02	2.44^{ns}
P (water)	1	3411.05	3411.05	10.13^{ns}
P*P	1	181.79	181.79	0.54^{ns}

The results of regression analysis for the effect of N and P application rate as KNO_3/P on P concentration in xylem sap of cabbages.

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	102853.89	102853.89	74.47*
N*N	1	174.59	174.59	0.13^{ns}
P (water)	1	4895.10	4895.10	3.54^{ns}
P*P	1	3408.06	3408.06	2.47^{ns}

* = Significant at 5%; ns = not significant

Appendix vii

The results of regression analysis for the effect of N and P application rate as Urea/P on cabbage dry matter yield.

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	38247.84	38247.84	396.20**
N*N	1	1750.62	1750.62	18.13^{ns}
P (total)	1	52.03	52.03	0.54^{ns}
P*P	1	0.85	0.85	0.01^{ns}

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	38247.84	38247.84	396.01**
N*N	1	1750.62	1750.62	18.13^{ns}
P (water)	1	51.61	51.61	0.53^{ns}
P*P	1	0.79	0.79	0.01^{ns}

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	38247.84	38247.84	396.14**
N*N	1	1750.62	1750.62	18.13^{ns}
P (citric)	1	51.88	51.88	0.54^{ns}
P*P	1	0.83	0.83	0.01^{ns}

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	38247.85	38247.85	396.15**
N*N	1	1750.62	1750.62	18.13^{ns}
P (formic)	1	51.92	51.92	0.54^{ns}
P*P	1	0.84	0.84	0.01^{ns}

** = Significant at 1%; ns = not significant

Appendix viii

The results of regression analysis for the effect of N and P application rate as Ams/P on cabbage dry matter yield.

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	7.68	7.68	0.04^{ns}
N*N	1	11319.23	11319.23	53.70*
P (total)	1	0.67	0.67	0.00^{ns}
P*P	1	227.99	227.99	1.08^{ns}

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	7.68	7.68	0.05^{ns}
N*N	1	11319.23	113129.23	78.98*
P (water)	1	0.13	0.13	0.00^{ns}
P*P	1	1038.04	1038.04	7.24^{ns}

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	7.68	7.68	0.09^{ns}
N*N	1	11319.23	11319.23	134.93**
P (citric)	1	0.59	0.59	0.01^{ns}
P*P	1	1750.72	1750.72	20.87^{ns}

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	7.69	7.69	0.10^{ns}
N*N	1	11319.23	11319.23	149.43**
P (formic)	1	0.30	0.30	0.00^{ns}
P*P	1	1848.71	1848.71	24.41^{ns}

**, * = Significant at 1, 5%; ns = not significant

Appendix ix

The results of regression analysis for the effect of N and P application rate as KNO_3/P on cabbage dry matter yield.

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	28513.36	28513.36	228.39**
N*N	1	7957.71	7957.71	63.74*
P (total)	1	100.95	100.95	0.81ns
P*P	1	31.13	31.13	0.25ns

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	28517.56	28517.56	228.10**
N*N	1	7954.48	7954.48	63.62*
P (water)	1	100.66	100.66	0.81ns
P*P	1	31.48	31.48	0.25ns

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	28513.36	28513.36	228.39**
N*N	1	7957.56	7957.56	63.74*
P (citric)	1	100.96	100.96	0.81ns
P*P	1	31.13	31.13	0.25ns

Source of variation	df	Sum of squares	Mean sum of squares	F
N	1	28513.36	28513.36	228.39**
N*N	1	7957.56	7957.56	63.74*
P (formic)	1	100.94	100.94	0.81ns
P*P	1	31.14	31.14	0.25ns

**, * = Significant at 1, 5%; ns = not significant

Appendix x Summary of B and C values derived from the different models for predicting N uptake during cabbage growth using heat units as a time base in the 1988 field trial.

Year	Treatment (N kg/ha)	Model 1[a] B	Model 1[a] C	Model 2[b] B
1988	0	2.16884	0.00216	0.943996
	100	1.92470	0.00338	2.208315
	200	2.48610	0.00312	3.370955
	300	4.30530	0.00284	4.135562
	400	4.81621	0.00278	4.796814[c]

[a]Y = 0.12+B*exp(C*X)
[b]Y = 0.12+B*exp(0.00285*X); where 0.00285 is the C mean value
[c]Bmax

Appendix xi Summary of B and C values derived from the different models for predicting N uptake during cabbage growth using heat units as a time base in the 1988 and 1989 field trials.

Year	Treatment (N kg/ha)	Model 1[a] B	Model 1[a] C	Model 2[b] B
1988	0	2.16884	0.00216	1.20253
	100	1.92470	0.00338	2.78737
	200	2.48610	0.00312	4.26063
	300	4.30530	0.00284	5.23729
	400	4.81621	0.00278	6.07306
1989	0	6.41059	0.00226	3.94391
	100	12.21552	0.00237	8.56820
	150	9.03716	0.00274	9.62000
	200	10.28515	0.00274	11.18246
	250	14.23898	0.00253	12.13922[c]
	300	14.52211	0.00239	10.49615

[a] $Y = 0.12+B*\exp(C*X)$

[b] $Y = 0.12+B*\exp(0.00267*X)$; where 0.00267 is the C mean value

[c] Bmax