GROWTH AND NITROGEN NUTRITION STUDIES OF ONIONS (*Allium cepa* L.)

A THESIS PRESENTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF HORTICULTURAL SCIENCE IN HORTICULTURAL PRODUCTION AT MASSEY UNIVERSITY

MOMODOU ALASAN CEESAY

1980

* * * * * * * * *

THIS THESIS IS DEDICATED TO

MY BELOVED MOTHER

* * * * * * *

YANDEH JAGNE

* * * * * * *

WHOM I LOST RECENTLY

* * * * * * * * *

ABSTRACT

The effect of nitrogen (N) fertilizer was studied in the field and in the greenhouse on the growth, development, maturation and storage life of onions (*Allium cepa* L.), cultivar "Pukekohe Long Keeper" (PLK). Samples were taken at specified harvest dates and morphological measurements, growth analysis and plant tissue analysis for nitrate-nitrogen (NO_3-N) and total nitrogen (total N) in the leaf blades, bulbs and roots of the onion plants were carried out. Also, high temperature storage for onions was investigated and compared with cool storage.

Fresh and dry weight of the entire plant and the bulb dry weight increased with time to a maximum at the end of the growing period. Root dry weight, leaf dry weight, green leaf area and green leaf number increased with time then decreased as maturity approached. In general, whole plant fresh and dry weight and the plant parts, leaf and bulb, increased with increasing N fertilizer. Root dry weight was generally higher with the low N treatments than with the high N treatments. However, when N was too low, root growth was severely restricted.

Low N rates tended to stimulate earlier bulb formation but delayed maturity. Very high N rates induced earlier maturity. Bulb weight and bulb diameter generally increased with increasing N fertilizer at the end of the growing season. Whole plant Relative Growth Rate (RGR) and bulb Relative Growth Rate (bulb RGR) were closely related. RGR and Leaf Area Ratio (LAR) decreased with time, however Net Assimilation Rate (NAR) was constant in the early growth stages but fluctuated in the later stages of growth. All the growth analysis parameters, RGR, NAR, LAR, Leaf Weight Ratio (LWR) and Specific Leaf Area (SLA), generally increased with increasing N fertilizer. The increase in RGR brought about by increases in N rate was mainly due to increases in LAR. The increase in LAR caused by increases in N levels was due mainly to increases in LWR.

In general, NO_3-N and total N concentrations in the onion plant parts increased with increasing N fertilizer but declined as the plants advanced in age. Critical NO_3-N and total N concentrations for onions were determined from the relationship between relative growth and the NO_3-N and total N in the leaf blades, bulbs and roots. The NO_3-N concentration in the leaves and bulbs was found to be very low and appeared to be less reliable for determining the N status of the crop. The NO_3-N concentration in the roots was much higher, probably because nitrate is reduced in the roots in onions. However, analysing for total N, rather than NO_3-N, in the plant organs, in particular the leaf blades, is a much better method for monitoring the nitrogen status of an onion crop.

The high N treatments generally removed more N than the low N treatments. A linear relationship was found between the bulb yield and the amount of N removed. For most soil conditions, 200 kg N/ha is considered an optimum level for onion production.

There was little difference in storage life between bulbs stored under high temperature conditions and those under cool storage. Nitrogen fertilizer rates had no significant effect on bulb storability.

* * * * * * * * * * *

ACKNOWLEDGEMENTS

I am very grateful to my supervisor, Dr M.A. Nichols, for his considerable help and guidance in the preparation of the thesis.

I am grateful also to the technicians of the Plant Growth Unit and Dean Anderson of the Horticulture Research Laboratory for their assistance.

Thanks are also due to staff of the Levin Horticultural Research Centre, Massey's Computer Centre, Department of Horticulture and Health, Soil Science Department and Agronomy Department for their advice and the use of their facilities.

I would also like to express my appreciation to the New Zealand Vegetable Growers Federation for sponsoring the project.

For so diligently typing this thesis, I extend my sincere thanks to Mrs E.V. Oram.

Finally, I am deeply indebted to my wife, Anna, for her invaluable help, interest and tolerance throughout the life span of the project.

* * * * * * * * *

TABLE OF CONTENTS

* * * * * * * * * * *

LIST OF FIGURES

* * * * * * * * *

LIST OF TABLES

* * * * * * * * *

LIST OF APPENDICES

* * * * * * * * *

INTRODUCTION

Onions (*Allium cepa* L.) together with leeks, garlic, chives and shallots, belong to the family Lilliaceae. The onion is of greatest economic importance. Its distribution and popularity as a vegetable is worldwide. The crop is interesting in being one of the few bulbous species used for vegetable production.

Research has clearly identified certain elements as essential for the growth of plants. It is generally agreed, however,that nitrogen (N) is of major importance because its deficiency and excess most commonly causes loss of crop yield and poor quality and is easily lost in the soil. A considerable amount of work has been done on the effects of environmental factors such as photoperiod and temperature on onion growth and development but very little on the effects of mineral nutrition, in particular N nutrition. Thus a detail study of the growth and development of the onion plant as influenced by nitrogen fertilizers would enhance our knowledge of onion growth.

It is often difficult to recommend a definite N fertilizer program because many factors such as soil, weather, cultural practices and crop have to be considered. In general, the amount of nutrient applied to a crop depends on a knowledge of the nutrient requirement of the crop and the nutrient supplying power of the soil in which the crop is to be grown. The chief methods used to assess the nutritional status of a crop and soil are:

(i) methods based on symptoms of nutritional disorders,

(ii) methods based on soil analysis,

(iii) methods based on plant analysis,

(iv) greenhouse or pot culture experiments and

(v) field experiments.

Each of these methods has its advantages and disadvantages and each can produce the desired information. However, the use of any one of them

does not preclude the use of another, as their results should be complementary. Nevertheless, the method(s) chosen depends largely on the resources available.

To this end, the thesis was carried out under field and greenhouse conditions with the following objectives in mind:

(i) To study the growth of onion plants using morphological features and growth analysis.

(ii) To study the effects of different levels of N on the growth, development, maturation and storage life of onions.

(iii) To determine the NO_3-N and total N concentration in the onion plant parts at different harvest dates.

(iv) To compare a conventional laboratory method (phenol-sulphonic acid method) with a rapid field test method for determining NO_3-N concentration in onion plants.

(v) To study the dynamic of N uptake in relation to different N rates and growth stages and to predict optimum N rates for high yield under various soil conditions.

(vi) To investigate high temperature storage for onions and to compare it with cool temperature storage.

* * * * * * * * * * *

SECTION A

LITERATURE REVIEW

CHAPTER 1

1. GROWTH AND DEVELOPMENT

Onions in comparison to many other vegetable crops, have a fairly complex life cycle involving several distinct developmental phases. Each phase is herewith considered in ontogenetic sequence from seed germination through bulbing to flower production.

1.1 SEED GERMINATION AND EMERGENCE

The sequence of morphological events during germination of the onion seed has been demonstrated in detail by Hoffman (1933). Development of the seed embryo begins with elongation of the lower and middle regions of the colyledon. Within 24 hours the hypocotyl protrudes through the seed coat and soon thereafter most of the cotyledon also emerges. The tip of the cotyledon, however, reamins embedded in the endosperm of the seed from which it absorbs food.

In experiments with seeds germinating at 24°C on moist filter paper, Melera (1971) observed that emergence took about 36 hours, at which time the radicle was about 1 mm long. The radicle extension rate increased with time until at 60 hours, when the radicle was 5 mm long, it had reached a constant rate of 0.8 mm per hour.

In general the rate of seed germination rises with increasing temperature up to about 35°C and this is also true of emergence in the field (Bleasdale 1973). The effects of soil temperatures on onion seed germination is well demonstrated by Knott (1957). Lovato and Amaducci (1965) reported that 20-25°C was optimal for onion seed germination.

Low temperatures frequently occur in the field and in theory these should only delay emergence but in practice many of the seeds fail to emerge if germination is too much protracted (Bleasdale 1973). The longer the germination period the higher the probability of infection, drought, or water excess, which cause a non-uniform emergence of the seeds and a decrease in the germination percentage.

Several workers have suggested that a high germination rate is indicative of vigour and of the likelihood that emergence in the field will be similar to that under the ideal conditions of the laboratory test. With the increasing emphasis on precision planting, crop uniformity and high yields, an understanding of the concept of seed vigour is now greatly sought. Several types of tests have been devised for seed vigour determination. These tests have been reviewed by Heydecker (1969).

Bedford and Mackay (1973) found field emergence in onions correlated with laboratory germination, although under moisture stress there was a tendency for fewer live seeds to emerge in samples of low rather than of high germination. However, in carrots emergence was related to germination in favourable field conditions, but not under moisture stress and with deeper sowing, when there was usually a positive correlation with seed weight.

Development of modern herbicides and reduced availability of labour for transplanting or thinning have resulted in increased numbers of vegetable crops being sown to stand. Thus accuracy in calculating sowing rates and in particular, the problem of predicting losses of viable seeds sown in the field is essential. Bleasdale (1973) suggested that growers should calculate the sowing rate by using the equation:

$$\text{Seed required in kg/ha} = \frac{\text{mean weight per seed in mg}}{\text{percent laboratory germination}} \times \frac{\text{number of plants required per m}^2}{\text{field factor}}$$

The field factor (FF) in this equation takes account of the common experience that field emergence is lower than laboratory germination. An FF of unity would mean all the viable seed were expected to emerge. In practice, under good conditions one might use FF = 0.8 and under poor conditions a value of 0.4. In practice the equation has been useful because it has enabled growers to avoid the errors which can arise if similar weights per unit area are sown each year without regard to seed size, percentage laboratory germination or field conditions.

Much research has been devoted to trying to discover if it is possible to improve vigour levels by post-harvest seed treatments. The technique of applying up to three cycles of water imbibition and drying (seed hardening) to seeds is claimed to improve the drought resistance of seedlings. Heydecker, Higgins and Gulliver (1973) developed a technique called "seed priming" in which seeds of onions are imbibed on filter paper saturated with polyethylene glycol solutions of osmotic potentials which allow imbibition but prevent radicle emergence. Seeds could be maintained in the imbibed condition for up to 23 days and when washed and put on a water-saturated substrate, germination was very rapid and nearly synchronous.

Currah (1975) found pre-germinate fluid-drilled onion seeds produced 17% more plants and a 13% higher yield than conventional sown dry seeds. The pregerminated seeds were sown using a specially developed seed drill in which the seeds were suspended in a sodium alginate gel which was injected into the soil. Some salad onion seeds were also fluid drilled and these produced seedlings which emerged 17 days before those from dry seeds. The plants from the earlier emerging seedlings were the largest at all stages of growth.

Soaking seeds in salt solutions has an effect similar to that of the polyethylene glycol solutions used by Heydecker *et al* (1973), providing the solutions have sufficient osmotic potential

to prevent germination. In addition, salt solutions provide an early supply of nutrients.

Several endogenous growth regulators or auxins have been closely implicated in the germination process and attempts have been made to stimulate seed by supplying natural or synthetic growth regulators. Vaish (1966) soaked onion seeds of the Patna Red variety in 1 ppm NAA or IBA; a slight increase in the percentage germination was found whereas 10 ppm solutions caused a considerable increase in germination and 100 ppm was deleterious. The stimulating effect of NAA was slightly greater than that of IBA. The rate of germination was similarly affected.

It is generally believed that seeds of onions apparently present no dormancy problems. However, Lovato and Amaducci (1965) found a fraction of dormant seeds in freshly harvested onions, but noted that the dormancy lasted for a short time only, as it may disappear within a couple of months following harvest.

Germination can be predicted at optimal soil moisture conditions by means of a heat sum in degree days and a minimum temperature for germination (Bierhuizen and Wagenvoort 1974). The low minimum temperature (1.4°C) found for onions means that it can be sown rather early in the season. However, germination will be very slow because of the high heat sum of 219 degree days. In general, Wagenvoort and Bierhuizen (1977) found that diurnal soil temperature variation, depth of sowing, variation in seed size (of radish) and cultivar differences (of lettuce) did not affect the minimum temperature for germination and heat sum of vegetable seeds to a great extent.

Onion seeds deteriorate quickly in hot humid climates, often losing their viability in less than a year (Purseglove 1972). Usually seed moisture contents of 4 to 6% will preserve the viability of seed for more than twice as long as moisture contents of 10% or greater (Bleasdale 1973). Furthermore, at a given moisture content viability is retained longer at low rather than high temperatures.

1.2 VEGETATIVE GROWTH

1.2.1 GENERAL ASPECTS

After the seedling is established, the young onion plant continues to produce new foliage leaves and adventitious roots, and its short stem slowly elongates and broadens (Jones and Mann 1963). The morphology of the young plant is shown diagrammatically below:

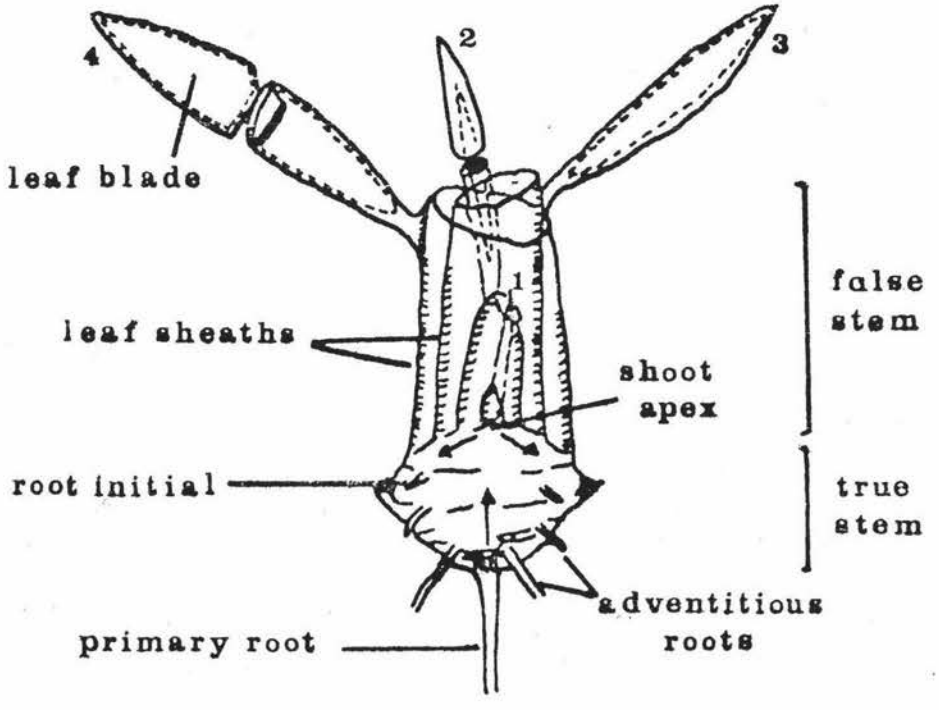


FIG. 1. Diagrammatic picture of the development of the stem, leaves, and roots, in a young plant of the common onion (Jones and Mann 1963).

In a study of the growth of the onion plant, Zink (1966) noted that plant fresh weight increased until harvest. Approximately 28% of the fresh weight of the plants were produced during the period when tops were drying and bulbs maturing. Plant fresh weights increased slowly during early growth. When half the total growing period had passed, approximately 7% of the fresh weight had been produced by the plants. When bulbing was first observed in trial 1, the plants had produced 27% of their fresh weight and in trial 2, the plants produced 36% of their fresh weight.

Similarly, plant dry weights increased until harvest (Zink 1966). It increased slowly during early growth. When half the total growing period had passed, approximately 5% of the ultimate dry weight had been produced by the plants. When bulbing was first observed, the plants had produced 20% of their dry weight. Approximately, 36% of the dry weight of the plants were produced during the period when tops were drying and bulbs maturing.

The percent dry matter in the whole plant increased fairly uniformly during crop growth, the rate increasing slightly as plants approached maturity (Zink 1966). Dry matter at harvest was approximately 14.45%. Southport White Globe onions produced more than 72% of their dry weight during the period of bulbing to harvest. The period of most rapid growth extended from early bulbing until tops started to dry. These data indicate that the period from early bulbing to when tops were drying and bulbs maturing is critical in obtaining maximum production of onions. Harvesting should be delayed as long as possible to obtain high yields.

1.2.2 Root Growth

Weaver and Bruner (1927) made a detailed description of the onion root system. They reported that an individual onion plant has a root system consisting of 20 to 200 shinning white, rather

thick roots varying individually from 0.5 to 2 mm diameter. Some of these spread horizontally just beneath the surface soil 30 to 45 cm on all sides of the plant before turning downward. Depths of 45 to 80 cm are usual. However, the authors noted that in compact soil, the roots are shorter, do not spread so widely and have shorter branches than in loose soil.

Similarly, Hamner and Bartz (1963) studying root distribution patterns of onions showed the shallow-rooted nature of the crop. At the time of harvest, approximately 85% of the root activity was measured in the top 20 cm of soil. Virtually all the roots of onions are within the top 60 cm of soil and the bulk within the top 23 cm (Drinkwater and Jones 1955; Strydom 1964). Thus, the onion has a rather meager root system not only in regard to lateral spread and depth but also in degree of branching.

Abdalla and Mann (1963) reported that adventitious roots emerged at the rate of four or five per week, reached a maximum of 70 live roots per plant 20 days before harvest, then declined in number because old roots died more quickly than new roots were produced.

Compared with other crop species, onion roots have a low surface to volume ratio. They also lack root hairs when grown in soil or solution, although short root hairs do form on roots growing in moist air (Brewster, Bhat and Nye 1976). Thus, new roots cannot grow out into dry soil. Soil moisture much reach the bulb base at least periodically during the growing season to permit elongation of the new roots.

Jones and Rosa (1928) demonstrated the importance of moisture in onion root production. They showed a striking photograph of onion plants with 3 to 5 leaves but only a single root each (the primary root). These plants had been grown since seed germination in a soil with a dry surface layer. Within 2 days after the bulbs observed by Jones and Rosa were watered, numerous new

roots were protruding from all the bulbs. However, the striking ability of onions to survive transplanting treatments in which virtually all the roots are removed, is an indication of an ability to survive prolonged and severe water stress (Brewster 1977).

Lower nutrient status of the soil tends to give deeper rooting systems for onions (Hamnes and Bartz 1963). But as pointed out by Russell (1961), if soil is very poor in a nutrient, all growth, including root growth, may be severely limited.

As noted earlier, the root length or root surface area per unit of plant weight is low in onions. This plant property is particularly important where the diffusion rate to individual roots limits the overall nutrient uptake rate. In soil, this diffusion barrier is normally important for phosphate and potassium but less important for nitrate (Baldwin 1975). The small extent of phosphate extraction from around onion roots and its contrast with that from around rape roots has been demonstrated and quantitiatively determined using autoradiography by Bhat and Nye (1974a and b).

Butt (1968) studied the influence of light and temperature on onion root growth. In general, increasing light intensity results in increased fresh weight, dry weight and total soluble sugar content of the roots. Also growth in root dry weight was favoured by exposure to long days particularly when incandescent light was used to prolong the main photoperiod. It could be assumed that under conditions where photosynthesis is restricted, e.g. low light intensity, carbohydrates are preferentially used in aerial organs whereas the growth of sub-soil parts (roots) furthest from the source, is slowed down most.

Butt (1968) also generally found that root growth and development of onions was more or less optimal at 15°C. Increase or decrease in air temperature from 15°C resulted in a decline

in root fresh and dry weight. At 20°C, however, the decrease was less marked as compared with that at other temperatures. Rapid growth of tops as compared with roots occurred at 20°C or higher, while root growth was best at lower temperatures (12-20°C). Thus, the top/root ratio, in general increased with rise in temperature.

One may perhaps suppose that depression of root growth at high temperature is due to shortage of oxygen, as the minimum oxygen requirement for root growth and function is not a fixed amount but that it varies directly with temperature (Butt 1968). The possibility, however, remains that the relation between top/root ratio and temperature is controlled by changes in the level of growth hormones within the plant.

1.2.3 LEAF/STEM GROWTH

Purseglove (1972) noted that onions have alternate distichous glaucous leaves which are produced in succession from the broadening stem apex, each arising as a ring which elongates to form the tubular leaf sheath and projects above ground. While the leaf-sheath, a hollow tube open at the top, gets its form by growing upwards from a ring-like initial, the leaf blade, also hollow, but completely closed develops in a quite different way (Jones and Mann 1963). The young leaf blade is solid, and as it enlarges, the central tissues fail to grow as rapidly as the surface tissues. This, along with some cell destruction, causes a large cavity to form within.

The hollow inflorescence-stem develops in the same way. A very short stem is produced at the base of the plant which increases in diameter as growth continues to give an inverted cone, the oldest part later decays (Purseglove 1972). New leaves are produced by the apical meristem, the latter eventually grows to produce the inflorescence axis or scape which pushes up through the pseudostem formed by the sheathing leaf bases.

Short-stemmed branches or buds may arise singly at the base of and within the leaf sheaths.

In a study of onion growth, Zink (1966) found the number of green leaves visible without disection increased fairly uniformly to a maximum of about 10 per plant. When bulbing was first observed the mean number of leaves per plant was approximately 8.5.

Leaf weight in contrast to root weight was found by Butt (1968) to be favoured by relatively high temperature. The time trend showed an increase in root, leaf and neck weight up to a certain moment which varied with temperature, thereafter usually decreased or levelled off. The higher the temperature, the earlier this tended to be. In the early stages of growth, leaf number increased with increase in temperature up to 30°C; later on, presumably owing to increased rate of leaf senescence, leaf number at 30°C was overtaken by that at 25 and 20°C (Butt 1968).

Leaf length in onion increased with temperature up to 20°C; at 25°C no further increase was observed (Butt 1968). Conversely, leaf length decreased again at 30°C. Milthorpe (1963) suggested that at high temperature the rate of leaf production is higher, and the plant is unable to maintain the supply of nutrients required by them; consequently each leaf does not grow as large. It appears likely that leaf diameter in the onion plant is chiefly controlled by cell division while leaf length is mainly determined by cell elongation.

The ultimate total green leaf area per plant is the resultant of leaf initiation, emergence and longevity, which may be differently influenced by temperature. Butt's data relating to the onion plant show that in the early stages of growth, leaf area increased with increasing temperature up to 25°C and then decreased with further increase in temperature. At the later

stages of growth, leaf area decreased; the higher the temperature, the earlier this happened so that leaf area then became greater at lower temperatures. This may be ascribed to an indirect effect of high temperatures on speeding up bulb development and to its predominance over new leaf emergence. However, this was clearer at 25°C than at 30°C (Butt 1968).

Whether under field or phytotron conditions, leaf number was positively correlated with light intensity (Butt 1968). Relatively longer and narrower leaves indicated by greater leaf length/diameter ratio were found with decreasing light intensity. The amount of leaf area/plant is the outcome of leaf number and leaf size, and any changes in leaf area will depend on how far light intensity affects these components (Butt 1968).

In general, longer leaves were produced under long day conditions and particularly with incandescent light supplementation. Leaf diameter under short day and long day with supplementary incandescent light was lower than under short day and under long day with supplementary fluorescent light (Butt 1968).

A positive effect of light intensity on neck diameter was also observed by Butt (1968). It increased with time to a maximum, and then fell off in most cases. Also neck length was greater under long day conditions, especially with incandescent light extension.

With reduction in light intensity Butt (1968) found the total soluble sugar content in the various onion plant organs decreased. The sugar level in the different plant parts increased with time to a maximum and then, in some cases tended to decline especially in leaf and neck.

1.2.4 Bulb Growth

The onset of bulbing is characterized by a rapid elongation of the leaves due to an extension of the neck region of the sheath (Kato 1963). The enlargement of the bulb is first brought about by the thickening of the bases of the foliage leaves and the bulk of the mature bulb may consist of these (Jones and Mann 1963). As bulbing progresses, leaf blades cease to form and scale-leaf initials, in which the blade is much reduced in comparison to the sheath, are differentiated from the apex (Heath and Hollies 1965). These scale leaves swell to form the inner storage tissue of the bulb. The innermost scale leaves are thickened to a lesser extent than the outer scales.

As the bulb matures, two or three foliage leaf initials are laid down at the apex. These initials elongate to produce leaf blades in the following season when the bulb sprouts (Abdalla and Mann 1963). With further bulb development, leaf blades cease to emerge and the older leaves begin to senesce from the tip downwards. Ripening is characterized by a loss of turgidity in a region of cells in the upper part of the sheath (Brewster 1977). The resultant 'soft neck' leads to the flopping down of the remaining green leaves. The blades proceed to die back from the tip until only the bulb tissue remains alive. Root initiation also ceases as the bulbs develop and the roots die off as maturity approaches (Kato 1963).

Bulb formation in onion is promoted by long days although cultivars differ greatly in the daylength required for bulbing, e.g. from 12 to 16 hours light a day (Magruder and Allard 1937). The longer the day, the sooner leaf growth ceases, and the sooner the bulb ripens (Austin 1972). However, Thompson and Smith (1938) showed that regardless of daylength, onions would not bulb if growing temperatures were too low. For bulbing to be initiated, both temperature and daylength must exceed certain minima.

Thus there seems to be an interaction between daylength and temperature. For a given daylength, high temperatures accelerate bulb formation, while at lower temperatures longer days are needed to obtain the same effect (Thompson and Smith 1938; Heath and Holdsworth 1943). Similarly, Steer (1980a) found bulbing was most rapid at the highest temperature and longest daylength. High temperature alone (not associated with long day had no effect on bulbing (Butt 1968).

In lower latitudes many common cultivars do not form bulbs and the so called "short day" bulbing types must be grown. These also have a long day requirement for bulbing but with a shorter critical daylength (Vince Prue 1975). However, Abdalla (1967) found that under arid tropical conditions with little variation in daylength, the influence of photoperiod may be less critical in the bulbing response of many early onion varieties, whose bulbing is influenced more by temperature than by daylength. Similarly, Robinson (1971) observed that bulbs formed and matured during the shortest days and during the coolest part of the year in the mild winter climate of the Rhodesian low veldt.

Steer (1980a) found significant interactions between cultivar, temperature and photoperiod in phytotron experiments with four Australasian cultivars (Creamgold (syn. Pukekoe Longkeeper), Braeside Golden Globe, Gladalan Brown and Early Lockyer Brown). For the cultivars the critical daylength for bulbing was about 14, 13.5, 13 and less than 11 hours respectively. At longer than critical daylengths, the occurrence and rate of bulbing was controlled by temperature. The rate of bulbing was retarded by low night temperatures (Steer 1980b). This appeared to be a function of the absolute night temperature and not of the difference between day and night temperatures.

Magruder and Allard (1937) reported that the age of the plants has little influence on the date of maturity, so that seed

sown at the same date on which plants 3 months old are planted, produced mature bulbs within 5 days from the date at which the mentioned plants did. On the other hand, Heath and Holdsworth (1943) and Jones and Mann (1963) noted that the size and age of the onion plant influence bulbing and time of maturity. Dry onion sets, transplants and seed of the same cultivar, planted on the same date, starts to bulb and mature in the order as named; even more, plants grown from large sets bulb and mature earlier than those grown from small sets. Similarly, Butt (1968) demonstrated that the size and/or the physiological age play a not yet further defined role in triggering off the mechanism of bulbing. Very young plants did not respond to the bulbing stimulus as rapidly as larger plants.

The photoperiodic control of the formation of storage organs like onions embraces all the usual features of photoperiodism. The leaf is the perceptive site; one or more stimuli originate in the leaves and are translocated to the responsive regions; nightlength rather than daylength determines the response; and phytochrome is the photoreceptive pigment (Vince-Prue 1975). As with flowering, the development of storage organs is an inductive process.

The quality of light is also very important in the promotion of onion bulbing. Several reports (Butt 1968; Woodbury and Ridley 1969; Austin 1972) showed that an extension of daylength with incandescent light is more effective in promoting bulbing than an extension with fluorescent light. Red and far-red light are said to be involved in the induction, and in the development of onion bulb. Terabun (1965) found that photoperiodic extensions using far-red light or blue light led to accelerated bulbing whilst red light surpressed bulbing. These results indicate that bulbing is a phytochrome-mediated response. The effectiveness of incandescent light for bulbing, and differences between different fluorescent light sources in causing bulbing, can be explained by the ratio of far-red to red light

in the lamp spectra (Austin 1972).

Light intensity also has an effect on onion bulbing. Given light of the same spectral composition and identical temperatures, the higher the light intensity the more rapid the bulbing and the sooner the ripening (Brewster, Hardwick and Hardaker 1975). Butt (1968) also arrived to the same conclusion where decreases in leaf area, indicating maturity, occurred first at high light intensities. Butt also showed that for a given photoperiod extension from incandescent lamps, the higher the incandescent lamp intensity the more rapid the bulbing and maturation.

According to Wilson (1934), the onset of bulbing results from the accumulation of sugars in all parts of the plant; large quantities of soil nitrates tend to delay bulb formation and reduce yields. It was found also that onion plants grown from sets under short day conditions (8 hrs) developed bulbs when fed with sugars (Heath and Hollies, 1963). Moreover, as pointed out by Cockshull and Heath (1962) the finding of Heath and Holdsworth (1948) that defoliation (removal of the leaf blades) delayed bulbing until after the emergence of new leaves, could be interpreted as showing the need for a continuous sugar supply.

On the other hand, some investigators believe that carbohydrate supply is not generally accepted as an important factor in morphogenesis, and it seems unlikely that accumulation of carbohydrate would by itself be sufficient to cause the complex growth associated with bulb formation (Clark and Heath 1962; Butt 1968). Thus the duration of the light period on bulb formation exercises a regulatory action on internal processes of the plant other than those which merely determine the total quantity of carbohydrate produced. Butt (1968) showed that whilst bulb development is accompanied by carbohydrate accumulation in various plant organs and that reducing light intensity

diminished carbohydrate content as a result of which bulb development was delayed, however, carbohydrate by itself does not seem to be a causal factor in triggering off the mechanism of bulbing.

The action of long days does not directly result in an increased carbohydrate level, but photoperiod may exert its effect through a regulation of the internal processes, so that carbohydrate is directed to be stored in the form of a bulb, instead of being used in new leaf or root production (Butt 1968).

Heath and Holdsworth (1948) formulated a hypothesis in terms of a bulbing factor which they thought, was hormonal in nature. This should result in mobilization of carbohydrates in the bases of the onion leaves, in cessation of growth of the apical meristem and roots, in cessation of cell division in general and in a lateral swelling type of growth by the young leaves. By colorimetric determination and by bio-assay, Clark and Heath (1962) found an increase in the IAA content to a very high level during the first week following bulb induction. Furthermore, in interpreting their results, Heath and Hollies (1963) did not exclude the possibility of the bulbing hormone being stored in the sets which induced bulb development under short day conditions when sugar was fed to the plants.

Levy and Kedar (1970) found that ethephon promoted early and rapid bulb growth under non-inductive conditions. Terabun (1967) found that a foliar application of 500 ppm maleic hydrazide (MH) could induce bulbing in normally non-inductive conditions. Exogenous growth regulators that induced rapid leaf senescence were found by Abdel-Rahman and Isenberg (1974) to reduce bulb size.

In contrast, several workers have found that foliar applications of synthetic auxins promote leaf blade growth and retard bulbing. Terabun (1967) retarded bulb formation in

inductive daylengths using foliar sprays of 20 ppm 2, 4-D. Mathur (1971) found that sprays of NAA, IAA and IBA at 100, 200 or 300 ppm all increased leaf number and weight and led finally to bulbs of greater diameter and total yield. NAA at 300 ppm gave the best results. Thus treatments that delayed leaf senescence led to the formation of larger bulbs.

The dry matter content of bulbs differs greatly between cultivars, ranging from 6% to 18% of fresh weight (Jones and Mann 1963). Cultivars with a high dry matter content tend to be long storing types with a longer growing season. McCollum (1968) noted that there was a negative correlation between bulb size and dry matter content.

Zink (1966) provided data on the mineral element content of leaves and bulbs at different stages of growth. There was a general decline by a factor of between two and four from tissue concentrations typical of young plants to those of the mature bulbs.

Nagai (1967) established that onion leaves export reserve carbohydrate and nitrogenous compounds to the bulbs as they senesce. Bennett (1945) observed that the bulk of the nitrogen and mineral content of leaves could be translocated from leaves to bulbs. Lorenz and Hoyle (1946) showed that the senescing tops increase bulb dry matter concentration by, both translocating dry matter into the bulb and withdrawing water from it.

1.3 Reproductive Growth

When onion bulb has reached full maturity the meristem ceases to produce leaf primordia. After a dormant period, provided the environment is favourable, an inflorescence is formed by the elongation of the internode to produce the scape, which is at first solid, but later, through differential growth, becomes hollow (Jones and Mann 1963; Purseglove 1972). The

scape, 30-100 cm long, is swollen below the middle. The developing inflorescence is protected by a membranous spathe, which splits to give 2-3 persistent papery bracts.

The number of inflorescences per bulb varies from 1-12 or more, depending upon the number of lateral bulbs present (Jones and Mann 1963). A terminal umbel of 50-2000 flowers is produced, which is an aggregate of cymes of 5 to 10 flowers each. The flowers in each cyme open in a definite sequence, but, as there are many cymes, the flowers of the umbel appear to open irregularly. A single plant producing several inflorescences, may have flowers opening for a month or longer.

It has long been known that individual onion flowers are protanorous, i.e. the anthers dehisce before the stigma becomes receptive. Masuda and Hayashi (1956) reported that the style was very short when the flower first opened, but elongated gradually, reaching its maximum size only after all six anthers had dehisced. The stigma became receptive on the second day after opening and remained so for 2-5 days. It is commonly assumed that protandry is an outbreeding mechanism. The onion invariably shows some loss of vigour on inbreeding, indicating that it is a predominantly outbreeding species (Currah and Ockendon 1978).

The flowers may be considered to be made up of five whorls of three organs each, which, starting at the centre, are: 3 carpels (united into a single pistil), 3 inner stamens, 3 outer stamens, 3 inner perianth segments, and 3 outer perianth segments. The members of each successive whorl alternate; i.e. they are on different radii from the members of adjacent whorls. The development of these flower parts has been described in some detail by Jones and Emsweller (1936).

Like bulbing, flower production is induced by environmental factors (Jones and Mann 1963). Temperature exerts a profound influence on onions through its control of flower initiation.

Photoperiod has little effect on the initiation of flowers; rather, bolting is induced almost entirely by cool temperatures (Jones and Mann 1963). The factors which influence bolting are of importance to the bulb grower because yield and quality are lowered by bolting. Both bulbs in storage and growing plants may be induced to bolt, but in contrast to bulbing, size is of critical importance, for small bulbs or plants show little or no induction of flowering by cool temperatures. Other factors such as cultivars, mineral nutrition, method of planting and soil type also influence bolting.

Abdalla and El Hassan (1977) showed that late planting when relatively low temperature prevails reduces the incidence of bolting in onions sown direct in the field or field transplanted. When the crop is planted early (high temperatures) the plant grows to a large size promoted by the high temperatures that prevail during the growing period prior to the onset of the winter. High temperatures tend to promote leaf production and elongation thus resulting in large plants, which are more susceptible to bolting.

Jones and Mann (1963) noted that high temperatures early in the growing season of onions may reduce bolting by deceasing inflorescence induction and by favouring rapid bulbing, but Abdalla (1967) did not find this to occur in the arid tropics where the temperatures tend to encourage leaf production and interfere with bulbing.

The effects of bulb storage temperature on flower initiation and subsequent emergence are complex because temperature affects more than one process simultaneously (Brewster 1977). To summarize briefly, temperature affects: dormancy, vernalization, reversion from a floral to a vegetative condition, and bulbing after storage. The dormant condition and a low rate of development within the bulb is maintained by a very low (0°C) and high (25-30°C) temperatures, thus these temperatures can be expected

to delay and prevent progress towards inflorescence initiation. The rate of development in stored bulbs is maximal around 15°C.

Holdsworth and Heath (1950) found that flower initiation did not occur above 17°C. Temperatures of 9-13°C appear most favourable to flower initiation. This could be due to a direct effect on the vernalization process or may involve an interaction between vernalization and development rate.

Storage at 30 or 28°C after floral initiation can promote reversion from a floral to a vegetative condition, i.e. devernalization (Aura 1963). The further the development of the inflorescence has progressed, the longer is the duration of warm storage required to cause reversion to a vegetative condition (Aura 1963).

High temperature storage delays bulbing in the following season. One or two months' storage at 28°C after prolonged storage at vernalizing temperatures has sometimes been observed to increase the percentage of plants flowering (Aura 1963). A reduction in the competition of inflorescence development from bulb development due to the delaying effect of high temperature storage on bulb formation may explain these observations which run counter to the devernalizing effects of high temperature (Brewster 1977).

The emergence of flower stalks subsequent to initiation is favoured by growth under temperatures around 17°C (Thompson and Smith 1938; Holdsworth and Heath 1950).

Daylength does not directly effect floral initiation but under cool temperatures, long days favour the subsequent emergence of flowers and elongation of the scape (Holdsworth and Heath 1950). Below, the authors tabulate the effects of temperature and daylength on flower initiation and emergence and on bulbing which can compete with flower emergence:

	SHORT DAYS	LONG DAYS	
High Temperature	No bulbing No initiation No emergence of initials previously formed at low temperature	Bulbing No initiation Previously formed initials are destroyed	
Low Temperature	No bulbing	<u>If bulbing</u> Previously formed initials are destroyed	<u>If not bulbing</u> Initiation of inflorescences
	Slow emergence of inflorescences	Initials formed which can emerge after bulb sprouting	Rapid emergence

The multiplicity of the effects of temperature and the differences in temperature from season to season makes the flowering behaviour of onions variable and rather unpredictable in the greenhouse and in the field.

CHAPTER 2

GROWTH ANALYSIS

2.1 General Aspects

Concepts such as Net Assimilation Rate (NAR) and Relative Growth Rate (RGR) introduced by Gregory (1917) and Blackman (1919) have been applied by many plant physiologists and found to be useful tools in the quantitative analysis of plant growth. These techniques have together become known as 'Growth Analysis' (Watson 1952), which in simple terms, may be defined as the study of the changes in the whole plant during its ontogeny. It has its faults as pointed out by Evans and Hughes (1962) and Millthorpe (1963), nevertheless, it has proved to be a useful means of assessing the integrated effect of environment on plant growth.

Two assessments are required to carry out a simple growth analysis; (a) a measure of the plant material present (W), and (b) a measure of the magnitude of the assimilatory system of that plant material (A) (Radford 1967). In practice the most common measures of W and A are (i) the total dry weight of the individual plant (W) and (ii) the total leaf area of the plant (A). The method presumes that dry matter increase is the result of net photosynthetic activity. Almost all the dry matter increase of a plant is attributable to the net result of gains due to photosynthesis and losses due to respiration of the whole plant (Richards 1969).

Two experimental approaches are normally used in the study of Growth Analysis:

(i) The 'classical' approach, in which the course of events is followed through a series of relatively infrequent, large harvest (with much replication of measurements).

(ii) The 'functional' approach in which the harvests are smaller (less replication of measurements) but more frequent.

The two approaches are not mutually exclusive if time and space are no object (harvests may be large and frequent) but it is not often that such a shceme makes the most efficient use of the resources available (Hunt 1978).

(A) CLASSICAL APPROACH

The attributes of growth of individual plants most commonly studied in classical growth analysis are:

(a) the Relative Growth Rate (RGR) = $\frac{1}{W} \cdot \frac{dW}{dt}$ or

the change in dry weight per unit of dry weight per unit of time, where W is the total dry weight;

(b) the Net Assimilation Rate (NAR) = $\frac{1}{A} \cdot \frac{dW}{dt}$ or

the change in dry weight per unit of leaf area, per unit of time;

(c) the Leaf Area Ratio (LAR) = $\frac{A}{W}$ or

the ratio of the leaf area to the total dry weight of the plant.

These three expressions are interrelated as

$$\frac{1}{W} \cdot \frac{dW}{dt} = \frac{1}{A} \cdot \frac{dW}{dt} \times \frac{A}{W}$$ (Briggs, Kidd and West 1920)

i.e. RGR = NAR x LAR

As plants increase in size, so does their absolute variability. Transformation of the primary data to logarithms renders the variability more nearly homogenous with time (Hughes and Freeman 1967). Thus the traditional use of these formulae involves the calculation

of mean RGRs, NARs and LARs over approximately weekly time periods using the formulae:

$$RGR = \frac{\log_e W2 - \log_e W1}{t2 - t1} \quad - - - - - \quad (i)$$

$$NAR = \frac{W2 - W1}{t2 - t1} \times \frac{\log_e A2 - \log_e A1}{A2 - A1} \quad - - - - \quad (ii)$$

$$LAR = \frac{A2 - A1}{W2 \quad W1} \times \frac{\log_e W2 - \log_e W1}{\log_e A2 - \log_e A1} \quad - - - - \quad (iii)$$

where W1 and W2 are the plant dry weights at the times of the two sampling occasions t1 and t2, and A1 and A2 are the corresponding leaf areas.

In practice, the instantaneous values of RGR often change smoothly with time and their drift may be followed approximately by deriving values of mean RGR for successive harvest intervals via equation (i) (Hunt 1978). If the harvest intervals, like T2 - T1, are long, mean RGR follows instantaneous RGR only crudely but as the intervals become shorter so the correspondence between these two estimates becomes progressively closer.

(B) FUNCTIONAL APPROACH

This alternative approach involves the fitting of smooth curves to the $\log_e$ of the dry weights and leaf areas against time (Hughes and Freeman 1967). Two equations are derived, which in their simplest form are:

$$\log_e W = a + bt + ct^2 + dt^3 \quad - - - - - \quad (iv)$$

$$\log_e A = e + ft + gt^2 + ht^3 \quad - - - - - \quad (v)$$

using W for total plant dry weight (mg), A for leaf area (cm^2) and t for time in days. With this method, the work load of large samples necessary with the classical method can be spread out by more frequent sampling of smaller samples. Other advantages of this approach has been discussed by Radford (1967).

2.2 Relative Growth Rate (RGR)

The RGR is a measure of the efficiency of the plant as a producer of new material and was originally termed the "efficiency index" by Blackman (1919). It is usually expressed in units of the form size $size^{-1}$ $time^{-1}$ but there are certain advantages attached to each of the more commonly-used versions (Hunt 1978):

$[g\ g^{-1}]\ week^{-1}$ - the time unit is often the same as the harvest interval and values tend to be of a convenient size;

$[g\ g^{-1}]\ day^{-1}$ - convenient when T is measured in days, but values tend to be rather low;

$mg\ g^{-1}\ week^{-1}$ - considerable accuracy is available without the need for decimal places.

In addition, percent per week, or per day have also been used where easy interpretation is required across a large range of values.

Environmental variables have great effects on RGR. In general, any departure from an adequate supply of light, mineral nutrients or water, or from a suitable temperature regime, or from freedom from external toxins, produces a clearly adverse effect on RGR (Hunt 1978). Such is the sensitive linkage of this quantity to the whole environmental relations of the plant. It might be added that these factors also interact strongly.

For example, the plant's growth response to 'low' levels of one factor depends very much on the available levels of the other factors.

The first comparison of interspecific differences in RGR came from Blackman. The following results on mean RGR (day^{-1}) were obtained after recalculating previously-published data: hemp 0.13, sunflower (*Helianthus macrophyllus giganteus*) 0.18, tobacco 0.21 and maize 0.071.

In comparison with other crop species onions have a low maximum relative growth rate (RGR maximum). Brewster, Bhat and Nye (1975a and 1976a) showed seedlings of onions and other cultivated *Allium* species had an RGR maximum about half that of the seedlings of a range of common vegetables, arable crops and forage grasses. For example, they found that under a photosynthetically active irradiation of 7.46×10^6 J m^{-2} day^{-1} at 25°C and with a continually replenished nutrient supply, onions had a RGR maximum of about 0.2 g g^{-1} day^{-1} in contrast to fodder rape (*Brassica napus* L.) with about 0.5 g g^{-1} day^{-1}.

The authors also applied growth analysis (Evans 1972) to a comparison of onion seedlings with those of Brussels sprouts (*Brassica oleracea* L. var. *gemmifera*). The plants were grown at 23°C under a 12 hour day giving 5.18×10^6 J m^{-2} day^{-1} of photosynthetically active radiation. The results were calculated from regular samplings of both species when they were between 2 and 100 cm^2 in total leaf area. The area of cylindrical onion leaves was taken as that of the total blade surface, that of Brussels sprout leaves as that of one side of the lamina only, in accordance with the usual growth analysis practice. The results were:

SPECIES	RGR $g\ g^{-1}\ day^{-1}$	NAR $g\ m^{-2}\ day^{-1}$	LAR $cm^2\ g^{-1}$	LWR
Onion (Cv. Hygrow)	0.145	0.54	269	0.63
Brussels sprouts (F. hybrid NVRS line)	0.266	1.52	175	0.70

From the amount of information available (very limited) it seems possible that intra-specific differences in RGR may occasionally rival the magnitude of interspecific differences, at least within ecologically similar groups of plants. Within crop species, of course, much comparative information is available from inter-varietal trials. For instance, Brewster (1976) compared the growth of 7 different onion cultivars originating from widely different latitudes, under the above level of illumination, at 20 and 10°C. No significant differences in RGR between cultivars at either temperature was found. Within all cultivars there was much less uniformity in growth at 10 than at 20°C, suggesting that there exists genetic variability in relative growth rates at low temperatures and that it may be possible to select for higher RGR at low temperature.

The effect of temperature on RGR during the exponential phase of onion growth is shown by Brewster, Salter and Darby (1977). It appeared that RGR is maximal at about 25°C. Butt (1968) studied the effect of temperature on onion growth and showed that growth was most rapid at 20 to 25°C and it appeared to be slower at 30°C. In the field, the $\log_e$ dry weight of onion seedlings was linearly related to the accumulated day degrees between 6 and 20°C during the autumn, winter and early spring (Brewster *et al* 1977). This suggests that RGR is largely

determined by temperature during over-winter growth in Britain.

The effect of light intensity on RGR and LAR of cv. Rijnsburger grown under warm white fluorescent lamps with a 12 hour day at 20°C is shown by Brewster (1977). These results should, however, be taken as approximate as they were reworked from the graphs of Butt (1968) using data from plants of 2 g total dry weight or less which were therefore still in the exponential phase of growth. It is clear that the response of RGR to light intensity declined with the increase in intensity towards 94 W m^{-2} (4.06 J m^{-2} day^{-1}).

The demand for nutrients may depend on the RGR of the plant (Brewster 1977). As discussed earlier, maximum relative growth rate is inherently low in onions. In experimental conditions designed to induce high relative growth rates, onions proved to be highly responsive to the soil phosphate concentration (Nye, Brewster and Bhat 1975; Brewster Bhat and Nye 1975a and b). The growth and uptake was in reasonable agreement with the predictions of a simulation model (Brewster *et al* 1975b). In contrast a species with fine roots and long root hairs (rape) did not respond to phosphate (Brewster, Bhat and Nye 1976b).

Finally, RGR provides a convenient intergration of the combined performances of the various parts of the plant. It is especially useful when the need arises to compare species and treatment differences on a uniform basis (Hunt 1978). But when calculated at the whole plant level it tells us nothing of the causal processes which contribute to the plant's gross performance. Thus, RGR can be calculated for each sub-component of the plant, say root and shoot; or leaves, stem and root; or leaves of varying ages, petioles, stem, main and lateral roots. The subdivisions are dictated only by convenience and the computations are directly analogous to those for whole plant RGR.

2.3 NET ASSIMILATION RATE (NAR)

The concept of NAR was first introduced and used by Gregory (1917) in an attempt to obtain an estimate of the assimilatory efficiency of leaves from simple growth measurements. Briggs, Kidd and West (1920) termed it 'Unit Leaf Rate' (ULR), a term explained by Evans (1972) to be more suitable. It is an expression of performance of the photosynthetic system and can be estimated from successive determinations of dry weight and leaf area at short intervals throughout the growth period. However, arguments can be made for using other measures of photosynthetic potential such as leaf weight, leaf protein or nitrogen content (Bleasdale 1973). These all give different values for NAR and often different trends with time (Williams 1946). Thus each of these values should be distinguished.

One of the factors that led to the introduction of NAR was a search for a relatively constant index of growth that was independent of plant size. Although, in general, NAR proves to be stable for longer periods than RGR its ontogenetic drift is still marked. Williams (1946) showed that for annual plants grown in a constant environment, the closer the approach to an effective measure of assimilating capacity, the more reliable and characteristic of the species become the estimates of mean NAR derived from this measure. When calculated on the basis of leaf weight, leaf area, and leaf protein a clear series of increasing stability of mean NAR emerged, particularly when nitrogen was in relatively short supply.

Significant differences of NAR has been found to occur between species grown in the same environment and even between varieties of the same species (Watson 1947). In an early examination of their own and other worker's data on interspecific differences in mean NAR, Heath and Gregory (1938) found almost six fold variation in mean NAR among British crops grown in summer. Values ranged from 12.5 g m^{-2} $week^{-1}$ in cucumber to 72.0 g m^{-2} $week^{-1}$ in sugar beet. It is now confirmed that wide variation in mean NAR may occur between species (Hunt 1978).

Net Assimilation Rate expressed as per unit leaf surface, any treatment which affects the LAR would alter the NAR (Richards 1969). In fact, Blackman and Wilson (1951a) have shown that increases in LAR, shoot/root ratio, and reduction in light intensity will all affect the NAR. They used a series of shade screens to demonstrate that during the early vegetative phase both the changes in NAR and LAR, over a wide range of illumination, were linearly related to the logarithm of percentage light intensity; in mean LAR this relationship was an inverse one. The slopes of these two relationships determined the trend obtained for mean RGR.

Variation in nutrient supply over a wide range has little or no effect on NAR (Watson 1947b). Blackman and Wilson (1951b) found that nutrient supply had little effect on NAR in low light intensities, but with increasing light intensities the NAR increased with improved nutrient supply. Fertilizers increase LAR but the major elements differ in the time when they are most effective. For example, Watson (1956) showed that N increases leaf area throughout the growth period of barley and potato; P increased leaf areas particularly in the early stages of growth, but later it hastened senescence of the leaves and eventually may decrease leaf area; K on the other hand, is most effective in the later stages of growth and it tends to delay senescence of the leaves. Watson (1952) found that in general the fertilizer responses (mainly of cereals) were due to increase in LAR.

Fertilizer trials on vegetables (Austin 1963; Nichols 1971a and b) seem to show that the increase in RGR is due to increasing NAR. According to Austin (1963), small percentage variation in NAR missed by Watson because of delayed sampling, has as much effect on yields as a considerably greater percentage variation in LAR. Nichols, using radish and lettuce, showed that the response to P fertilizer was due to a higher NAR. However, Briggs *et al* (1920) showed for certain annual plants that the LAR exhibited an ontogenetic drift essentially similar to that of the RGR and that consequently the NAR changed relatively little during a large part of the life cycle of the plants.

2.4 LEAF AREA RATIO (LAR)

The index of leafiness is the other quantity that can be derived, with NAR, to produce an informatively subdivided summary of the plant's performance. Briggs, Kidd and West (1920b) called this other quantity the leaf area ratio (LAR) and defined it as the ratio of total leaf area to whole plant dry weight. In a broad sense, LAR represents the ratio of photosynthesizing to respiring material within the plant (Hunt 1978). Simply expressed, the growth rate of the plant depends simultaneously upon the efficiency of its leaves as producers of new material and upon the leafiness of the plant itself.

Leaf area ratio can be considered as being made up of two components, the leaf weight ratio (LWR) and specific leaf area (SLA) (Evans and Hughes 1961). Hence

$$LAR = LWR \times SLA$$

$$= \frac{Lw}{W} \times \frac{A}{Lw}$$

Thus:

$$\text{Mean LWR} = \frac{\log_e W2 - \log_e W1}{(W2 - W1)} \cdot \frac{(Lw2 - Lw1)}{\log_e Lw2 - \log_e Lw1}$$

$$\text{Mean SLA} = \frac{(A2 - A1)}{(\log_e A2 - \log_e A1)} \times \frac{(\log_e Lw2 - \log_e Lw1)}{(Lw2 - Lw1)}$$

where Lw is leaf weight. This concept enables differences in LAR to be attributed to either (i) the differential distribution of photosynthetic products between leaf growth and other plant growth, or (ii) the differences in leaf thickness (Radford 1967).

Specific Leaf Area is the mean area of leaf displayed per unit of leaf weight (in a sense a measure of leaf density or relative thickness) and LWR is an index of the leafiness of the plant on weight basis (Hunt 1978). Thus

$$\frac{1}{W} \cdot \frac{dW}{dt} = \frac{1}{A} \cdot \frac{dW}{dt} \times \frac{Lw}{W} \cdot \frac{A}{Lw}$$

or

$$RGR = NAR \times LWR \times SLA$$

As with LAR, SLA and LWR are both amenable to calculation of instantaneous values at the time of harvest. Mean values between harvest intervals may also be estimated in the same manner as those of LAR and statistical analyses may be performed.

Of the two, SLA and LWR, the former is in general both the more sensitive to environmental change and the more prone to ontogenetic drift (Hunt 1978). Blackman (1956) clearly demonstrated in shading experiments that the change in LAR is largely dependent on the change in SLA, and that LWR remains relatively constant. Also, Butt (1968) noted that the increase in LAR caused by low light intensity was due mainly to an increase in SLA. At low light intensities the plants had much longer but narrower leaves. However, in some plant species leaf weight ratio (LWR) contributes to changes in LAR besides SLA and Butt (1968) showed that the onion plant belongs to this last group.

In another series of experiments Blackman (1956) found that temperature had a positive effect on LAR and SLA, but had little effect on LWR. Evans and Hughes (1961) also obtained the same effects of light and temperature on LAR and SLA. In young plants of *Impatiens parviflora*, they were able to show a marked ontogenetic drift in SLA while the LWR remained almost linear. Variation in light intensity has the greatest influence as deep shade causes striking increases in SLA which may partly offset decreases in NAR (Hughes and Evans 1962).

Differences in both LWR and SLA occur even between closely-related species. For example, Evans (1972) explains that in two species of sunflower, *Helianthus debilis* has a substantially higher proportion of its dry matter in the form of leaves than has *Helianthus annus*; values of LWR were commonly greater by

20%. It was established that the much less leafy nature of Scots pine, in comparison with sunflower was due almost entirely to the relatively greater density of the pine needles and hardly at all to any variation in LWR (the 'productive investment' of the plant) which, in fact, showed a small difference in favour of pine.

2.5 Crop Growth Rate (CGR)

A second approach in growth analysis is through the crop growth rate (CGR) which has been defined as the rate of increase of dry weight per unit area of land (Watson 1956). The CGR is partitioned into the components which reflect the efficiency and the size of leaf surface (Watson 1958). The components are related to the growth rate as follows:

$$CGR = NAR \times LAI$$

where LAI, or leaf area index, is the area of leaf per unit area of ground surface occupied by the crop.

As the crop approaches maturity, NAR normally declines in magnitude and LAI normally increases (Hunt 1978). Indeed the former trend is at least in part, a consequence of the latter. Now, since CGR is the product of NAR and LAI, the direction and extent of its own drift with time depends on the relative magnitude of these trends.

It has been demonstrated that increased LAI at high densities of planting led to increased CGR despite a fall off in NAR (Hunt 1978). Conversely, Watson (1958) removed different fractions of the foliage of kale and sugar-beet crops growing at Rothamsted and found that increased values for NAR resulted. Judicious thinning of kale crops, but not sugar-beet, might thus increase total dry matter yield.

Watson (1952) discussed the relative importance of variation in LAI and NAR in determining CGR and concluded that LAI is on the whole more important because it is more strongly dependent on the environmental conditions and management regime of the crop.

2.6 Leaf Area Duration

Another useful concept introduced by Watson (1947a) is the leaf area duration (LAD) or the integral of LAI itself over the whole growth period of a crop and hence its capacity for assimilation. When LAI is plotted against time the resulting curve allows an estimate of LAD (the area lying beneath curve). The LAD takes into account both of the magnitude of leaf area and its persistence in time. In effect, it represents the leafiness of the crop's growing period (Hunt 1978). Thus, if NAR were constant the dry matter produced would be proportional to the leaf area duration.

If the LAD of a crop and its mean NAR are known then its final yield may be predicted. Less perversely, if this yield is already known (as it would be if NAR had been derived) then it may be broken down into these two components (Hunt 1978):

$$\underset{(\text{wt. area}^{-1})}{\text{Yield}} \;\underset{\sim}{\sim}\; \underset{(\text{time})}{\text{LAD}} \times \underset{(\text{wt. area}^{-1}\ \text{time}^{-1})}{\text{NAR}}$$

The approximation sign is used here because the concept of mean NAR over a whole season is inevitably very crude and because, in the concept of leaf area duration itself, equal areas beneath the LAI curve are treated as being, equally useful 'opportunities for assimilation' - an even more crude assumption in view of the changes that take place, both ontogenetically within the crop and climatically in its environment, during the course of the crop's growth (Evans 1972).

Using four species grown at Rothamsted, Watson (1947a)

demonstrated that LAD was a more important factor in determining final yield than mean NAR. The time of year at which most of the crop's foliage is displayed is of some importance. Other things being equal the greatest possibilities for high production occur when a substantial LAI coincides with the midsummer conditions, where NAR is maximal.

There are a number of possible approaches to an increased LAD, some of which are already at the stage of practical development. Firstly, one can establish the crop canopy earlier in the year. This is the basic advantage of transplanting (Brewster 1977). The technique of sowing pregerminated seed can advance emergence of spring-sown onions by 10 days in central England (Currah 1975). Ten days extra growth at full leaf canopy could add about 170 g m^{-2} to dry matter yields.

A second approach is to consider extending the duration of leaf cover at the end of the season. Four weeks growth of onions at full leaf cover and maximum crop growth rates would represent about 476 g m^{-2} of dry matter (Hewson 1971). The regulation of maturation so as to attain the maximum possible LAD in all seasons and yet permit adequate bulb ripening appears to be an attractive possibility.

CHAPTER 3

MINERAL NUTRITION

3.1 General Aspects

Research has clearly identified certain elements as essential for the growth of plants. According to Epstein (1965), an element is essential (i) if, without it, the plant cannot grow normally and complete its life cycle, and (ii) if it is part of the molecule of an essential plant constituent or metabolite. There are sixteen elements that are generally accepted as essential for plant growth. The macro-nutrients - carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), sulphur (S), potassium (K), calcium (Ca) and magnesium (Mg) - are required in much larger concentrations than the micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), boron (B), copper (Cu), molybdenum (Mo), and Chlorine (Cl), though this is no indication of their relative influence on crop performance.

These elements are used to synthesise the complex chemicals of plants. Each element has its part to play - some prominent like carbon, oxygen and hydrogen that give sugars; nitrogen being part of proteins; and phosphorus forming salts which are energy carriers. Calcium pectates have the job of cementing cell walls together and magnesium is part of the chlorophyll molecule (Bleasdale 1973).

The capacity of soils to supply these essential elements is a fundamental edaphological problem. To the extent that they cannot be supplied by soils, these elements must be added in fertilizers, manures and crop residues.

Certainly the world consumption of fertilizers is increasing very considerably. The cost of fertilizers which is also increasing is a substantial proportion of the total cost of

growing crops, particularly vegetable crops and there is, therefore, a need to use fertilizers as efficiently as possible and to keep waste to a minimum. But perhaps of greater importance is the need to ensure that yields are not restricted by poor fertilizer practice. Thus a sound knowledge of the science of plant mineral nutrition is necessary to the solution of problems arising from fertilizer practice.

3.2 NUTRIENT RESPONSES

Nitrogen, phosphorus and potassium are the production or fertilizer elements as they have large general effects on growth that vary with the amount supplied over a wide range (Cooke 1972). Soils differ greatly in their capacity to furnish these elements, both inherently and because of their previous treatment. In most cases soils provide too little of these elements to produce maximum yields, hence the need to use fertilizers to ensure that deficiencies of these elements do not exist.

Experiments which compared more than 20 vegetable crops under field conditions, have shown onions to require higher levels of N, P and K fertilizers for maximum yields than most other vegetables (Greenwood, Cleaver and Turner 1976). The response to P and K can be explained in terms of our present understanding of nutrient supply to roots. The root length or root surface area per unit of plant weight is low in onions (Brewster 1977). This is particularly important where the diffusion rate to individual roots limits the overall nutrient uptake rate. In soil, this diffusion barrier is normally important for phosphate and potassium but less important for nitrate (Baldwin 1975).

There is uncertainty about the levels of N, P and K to aim at for onions as they depend on such things as weather conditions which change from year to year. If the levels are very high, waste of fertilizer could be excessive, far larger quantities of nutrients would be taken up by the crops than would be needed

for maximum growth, considerable quantities of available phosphate would be immobilized in the soil by chemical reaction and deficiencies of magnesium and other nutrients may be induced in the crop (Greenwood *et al* 1976).

Clearly, the P and K should be maintained at no higher levels in the soil than are required to ensure that very little response would be obtained by further applications of these fertilizers. According to predictions by Greenwood, Cleaver and Turner (1976) no appreciable responses would be expected to occur with onions in the United Kingdom on soils containing more than 80 ppm of sodium bicarbonate extractable P or more than 200 ppm of ammonium nitrate extractable K. Thus sifficient P and K should be added to bring the soils up to these levels and that they should be maintained as near as possible to them.

A complicating factor in the understanding of the response of onions to soil phosphate is the possibility that the roots are infected with symbiotic mycorrhizal fungi. It has been demonstrated that onions so infected grow well in soils of much lower phosphate status than non-infected onions (Hayman and Mosse 1971). The ratio of surface to volume of the root plus mycorrhizal system greatly exceeds that of the non-infected root and the effect of infection on phosphate response is most simply explained in terms of diffusion to a larger absorbing surface (Sanders and Tinker 1971).

High phosphate is reported to increase onion bulb growth and hasten maturity (Downes 1959), but decreased leaf growth when compared to low phosphate levels. Applications of P resulted in a 2 - to 3 - fold increase in bulb concentrations of phosphate, but did not affect the P content of the leaves.

Potassium increased both leaf growth and bulb yields and tended to counteract the detrimental effect of excessively high nitrogen levels. The magnesium contents of the plants were

significantly reduced by potassium applications, but were not affected by magnesium applications (Downes 1959). Zinc and copper applications produced less clearly defined responses in growth and composition of onions.

Where N was limiting, its application resulted in significant increases in the growth of leaves and of bulbs (Downes 1959). At a high level of N, concentrations of manganese were increased 4 or 5 times in the leaves and were more than doubled in the bulbs as compared with plants receiving low N levels. High levels of S and Mn had no significant influence on plant composition.

3.3 Nitrogen Nutrition and Onion Growth

In general, nitrogen is the element whose deficiency or excess most commonly causes loss of crop yield (Scaife and Stevens 1977). In contrast to P and K, there are usually only small amounts of available N in the soil at the start of the growing season and so it must be applied for almost every crop. Any nitrogen added to soil, in either inorganic or organic form, enters the nitrogen cycle on which crops depend for their nitrogen requirements. They absorb N as the two simple inorganic forms, nitrate and ammonia (usually the former). Ammonia is normally oxidised (or nitrified) fairly rapidly in the soil and the resulting nitrate is liable to be lost by leaching, denitrification and immobilization. Thus, nitrogen deficiency can easily occur.

Nitrogen deficiency symptoms of onions growing in the field is shown by an erect growth of the leaves, which are pale-yellow or greenish yellow in colour (Jones and Mann 1963). Onion plants grown in nutrient solutions that were low in nitrogen grew slowly, became stiff and upright in habit, and developed short narrow leaves of a very light green colour. Later the tips of the older leaves died and became bleached and yellow.

Excess application of N fertilizers can also be harmful to crop performance. Page (1973) noted that high N rates depressed emergence. This is caused by the immediate nitrate effect on the osmotic pressure of the soil solution. Other harmful effects of excess N fertilizers are, reduced crop growth caused by toxicity effects, superfluous foliage and less marketable crops and undesirably high nitrate levels in vegetables and in drainage water (Scaife and Stevens 1977). Thus overdosing is not a satisfactory solution, quite apart from the fact that it is uneconomical.

Most species grow better with nitrate than with ammonium nitrogen even when optimal pH conditions are provided for uptake of each type of nitrogen source (lower pH favouring nitrate uptake), but it is also clear that when rapidly growing plants are investigated, the differences at the optimal pH values may be greatly reduced (Hewitt and Smith 1974). Low light intensities accentuate the unfavourable effects of ammonium compounds. Micronutrients such as Mn and Cu may be required at higher concentrations, and aeration may be more necessary in the presence of ammonium than of nitrate nitrogen supplies. Ammonium nitrogen supplies are toxic to many species at concentrations which are quite harmless for nitrate, but a few species, e.g. rice at early stages of growth and maize may tolerate or thrive better on ammonium than on nitrate nitrogen. The relative merits of nitrate and ammonia are extensively discussed by Hewitt (1966).

Peat is usually the main ingredient used in potting media. Although markedly deficient in most plant nutrients, peat contains considerable quantities of nitrogen, e.g. (Hauraki peat 1.22% total N (Prasad 1980)). However, seldom does more than 5% of the total N occur in mineral forms available for uptake by plants. Under natural conditions production of mineral nitrogen in peat depends on microbiological activity and takes place very slowly. However, where temperature, moisture and nutrient levels are near optimal, as under glass, the rate of conversion of organic

nitrogen to mineral forms may be relatively rapid (Puustjarvi and Robertson 1975). Prasad (1980) studied the retention and release of major nutrients by New Zealand peats and wood wastes. Retention of N was low for all peats. At 24 weeks, the peats retained less than 20% of the applied N. There was little or no release of N by the peats.

Riekels (1977) conducted field experiments on organic soil to evaluate the influence of frequent irrigation and top dressings with N on growth, maturity and storage life of onions. With no irrigation, growth to mid-season, maturity and final yield were not influenced by increasing amounts of N. However with irrigation, increasing N levels increased growth to mid-season, yield and stimulated earlier maturity. Similar results were obtained by Riekels (1972).

Wilson (1934) found that a severe N deficiency in onions will prevent normal maturity. Riekels (1977) did not find this but noted that maturity was delayed when N was limiting with high moisture conditions. All irrigated onions matured a week or more later than non-irrigated onions, even with the highest rates of N. This response indicates that maturity is controlled more by the moisture supply than by N. Thus, it is suggested that heavy irrigation should be avoided to prevent delays in onion maturity.

The level of N nutrition has also been found to influence bulb formation. Scully, Parker and Borthwick (1945) established that, near the critical daylength for bulb formation a high level of nitrogen nutrition reduced relative bulb formation and a low level promoted bulbing. Thus, a deficient level of N has the same effect as lengthening the photoperiod, and a high N supply has the same effect as shortening the photoperiod. Bremer (1936) also reported that bulb formation was promoted by a low N supply or by a high ratio of potassium to nitrogen.

Paterson, Blackhurst and Siddiqui (1960) reported that high levels of N fertilizer reduced flowering in the field in over-wintered onion crops. Similar results were reported by Cleaver and Turner (1975). Also, Stuart and Griffin (1946) reported that a phase of low N nutrition promoted subsequent flowering in plants growing in culture solutions in the greenhouse.

3.4 Nitrogen Nutrition and Bulb Yield and Quality

Yields of ware-sized (>45 mm diameter) onion bulbs equal to 500 g m^{-2} of dry matter (about 50 tonnes per hectare of fresh bulbs) are in practice considered very good. However, yields of 1300 g m^{-2} dry matter have been attained on small plots at NVRS (Brewster 1976). The theoretical maximum or ceiling yield of a crop will occur when daily gross photosynthesis is equal to daily respiration (Brewster 1977). Present evidence suggests that the ceiling yield of onions may be well above that of leafy crops which is around 1000 g/m^2 in Britain.

A number of research workers have recorded significant increases in yield with increases in N fertilization. Greenwood *et al* (1976) compared more than 20 vegetable crops under field conditions and noted that onions required higher levels of N for maximum yields than most other vegetables. Hassan (1977) reported significant increase in total yield with high N levels. However, Sypien *et al* (1973) noted decreased total and market yield of onion bulbs with lack of N fertilization as well as very high pre-sowing dose of N. The no N treatment yield decrease was caused by the retardation of the plant's growth whilst the very high N treatment was due to seedling toxicity, caused by a big amount of N given in one dose.

In general, fertilizer applications, particularly N fertilizers, can either increase or depress yields and their effects vary greatly from year to year (Greenwood *et al* 1976).

With low rainfall, Riekels (1972) found onion yields declined with increasing rates of N. The decline in yield was originally attributed to ammonium toxicity, but observations with three sources of N indicated that high concentration of fertilizer salts also could have caused injury to the plants. With high rainfall, yields increased with each increase in N.

Also Riekels (1977) noted that with irrigation, yields with the greatest amount of N were equal to or greater than the corresponding treatments grown without irrigation, suggesting the desirability of supplying the crop with regular moisture to obtain maximum effectiveness of N applications.

Onion crops at their maximum leaf cover intercept only about 60-70% of the incident radiation in the field (Hewson 1971). However, a very high proportion of the total yield is diverted into bulbs if the plants are left to mature fully. Brewster *et al* (1977) noted that delaying harvesting by one week increased yield. Romanowski (1962) reported 15 to 20% increases in yield as a result of delaying harvest from 80 to 90% die down until only two or three leaves remained green. It seems, therefore, that the onion crop is inefficient in intercepting solar energy and converting it into dry matter but that a high proportion of the dry matter fixed is converted into edible bulbs.

Experiments in temperate regions have generally indicated an optimum spacing of about 70 plants m^{-2} for maximum yields of ware-sized bulbs (Bleasdale 1966; Frappell 1973). Higher densities increase total yields but the bulbs become unacceptably small. Ware bulb yields of around 1000 g m^{-2} have been attained by transplanting seedlings (Brewster *et al* 1975) and by regular irrigation at a high level of nutrition (Brewster 1976). Given such conditions a higher plant density can produce good sized bulbs.

The effect of fertilizers on the quality of vegetables has

been reviewed by Vittum (1963) and Fritz and Habben (1973). Published reports indicate that, although mineral fertilizers can increase nutritional value of vegetables, their effect on quality is correction of defects caused by nutrient deficiencies (Vittum 1963). A well fertilized crop is usually a high quality crop.

Sypien *et al* (1973) examined the influence of nitrogen fertilization on the quality of onion bulbs and observed the following results: The highest N treatment (300 kg N/ha) had the biggest bulb size (average 4.5 - 7 cm diameter). The smallest bulbs were in the no nitrogen treatment (average 3.5 - 4.5 cm). The biggest amount of thick-necked onions was observed in plots with very high dose of N applied basally (300 kg/ha in one dose), or when sufficiently high doses of N had been applied as a top dressing late (150 + 150 kg N/ha). Smaller doses of N caused the smaller amount of thick-necked onions in the yield. However, no thick-necked onions appeared in any treatment of N fertilization when the experiment was performed in a hot dry weather season. Thus, the high N doses may only cause the tendency for such plants to develop. The morphological characteristics of the onion bulbs such as shape of the bulb, resistance of the skin for cracking and its adherence to the bulb, and thickness of the neck, were only slightly affected by nitrogen fertilization.

Hassan (1977) also found increases in nitrogen levels gave highly significant increases in the amounts of large bulbs. Similarly, the addition of N increased the average bulb weight. These were shown as 125.9, 146.2 and 139.7 g for 0, 95 and 190 kg N/ha respectively. Freedom from bulb disorders such as doubles and splits is a desirable character for onions. However, Hassan noted that increasing the amount of N applied resulted in increasing the amounts of doubles.

Nitrate accumulation in vegetables as it affects health

has been reviewed by Maynard *et al* (1976). The potential for nitrate poisoning from vegetables arises from the reduction of nitrates to nitrites before or after ingestion. When nitrites are absorbed in quantity, ferrous haemoglobin is oxidized to ferric haemoglobin, thus oxygen is not transported and tissues are subject to anoxia. Thus good quality vegetables should contain very low nitrate levels. Maynard *et al* (1976) also suggested ways of reducing NO_3 content in plants like celery that accumulate a lot of it. Onions accumulate very little nitrate.

Greenwood *et al* (1976) noted that the quality of vegetables is almost unaffected by levels of fertilizer near the optima. It is noted that the effects of fertilizer on quality is small compared to the effects on yield. In general, external quality and the nutritional value are optimal when fertilization is adapted to the physiological requirements of the plant.

3.5 Plant Tissue Analysis

3.5.1 General Aspects

The term plant analysis, as commonly used refers to the study of the relationship between the nutrient content of a plant and its performance. It is based on the concept that "what is in the plant is related to growth" (Ulrich 1978). The early development of plant analysis has been reviewed by Goodall and Gregory (1947). Much has happened since then and plant analysis has become an integral part of most agronomic experiments. Plant analysis services are now extended to farmers, and the use in the field has greatly increased.

The aim of plant analysis is to define the nutrient levels in the plant associated with deficiency, adequacy and toxicity so that the nutrient status of a growing crop may be diagnosed. Thus fertilizer responses may be evaluated by a comparison of

plant analysis results to critical nutrient values. Hence, changes in the fertilizer program can often be made immediately, or if that is impossible as may be the case with some annual crops, in time for the next crop. In this way a good plant analysis program evaluates current nutrient needs and anticipates those of the next crop on the same field.

Plant analysis, however, cannot be used to determine basal fertilizer applications for the current crop. Soil analysis is normally used in this regard. Soil analysis methods have the chief advantage of offering predictive information, but suffer the great disadvantage of being unable to take availability into consideration. Only the nutrients taken up by the plant are significant, and nutrient uptake is not a simple function of their concentration in the soil medium. The total amount of soil nutrient present is not then necessarily a good index of nutrient available for plant growth.

There is as yet no satisfactory method of soil analysis for available nitrogen. The problem arises from the fact that nitrogen is easily lost in the soil by leaching, denitrification and weed competition. As much as 60 kg/ha of inorganic nitrogen can disappear from the soil within a single week, even when there is no waterlogging or any evidence of leaching (Scaife 1975). Thus, soil nitrogen nutrition status predictions from soil analysis becomes more uncertain and so only plant analysis gives a meaningful result.

Analytical results of plant analysis are not absolute numbers, therefore, they need to be calibrated with crop performance and response to fertilizer application. Research has established standard or optima values as well as deficient, low and excess ranges, for various nutrients. Nutrient concentrations found in 'normal' plants which can be used as guidelines for vegetable crop production have been presented by Geraldson, Klacan and Lorenz (1973).

In essence, the crop through plant analysis shows that the power of the soil to supply a nutrient has not kept pace with the nutrient requirements of the crop. Consequently, if the crop is to grow satisfactorily, supplies of the nutrient must be increased either directly by fertilization or indirectly by enhancing the nutrient supplying power of the soil through improved cultural practices such as crop rotation, improved soil structure, better varieties, improved irrigation, better drainage, wider plant spacing, better weed control, etc.

3.5.2 Sampling and Sample Preparation

The need for samples taken for plant analysis to be representative cannot be over-emphasized. If the samples are not representative of the plants or plant parts from which they were obtained, the results of the analyses will not be valid.

Sampling and sample preparation are probably the biggest variables in plant analysis. With vegetables, Lorenz and Tyler (1978) noted that the time of sampling or more specifically, the age of the plant when it is sampled is very important in reducing variability. The overall growth period of crops can vary greatly. Thus one cannot select any sampling period based on a precise number of days from seeding or even from emergence. Sampling, therefore, must be related to some physiological stage of growth.

In general, the plant part analysed is not critical. The leaf blade, leaf petiole, stem, or in some cases even the roots can be used (Lorenz and Tyler 1978). For most nutrients, however, an actively growing plant part is selected for example, selection of the youngest fully mature leaf is excellent for tomatoes, beets, carrots, onions, potatoes, and many other crops (Geraldson *et al* 1973). In any case, the plant part selected and the time of sampling must correspond to the best relationship that exists between the nutrient element concentration and

yield or the physical appearance of the plant (Bates 1971).

It is far better to make samplings at several stages of growth than to concentrate on a large number of samples at any one time. Nutrient concentration in a fast growing crop of potatoes can change by 100 percent in one week (Lorenz and Tyler 1978). Concentrations of nitrogen, phosphorus and potassium usually decrease greatly with plant age, and to adequately evaluate a particular crop a minimum of three samplings is required. If conditions are such that only one sampling can be made, then the most reliable information for nitrogen and phosphorus is obtained from samples obtained during the early growth period; for potassium, samples taken from more mature plants give the best correlation with crop performance (Lorenz and Tyler 1978).

A summary of sampling techniques that have been generally accepted for interpreting plant analysis have been produced by Jones, Large, Pfleiderer and Klosky (1971). It contains a list of recommended sampling procedures for various crops. For onions, it is recommended to sample 20 to 30 plants, choosing the centre mature leaves prior to bulb enlargement.

For rapid tissue tests in the field, sufficient number of plants should also be sampled. Scaife and Stevens (1977) noted a ten fold variation in nitrate levels between supposedly identical cabbage plants in the field. They suggest sampling 10 plants chosen at random to get a representative result.

Jones and Steyn (1973) discussed the different preparative steps the plant material is usually subjected to after sampling before the actual chemical analysis is carried out. These include (i) cleaning the material to remove surface contamination; (ii) drying to stop enzymatic reactions and prepare the material for grinding; (iii) mechanical griding to reduce the material to a fineness suitable for analysis; (iv) final drying

to constant weight to obtain a standardised value on which to base the analytical figures. Also, (v) storage and transport of the fresh material prior to cleaning and drying; and (vi) storage of the tissue powder prior to analysis.

In general, samples are washed in distilled water to avoid dust and possible nutrient and pesticide contamination. Samples are then placed in clean paper bags and dried at temperatures of 60 to 70°C. After drying they are ground to 40 mesh and stored in air-tight containers until analysed.

3.5.3 Analytical Methods

In general there are two methods of analysing plants: (i) quantitative or laboratory methods and (ii) semi-quantitative methods. The former normally involves total chemical analysis or spectrographic analysis and the latter involves rapid tissue tests. Each may be used at several stages of plant growth and on various plant parts or on the entire plant.

(A) Laboratory or Quantitative Analyses

This method usually involves considerable laboratory work. It measures both the elements that have already been incorporated into plant tissues and those that are still present as soluble constituents of the plant sap (Aldrich 1973). Numerous methods have been developed for these analyses. Most procedures involve ashing of tissue to destroy the organic component leaving the various elements for analysis.

Two methods of ashing, wet and dry, are usually used. Wet ashing can be accomplished by using various combinations of HNO_3, H_2SO_4 and $HClO_4$. Dry ashing procedures vary as to temperature and length of ashing time. Most recommend that the ashing temperature not exceed 500°C and that 2 to 8 hours is

sufficient time (Jones and Steyn 1973). The techniques of wet and dry ashing have been described in some detail by Johnson and Ulrich (1959).

The primary method for nitrogen determination is by Kjeldahl digestion (Horowitz 1970). A number of modifications have been suggested and more rapid procedures devised, using Auto-Analysers. Also, an Auto Analyser method has been described by Steckel and Flannery (1971) for the determination of Ca, K, Mg and P. Sulphur can be determined by several methods. Each has its own limitations and requires particular skill on the part of the analyst.

It is difficult to specifically select any one method or technique as being superior to another for the analysis of plant tissue ash. Most analysts have used colorimetric, flame emission, atomic absorption or direct-reading emission spectrographic techniques. An interesting study related to methods of analysis of plant tissue for N, P, K, Na, Ca, and Mg which give the best results with the least variance was reported (Inter-Inst. Comm. Study Anal. Tech. Foliar Diag., 1959). They found that dry ashing, the Kjeldahl method for N, flame spectroscopy for K and Na, P by the phosphovanadomolybdic complex, Ca by complexometry, and Mg by the titan yellow spectrometry method gave the best results (Jones 1978).

Despite the present technological advancement of these analytical methods, variation in results recorded by various laboratories analysing the same sample still occurs. It has been thought that some of these discrepancies may be due in part to standardisation techniques employed in the various laboratories (Jones 1978). Similarly, standardized techniques are needed that specify drying, ashing, and solublization procedures prior to analysis if variation in results is to be reduced. Compensation techniques to minimize interferences and inter-element reactions are also needed.

(B) Semi Quantitative Analyses (Rapid Tissue Tests)

The semi-quantitative analysis, exemplified by the rapid tissue tests, measures the unassimilated soluble contents of the plant sap. In essence, the constituents that are measured are en-route from the point of entry to the site of utilization within the plant (Aldrich 1973). This method is conducted in the field and is normally limited to the major elements, N, P and K.

The present conventional laboratory techniques of plant analysis are laborious, costly and time consuming, often requiring sophisticated equipment, dangerous chemicals and complex techniques. These problems make the rapid adoption of plant analysis as a routine practice in crop production by growers very difficult. Also, research workers in developing countries wanting to perform plant analysis in their trials are usually handicapped by these problems. Thus, the rapid tissue test could be a useful substitute for the laboratory methods of analysis if it could be made reliable and sensitive since it is simple, quick and inexpensive.

Scaife and Bray (1977) noted four major ways in which sensitivity can be improved: (i) by measuring inorganic fractions, such as NO_3-N, PO_4-P, and SO_4-S and ionic forms such as Ca^{++} rather than total amounts of elements present; (ii) by analysing petioles or stems, which contain relatively large proportions of these inorganic fractions and very little cyloplasmic material; (iii) by analysing the oldest leaves (or their petioles) - possibly even cotyledons - for mobile nutrients (N, P, K, Mg), which are moved to the apex in times of deficiency, and youngest leaves for immobile elements (Ca, B, Fe, S) for which deficiency symptoms first appear in these leaves; and (iv) by analysing sap rather than dry plant tissue, and expressing results as sap concentrations rather than amounts of nutrient relative to the dry matter present. Thus rapid tissue tests in which concentrations of inorganic nutrients in the petiole sap is measured should be a reliable and sensitive method of plant analysis.

The idea of rapid tissue tests in the field for determining plant nutrient status is not a new idea. Emmert (1934), Nicholas 1948 and Williams (1969) all worked on the idea. However, their methods were not widely adopted by farmers probably because they were not easy and straight-forward to perform. For such a method to be quickly taken up by the farmer for monitoring the nutrient status of a crop, it should be safe, clean and simple with a minimum of wet reagents, a long shelf life for the ingredients and for colorimetric methods, permanent colour standards provided (Scaife and Bray 1977).

Recently at NVRS, England, rapid tissue tests techniques are being improved to make it easy for the grower and to enable the technique to be used to diagnose deficiencies before symptoms appear and at a growth stage which permits correction by soil applications of fertilizer (Scaife and Stvens 1977). 'Merckoquant' test strips, manufactured by E. Merck, Germany, for simple and rapid semi-quantitative determination of nitrate (NO_3^-) in all aqueous media are being used in diagnosing plant nutrient status (Scaife and Stevens 1977; Scaife and Bray 1977). Also Hunt, Barnes and Greenwood (1979) have used the strips as the basis of a technique for measuring the average nitrate concentration in a field soil. 'Merckoquant' strips are also available for K^+ and Ca^{++}.

The nitrate strips consist of thin plastic strips (75 mm x 5 mm) to which are attached two zones of white filter paper, impregnated with an aromatic amine and N- (1 naphthyl) ethylene diamine. The lower zone of the test strip contains a reducing agent and indicates both nitrate and nitrite whilst the upper zone only nitrite. The upper zone (nearest the blank end) serves as a warning zone, since its pink to red-violet colour indicates interferring nitrite. When the lower zone is wetted with a nitrate solution, the nitrate is reduced to nitrite by the reducing agent. The nitrite formed produces nitrous acid in the presence of a buffer, the nitrous acid then diazotises

the aromatic amine. Coupling with N- (1 naphthyl) ethylene-diamine then produces a red violet azo-dye.

In the pH range 1-12 the accuracy of the detection is independent of the pH of the solution being tested. Colour development takes two minutes after which the test zone, coloured red-violet in the presence of nitrate is compared with the colour standards printed on the tube containing the strips and graduated as 0, 10, 30, 100, 250, and 500 mg/l (ppm) NO_3^- (= 0, 2, 7, 23, 57, 114 mg/l (ppm) NO_3-N. For nitrate concentrations above 500 mg/l (ppm), the test solution is diluted such that the resulting colouration lies within the range of the colour scale. However, Scaife and Stevens (1977) found that by accurately recording the time in seconds for the colour to develop to that of the 500 ppm standard on the tube, the highest concentrations ever found in petioles can be estimated with sufficient accuracy.

Plants take up most of their nitrogen from soil as nitrate and in most species is moved in this form to the leaves where it is reduced to ammonia and then combined with carbohydrates to form amino acids, amides and thence proteins. Nitrate is therefore a raw material of new leaf growth and its concentration in the plant is a very sensitive indicator of the ability of the plant to find enough N to meet immediate demands (Scaife and Stevens 1977). If N supply exceeds demand, nitrate accumulates in the plant : when the reverse is true, nitrate rapidly disappears. However, some crops reduce most of their N to amino acids and amides in the roots so very little nitrate is to be found in shoots.

For most young crops there is little doubt that sap nitrate levels should always be above the 500 ppm NO_3^- standard on the tube, even for the lowest leaves. It is probably equally safe to say that in any crop a reading of less than 30 ppm NO_3^- represents a severe deficiency (Scaife and Stevens 1977).

The amount of extra N to apply when such a deficiency is found depends largely on the stage of growth : in a young crop almost a complete season's application is needed, whereas in a nearly mature crop there may be no point in adding further N.

Methods of sap extraction from plants for tissue analysis are still unsatisfactory. Pliers have not been generally useful (Scaife and Bray 1977). For many crops, the petiole or stem sap can be 'rolled' out onto the sensitive square using a ball pen. Also, Scaife and Bray (1977) showed the features of a simple press which forces the sap out of a small orifice and produces a drop of fairly constant volume. However, with all these methods, using leaf blade or petiole, chlorophyll may contaminate the sap and can obscure some colour tests.

Both total nutrient composition and soluble fractions have been used successfully to obtain data which can be correlated with crop production. Nicholas (1956) compared various soluble fractions of a number of nutrients with the total concentration and in general found that they were closely correlated except in the range of luxury consumption.

Lorenz, Tyler and Fullmer (1964) compared total and 2% acetic-acid-soluble nutrients in potatoes and found that they were highly correlated for N, K, and Mg but less so for P and Ca. Ulrich (1942) stated that NO_3-N in sugar beet petioles reflects the N status better than any other fraction. Burhan and Babiker (1968) found NO_3-N in cotton petioles superior to total N. This preference for NO_3-N is rather common for tissues which accumulate nitrate. Lorenz and Tyler (1978) noted that when N is very low, total N determined by Kjeldahl procedure is a better estimate of the nutrient status than is the soluble or nitrate fraction.

3.5.4 TOTAL-N AND NO_3-N CONCENTRATION

Nitrogen is probably the most important nutrient to monitor in plants, because nitrate in soil is unbuffered and very much subject to losses by leaching, denitrification and immobilization. Both total N and NO_3-N have been used successfully to evaluate the N nutritional status of plants with total N more predominant in the literature. However, in recent years NO_3-N determinations seem to be favoured more by research workers.

Jungk and Wehrmann (1978) showed that in the sub-optimal range of N nutrition an increase in N supply is registered much more sensitively by an increase in NO_3 content in the plant than by an increase in total N. Beyond optimum N supply the nitrate concentration of the plant dry matter decreases with increasing N concentration of the nutrient solution.

Working with onions, Zink (1966) noted that total N tended to decrease during growth. Total N ranged from 4.16 to 1.52%. This decrease may be related to the accelerated plant growth during the bulbing period. Geraldson *et al* (1973) found the total N content of young mature leaf onion at the midgrowth stage ranged from 1.5 to 2.5%. The concentration ranges shown do not indicate deficiency or excess limits, since such limits are dependent on all factors affecting nutrient uptake. Relative to the dry matter content, Zink (1966) found total N higher in the bulbs than in the whole plant. Also, the N content of the bulbs was significantly lower than that found in bulbs grown with a higher N fertilizer regime.

Furthermore, Zink (1966) found the NO_3-N content of onion plants was 0.18% (average of two trials) shortly after emergence but declined to 0.015% of dry weight later in the growth of the crop and was reported as a trace. This made him to suggest that NO_3-N analysis of the whole plant is not a reliable method of determining the nitrogen status during growth of a bulb onion crop.

Lorenz (personal communication) also noted that the NO_3-N content of onion bulbs and leaves was low but was high in roots. However, the use of roots to minitor N levels is not practically sound in the field. For fresh onion bulbs, Maynard and Barker (1972) found the NO_3-N concentration to be 14 ppm.

A detailed review of NO_3 accumulation in vegetables was made by Maynard, Barker, Minotti and Peck (1976). A number of factors affecting NO_3-N accumulation were discussed. These included, genetic control, source of N, method of application, environmental variables such as light, temperature and moisture, other macro-nutrients and nitrification inhibitors. The effect of high nitrate levels in vegetables to health were also discussed and methods of reducing nitrate accumulation were suggested.

The only nutritional factor having a marked effect on NO_3-N accumulation is N (Maynard and Barker 1972). At levels of N where growth was restricted, accumulation of nitrate was very low. With increasing levels of N fertilization the rate of accumulation increased (Lorenz and Weir 1974). In general, as nitrates accumulated the proportion of NO_3-N to total N also increased.

Nitrate-nitrogen is not uniformly distributed throughout the plant or for that matter in the edible portions of the plant (Wright and Davison 1964). Flower parts, storage organs and fruit are usually low in NO_3-N, roots are slightly higher while leaves have a still greater NO_3-N concentration. Petioles and stems seem generally to be the sites of maximum nitrate accumulation (Maynard *et al* 1976).

Plants that develop storage organs show a decline in NO_3-N concentration in the petioles as the crop approaches harvest (Geraldson *et al* 1973). The decline in petiole nitrate concentrations is associated with translocation of soluble N to the developing storage organ, as well as a gradual decrease

in available soil N. A greatly different pattern of NO_3 accumulation occurs in vegetables that do not develop storage organs as the food product in that nitrate generally continues to accumulate with age.

Finally, it should be noted that nitrate accumulation is a natural phenomenon representing the difference between uptake and reduction of nitrate. Certain vegetables because of a very efficient uptake system, an inefficient reductive system, or an unfavourable combination of both, tend to accumulate more nitrate than others. Thus nitrate accumulation is dependent on and related to the genetic makeup of the plant and also to the nitrate supplying power of the soil and the environmental conditions under which the plant is grown. Despite these variables, the determination of NO_3-N concentrations for vegetables offers an effective procedure for predicting nitrate requirements.

3.5.5 Nutrient Uptake

Removal of nutrients from the soil by a crop can be calculated from plant mineral analyses and dry weight growth data. The percent nutrient concentration in the total crop times the total dry matter weight gives the total uptake for a given time interval or crop yield. Such information is useful in determining nutrient maintenance levels to apply for different soil test levels and crop yields (Munson and Nelson 1973).

When attempting to relate plant tissue analysis to plant nutrient requirements, careful consideration should be given to nutrient uptake patterns as affected by growth stage. During the vegetative stage of plant development, nutrient uptake closely parallels the plant growth rate (Geraldson *et al* 1973). Following floral initiation, tuber formation or enlargement of storage organs, the rate of nutrient absorption often decreases on a dry weight basis. There is usually a transport of certain

elements from the vegetative portions of the plant to the developing flower, fruit, seed, root, bulb or tuber.

Nutrient uptake by crops is usually linear over wider ranges of application rates than is crop yield (Terman and Engelstad 1976). This is mostly true with N, K and S. Uptake of less mobile nutrients such as Ca and P may be linear at low application rates, but frequently is curvilinear.

The possibility exists that predicted optimum levels of fertilizer may supply less nutrients to nutrient deficient soils than are removed by harvest of the crop and will thus lead to a further decline in the nutrient status of the soil. However, Greenwood, Cleaver and Turner (1974) tested such a possibility and found that whilst the levels of N and P would be unlikely to lead to any decline in the N status of an N deficient soil or P status of a P deficient soil, those of K might lead to a decline in the K status of a K deficient soil. On the other hand if too much fertilizer is applied there can be much luxury consumption.

Direct comparisons of results are difficult because of the influence that climatic and edaphic variables, cultural practices, and variety have on nutrient uptake (Geraldson *et al* 1973). In addition, reported nutrient levels are influenced by differences in sampling, extraction and analytical techniques. Nevertheless, crop removal figures give a good indication of how much nutrient to apply.

Zink (1966) found the rate of nutrient removal by onion to be very slow during early growth. Approximately 85 days after planting (half the total growing period), the plants removed less than 14.7 kg of N, 1.5 kg of P and 17 kg of K/ha. During the period of bulbing to harvest the plants removed approximately 68% of their total N, 75% of the P and 47% of the K. At harvest, the crop removed an average of 162 kg of N, 26 kg of P,

128 kg of K, 98.7 kg of Ca, 14.7 kg of Mg, and 11 kg of Na/ha. Thus it is important that sufficient nutrients are available to onion plants from bulbing to harvest, in particular for maximum growth and yield.

3.5.6 INTERPRETATION

The usefulness of plant analysis in guiding fertilizer programs in crop production depends on our ability to translate them into intelligent management recommendations. These recommendations depend not only on accurate sampling and analysis but also on interpretations based on sound research and judgements.

Interpretive guides for tissue concentrations of NO_3-N, PO_4-P and total K for a number of vegetable crops (onions not included) have been produced by Geraldson *et al* (1973) and Lorenz and Tyler (1978). Specific directions for time of sampling and part of the plant to use for analysis are provided in the table. Plants classified as deficient would almost certainly respond in yield to additional fertilizers and it is extremely unlikely that plants classified as sufficient would show any response from increased fertilization.

The main methods for interpreting plant analyses are based on a critical concentration of a nutrient or nutrient fraction within the plant, or some plant part, below which growth or crop yield is restricted. This concept as developed by Ulrich (1952) and expanded by Ulrich and Hills (1967) select the critical level as that which produces 90% of the maximum yield.

The concept of critical concentrations is based on a predictable functional relationship between nutrient concentration and yield (Goodall and Gregory 1947). The response curve obtained by research workers generally has an ascending portion where yield increases sharply and a more or less level portion

where yield is not limited by the nutrient in question (Bates 1971). A second "C-shaped" curve called the "Steenbjerg effect" is sometimes encountered. This curve has limited value in plant analysis for diagnostic purposes. Bates (1971) describes several means of avoiding the "C-shaped" curves by being particular about sampling procedures.

A number of factors are known to affect the critical nutrient concentration. These have been reviewed in detail by Bates (1971) and are mostly: (i) age of tissue; (ii) choice of tissue; (iii) fraction of nutrients to be measured; (iv) effect of cultivar; (v) interactions among nutrients; (vi) environment and (vii) field vs greenhouse. In general, the tissue to be sampled should be carefully selected and uniform physiological age is particularly emphasised. It should also be noted that cultivars of a single species can differ appreciably in their critical concentrations of any one nutrient. Nutrient interactions can have appreciable effects on critical nutrient concentrations. Similarly, environmental variables such as moisture supply, temperature and light can markedly alter the nutrient content of plants. However, plant analysis can provide a rough guide to fertilization while ignoring nutrient interactions and environmental variables (Bates 1971).

There is some difference in opinion expressed in the literature as to whether critical concentrations determined in the greenhouse and in nutrient cultures are valid for use in the field. It is certainly easier to determine values in the greenhouse if they are valid. Ulrich and Hills (1967) suggested that critical concentration can be determined in solution, soil culture or field experiment. From the information available it appears that critical concentrations determined in the greenhouse may on occasion be satisfactory for field. However, there is sufficient evidence and opinion to the contrary.

Scaife and Barnes (1977) noted that the critical concentration if defined in terms of percentage growth rate depression,

it is possible that it would be found to be much less variable than it now seems. They argued that variation in critical concentration could arise from two simple, but reasonable assumptions: (i) that the percentage depression of growth rate due to nutrient deficiency is related by a simple diminishing-returns type function to plant nutrient concentration in a manner which is independent of growth stage and (ii) that the absolute growth rate of non-limited plants declines as their weight increases beyond a certain value.

A simple equation was derived which combines logistic growth of non-deficient plants with a function (which is independent of growth stage) relating percentage depression of growth rate to leaf nutrient concentration. On integration this can be used to produce yield-nutrient concentration curves very similar to those actually observed, and critical percentages which vary in a realistic manner with stages of growth (Scaife and Barnes 1977).

Plant analysis is now being used not only as a diagnostic technique of plant nutrient deficiencies but also for monitoring nutrient status of crops. The latter is achieved by routine sampling and analysis made easier by rapid field tests. With experience, plant analysis can be used to improve crop production in several ways including evaluation of fertilizer programs. For best results with plant analysis, a series of plant samples should be collected at appropriate times during the growing season and the analytical results compared to previously determined critical concentrations. If at any time the nutrient concentrations drop below the critical concentration, the plants are deficient in that nutrient at that time and changes in the fertilizer program must be considered if adequate crop production is to be maintained.

3.6 FERTILIZER APPLICATION

One of the important factors in the use of fertilizer is proper timing and placement. This involves efficiency of plant usage, convenience and economy of application. To be effective fertilizer must be applied where and when the plant needs it. Responsive growth stages and seasonality of production should particularly be considered in deciding when and how to apply fertilizer.

The choice of time of application is diverse, depending upon crop requirement, soil, climatic conditions and economic consideration. Nitrate ions are readily leached whereas phosphorus and potassium ions are not (Terman and Engelstad 1976). Thus for maximum utilization of N fertilizers, plants must be in a vigorous growth stage soon after it is applied. Otherwise, the nitrate may move below the root zone, especially in humid areas or areas under irrigation. This loss, together with competition from micro-organisms and weeds, often reduces crop recovery of N fertilizer as the interval increases between time of application and crop use.

Usually all the phosphorus and potassium are applied as base dressing but heavy nitrogen applications are often split into base dressing and one or more top dressings. One reason mostly given for splitting is the maintenance of the nitrogen supply throughout the growing season. In long season annuals such as onions, it may be more efficient to control carefully nutrient availability throughout the season, and for this reason top dressings are usually recommended for N fertilizers. Riekels (1977) found the most effective time interval to top dress an onion crop appears to be between 1.1/2 to 2.1/2 months after seeding. Davis (1957) suggests that all of the N can be applied at planting on soils that do not leach readily; recommends split applications only for very light soils that are readily leached and indicates that at least one-third should be applied when the crop is planted.

Top dressing is, however, expensive in both time and labour. In addition there is danger of damage to the crop by passage of the machinery down between the rows, or by scorching if fertilizer lodges on the foliage. Thus it would be ideal if the whole requirement of the crop for all three major nutrients could be applied in one operation.

Page (1973) noted that the most important reason for splitting N applications is to avoid creating unfavourable conditions for germination in the seed bed rather than maintenance of N supply throughout the growing season. Thus other ways of applying N in large quantities should therefore be considered. Page showed that N in the base dressing for vegetables with a long growing season is not necessary because there is quite enough N in most soils, even low fertility ones, to provide the plant requirements in the early seedling stage of the crop. Thus all the N can be applied after the crop is established using a spinner to spread solids, or spraying liquid fertilizers or injecting N into the soil.

Another suggestion is to supply nitrogen in a slow release form, which ensures that the nitrate supply is restored after a period of leaching or denitrification, without ever creating unduly high nitrate concentrations in the soil water (Scaife and Stevens 1977). This approach unfortunately is not often economic due to the high cost of slow release fertilizers. Perhaps an efficient method of placing the fertilizer will reduce such a cost.

There are various methods of applying fertilizers. These are usually broadcasting and placement. The method used depends on the particular cropping system, the fertilizer used, the character of the soil and the rainfall.

Many vegetable crops have short growing seasons and restricted root systems. These are likely to benefit more from

placement methods than from broadcasting. Cooke, Jackson, Widdowson and Wilcox (1956) found placing fertilizer gave higher yields of cabbage, lettuce, beetroot, onions, broad beans, runner beans and maize, than broadcasting. Greenwood *et al* (1974) also observed that broadcast applications are a very inefficient way of supplying nutrients for vegetable crops. They found broadcast applications of N fertilizer depressed stand, sometimes considerably, in some but not all of their experiments. Where there was an effect, emergence fell in proportion to the amount applied even if this was small.

Page (1973) noted that N placement avoids emergence damage but most importantly ensures the most efficient subsequent use of the N. The N is then situated in moist soil, immediately accessible to the roots of the plants, and is not dependent, as broadcast solids must be on rain to carry it into the soil. Losses by volatilization, which can be serious especially from alkaline soils, are also minimised. However, work done at NVRS has shown that placement should in general be no nearer than 7 cm to the side and 7 cm below the seed.

For onions, Leggett (1973) recommended placing fertilizer 5 to 8 cm beneath the row at sowing. As the bulk of onion roots is in the upper 30 to 60 cm of the soil (Jones and Mann 1963), it is important that fertilizers are placed where the roots can easily get them. A fairly high concentration of plant nutrients must therefore be in the upper 30 cm of soil (Zink 1966).

On a study on liquid, dry and gaseous fertilizers for onions, Lorenz, Bishop and Wright (1955) reported best yields resulted from ammonium sulphate placed 10 cm deep under the plant row; nitric acid, aqua ammonia, urea, calcium nitrate and ammonium sulphate in the irrigation water gave much lower yields. Aqua ammonia placed in the bed under row resulted in low yields and created severe plant toxicity. When nitric acid

was placed under the plant row the yield was very low, and poor growth was presumed to be due to leaching of nitrates in the soil.

For accuracy of fertilizer application the need for precision drills and fertilizer distributors cannot be over-emphasised. Various machinery is available for broadcasting or placing fertilizers in bands, near the seed. However, more efficiency is needed with these machines. Some types do not place the fertilizer properly on rough land or when driven at high speeds, and seed damage usually results. If the planter does not band the fertilizer properly, it is safer to apply most of the fertilizer by some other method. Thus, the use of band or pre-drill placement of fertilizer to a large extent depends on an efficient fertilizer drill.

Finally, what is important to the onion grower is that an adequate supply of N be in the root zone during crop growth, especially during the period of bulbing when the demand for this nutrient is the greatest in the growth cycle (Zink 1966).

3.7 Slow Release N Fertilizers

A lot of effort has been directed toward development and use of N fertilizers to minimize losses and increase crop recovery of added nitrogen. One such effort is the development of slow release N fertilizers. In general, slow release fertilizers are of three types or combinations thereof: (i) biodegradable organic compounds; (ii) compounds of low water solubility that release nutrients by slow dissolution and/or hydrolysis; and (iii) coated soluble sources (Allen, Terman and Clements 1976).

Urea-formaldehyde (type i) is a mixture of unreacted urea, methylene diurea, and longer-chain linear or cross linked polymers. Early crop response comes from unreacted urea, while

residual N is derived from biodegradation of the water-insoluble portion. Isobutylidene diurea (IBDU, type (ii)) is a reaction product of isobutyraldehyde and urea. The product formed is very low in water solubility, but hydrolysis with production of NH_3 is rapid, once dissolution commences. Thus, slow release of N is derived primarily from varying granule size and hardness of particles. Upon dissolution and hydrolysis of IBDU, nitrification of ammonia is rapid and crop response to N proceeds by the usual mechanism.

Sulphur-coated urea (SCU, type iii) is prepared by coating urea granules with molten elemental sulphur (S), followed by sealing with a suitable wax and conditioner. The typical product contained about 32-37% N, 16% S, 3% wax, 0.2% coal tar and 1.8% conditioner (Sharma 1979). Current modifications exclude wax coating to reduce cost. Sulphur has the advantage of being a secondary nutrient for the plants and its cost is low. At present, the only commercially available product in North America is from the Canadian Industries Ltd, (affiliate of Imperial Chemical Industries Ltd, U.K.) under the trade name of Gold-N.

Many naturally occurring or high organic solid waste substances, such as rock phosphate, soil humus, sewage sludge and blood meal, also exhibit slow release properties (Sharma 1979). The nutrients, in general, are not available until they have been broken down by biological action into the simple inorganic forms. However, the rate of breakdown is very much affected by environmental conditions, both in regard to rate and end product.

Dissolution of SCU proceeds by various processes, primarily physical, which result in water gaining access to the substrate (Allen *et al* 1976). Once the coating is broken, urea solution moves rapidly into the soil, where nitrification and crop uptake proceed as for uncoated urea. Thus, the slow release properties of SCU result from a mixture of granules with varying resistance to dissolution. Variations in the release patterns is usually

achieved by the use of different thicknesses of sulphur coating (Sharma 1979).

Lunt (1967, 1968) noted that the release is slightly higher in soil than in water, with greater release in acid than in alkaline soils. The rate of N release has also been found to be much greater in moist than in flooded soil, since granules of SCU become coated with Fe S after two weeks in flooded soil. When the flooded soil was dried to about field capacity, oxidation of the Fe S coatings appeared to seal the granules so that very little N was released (Prasad 1976a).

Prasad (1976b) also found that higher temperature increased ammonia losses from SCU, but the magnitude of such loss was less than that for ammonium sulphate and urea. Faster N release from SCU was observed when the fertilizer was mixed in the soil than when it was surface applied (Prasad 1976a). However, the total amount of surface applied slow release fertilizers lost is less than for soluble fertilizers, since ammonia is seldom formed in large quantities at any specific time (Allen *et al* 1976). With release of ammonia slowly over a longer period, chances of exceeding the capacity of soil or crop to retain it are much reduced.

For maximum efficiency, nitrogen should be supplied to the crop at a rate that is sufficient for growth and yet avoids an excessive concentration of N in the soil solution. Two main advantages are sought, firstly, a single application of fertilizer sufficient to supply the needs of the crop during the growing season, and secondly, a more efficient utilization of applied N by the crop. Slow release fertilizers are useful in this regard. Potential benefits from them include: (i) increased efficiency of nutrient use by the crop, primarily through control of luxury uptake; (ii) decreased leaching of nutrients from coarse textured soils; (iii) reduced seed or seedling damage from high local concentrations of salts; (iv) longer lasting nutrient

supply, thus requiring fewer applications; (v) reduction of rapid nitrification and nitrogen loss through ammonia volatilization and denitrification (Allen and Mays 1971; Sharma 1979).

The premise of low-cost of SCU's has drawn considerable interest in their evaluation for vegetables. Most vegetable crops require a continuous supply of N for maximum yield and quality. With the use of slow release fertilizers such as SCU, split applications, which are generally expensive may be avoided. Sharma (1979) reviewed the work done so far on vegetable crops which is limited and observed that very expensive slow release fertilizers offer little or no economic advantage over conventional materials for vegetable production. However, it was noted that certain conditions (light soil, heavy rainfall and long growing season) may offer sufficient advantage, where slightly higher cost of N in the form of SCU may be offset by a higher yield or by labour savings realised by fewer applications. Onions which have a long growing season compared to most vegetables have not been evaluated with slow release fertilizers.

CHAPTER 4

POST HARVEST PHYSIOLOGY

4.1 General Aspects

Onions, like other vegetables, are living organisms which undergo all physiological and pathological processes associated with life. To sustain essential chemical and physiological activities, they draw energy from the food reserves stored within them prior to harvest (Pantastico 1975). They are in a continual state of deterioration from harvest on, and successful marketing depends upon reducing the rate of deterioration by slowing the processes which cause damage.

4.2 Causes and Control of Deterioration

Post harvest losses are manifest in loss of quantity or quality of the produce or a combination of both. These losses result from physical, physiological or pathological factors or various combinations of all three. Thus, these factors should be well understood in order to reduce deterioration during the major operations of harvesting, curing, grading, storing and transportation performed in getting a mature onion crop from the field to the consumer.

4.2.1 Physical Factors

Physical factors take many forms and may occur at all stages in the history of the produce from planting right through to final consumption. Losses due to mechanical damage are frequently overlooked and because of the added complexity of secondary physiological and pathological losses are difficult to estimate. In addition to causing such direct losses, less immediately obvious damage increases physiological losses and allows the entry of destructive micro-organisms.

Bruising is the most common mechanical injury suffered by onions, although cuts also are common (Ryall and Lipton 1978). Bruising results in undesirable softening of damaged tissue, whereas both injuries lead to shattering or separation of the protective dry scales, thus enhancing the chance of decay. Bruising and cutting can occur during any stage of handling, but machine harvest and rough floors in truck trailers, rail cars or bins are the most common causes.

It has been shown by Isenberg (1955) that onions cannot be dropped onto a non-resilient surface more than 1-2 m depending on size, without significant damage resulting. When onions are dropped onto other onions, however, much less damage occurs because of the cushioning effect between onions. The depth to which onions can be stacked in bulk stores is reported to be between 2 and 4 m. Excessive damage from pressure bruising occurs at greater depths. Also Musa, Habish, Abdalla and Adlan (1973) found regular inspection of bulk-stored onions increased storage losses, probably due to injuries resulting from the frequent handling.

Mechanically injured produce will normally deteriorate rapidly and should never be used for long term storage (Booth 1974). Damage can be greatly reduced by improving methods of crop harvesting and handling. While more emphasis is being placed on crop mechanisation to reduce crop production costs, consideration should also be given to the increased losses which usually occur following the mechanical harvesting of onions. Successful avoidance of injury could be achieved by careful handling throughout marketing and use of protective pads on floors of conveyances, unless onions are packed in cartons.

4.2.2. PHYSIOLOGICAL FACTORS

Because produce is alive, natural endogenous respiratory losses of dry matter together with transpiratory or wilting losses of water will always occur (Ryall and Lipton 1978). High temperature encourages high water loss. Wilting and shrivelling caused by water loss seriously damages the appearance of the produce and thus affects consumer appeal.

Proper relative humidity (RH) is important in preventing water loss from the fresh produce, but temperature of the produce and its surrounding atmosphere, as well as air velocity also affect the amount of loss. A comparatively low relative humidity of 70 to 75% is very desirable for the successful storage of onions (Lutz and Hardenburg 1968). At higher humidities, in which many other vegetables keep best in storage, onions are disposed to root growth and decay. Despite the importance of achieving a low RH, it must not be too low and certainly not as low as 50%, for this is likely to cause skin shedding. The skin gives valuable protection against evaporation of water from the onion.

Air movement can cause serious loss during storage. Unless air is a bit humid, it is extremely important to limit its movement in the storage area to the least that suffices to carry away heat produced by respiration of produce and heat leaking into the area (Lutz and Hardenburg 1968). Air movement of 4 m/min is often sufficient to maintain desired temperature during storage, if the produce has been thoroughly cooled. Water loss at this air velocity is very low.

In a tropical environment, Musa *et al* (1973) noted that the total losses of 'Wad Ramli' onions were about 50% after 6 months storage, mainly due to shrinkage (about 30%) and diseases and pests (about 18%). The higher rate of shrinkage was attributed to the high temperatures (20.9-37.6°C) and the low RH (20-59%) experienced under Sudanese conditions.

High temperatures also encourage respiratory losses of dry matter. Fortunately, onions have been found to have a slower respiration rate than most crops as the temperature rises (Lutz and Hardenburg 1968). Ward and Tucker (1976) reported that the respiration rates of onions were low and showed a small increase with temperature during the first 5 months of storage. Ward (1976) reported that onion bulbs which were transferred from 2 to 25°C showed a higher respiration rate than those stored continuously at 25°C.

As metabolic processes generally slow down with a decline in temperature the use of refrigeration is frequently recommended for the reduction of water and respiratory losses during storage. Low temperature storage also slows down the metabolism of pathogens and so frequently arrests rotting. However, the use of refrigeration for the storage of onions is limited by economic, managerial and social factors. A certain degree of control and reduction of storage temperatures may be achieved in simple storage structures by use of shading and simple ventilation techniques.

Tucker, Stow and Ward (1977) investigated the feasibility of storing onions at high temperatures in the United Kingdom. They observed that sprouting was lower but rotting and weight loss due to dessication were higher at 30 and 35°C compared with 20 and 25°C. Overall wastage was least at 25°C within the range 50-70% RH but totalled 50% after 9 months storage and was still high (38%) when used for a comparatively short time (3.5 months) following cheaper storage under force-ventilated ambient cooling. Much smaller losses at 0°C showed that refrigerated storage offered more advantages than high temperature storage for marketing onion bulbs in the United Kingdom in June. However, it seems that high temperature storage could be an economically viable proposition in the tropics. The fact that new skins of good colour have been found to form beneath the outer skins when temperatures are relatively high is further promoting interest in warm storage techniques.

Practical storage trials have shown that either very low (-1 to 2°C) or high temperatures (25 to 30°C) are best for a prolonged storage life for onion bulbs (Yamaguchi, Pratt and Morris 1957; Abdalla and Mann 1963; Aura 1963). These conditions are also said to prolong dormancy which is necessary to prevent sprouting and root growth. Dormancy disappears most rapidly at temperatures in the range 12 to 16°C (Abdalla and Mann 1963: Aura 1963). Storage at very high temperatures (35°C) for one week has also been found to hasten sprouting upon planting the bulbs (Kampen 1970). Musa *et al* (1973) reported that loss due to sprouting reached approximately 40% when the mean monthly temperatures were 22.3 and 20.9°C. Karmarkar and Joshi (1941) found that onions stored at 0°C sprouted more rapidly at 11°C and at 20°C, after removal from store than those stored at 33°C.

Onions vary greatly in their tendency to sprout. Pungent cultivars are least likely to sprout under given storage conditions whereas mild ones sprout most readily (Ryall and Lipton 1978). Also Abdalla and Mann (1963) showed that the long storing cultivar 'Australian Brown' took longer to sprout than 'Excel'. Their results indicate that there is a correlation between storage life of a cultivar and time it takes to root and sprout.

Factors that foreshorten natural leaf die-down such as leaf disease, premature topping and premature dessication may lead to shortened dormancy and storage life (Stow 1976). Kato (1966) reported that bulbs grown under shaded conditions sprouted sooner than those grown under full light. The removal of the outer thickened leaves from bulbs was also found to hasten sprouting.

There is considerable evidence that dormancy and sprouting are under the control of a balance between endogenous growth inhibitors and promoters (Thomas 1969; Thomas and Isenberg 1972).

Maleic hydrazide (MH) a well known inhibitor of plant growth is known to be very effective in preventing sprouting in stored onion bulbs (Isenberg 1956; Wittwer, Sharma, Weller and Sell 1950). Preharvest application of MH as a 1500 ppm spray at 3.4 kg a.i. per hectare 10 to 14 days before harvest, when the tops are 50% collapse, is a well established technique for prolonging storage life.

Root growth of onion bulbs during storage is another undesirable phenomenon. Roots emerge from the base of the shortened stem and can grow several centimetres long during storage (Ryall and Lipton 1978). Roots render the bulbs unsightly and may become a focus for decay. Root growth is confined to onions held in high relative humidity, generally above about 85%, conditions that occur in insufficiently ventilated plastic bags (Kaufman, Hruschka and Hardenburg 1953). When humid conditions and high temperatures exist, roots will grow within a few days. Root growth can therefore be prevented by keeping onions under fairly dry conditions, always below 85% RH, and preferably between 65% and 70%. However, it is not always practically possible to be able to control the RH.

4.2.3 Pathological Factors

Attacks by micro-organisms (fungi and bacteria) are probably the most serious causes of post harvest loss in onions. Quantitative losses result from the extensive breakdown of host tissues by micro-organisms. There is usually initial attack by one or a few, specific primary pathogens, followed by massive infection by a broader spectrum of non-specific secondary biodeteriogens which are weakly pathogenic or are saprophytic on the dead or moribund tissue. These secondary invaders play an important role in post-harvest pathology, as they enhance the damage initiated by the primary pathogens. Qualitative losses result from blemish or surface diseases which render the produce less attractive and marketable.

The most destructive post harvest diseases in onions are bacterial soft rot, gray mould rot or neck rot (*Botrytis* spp.), Fusarium bulb rot (*Fusarium* spp.), black mould rot (*Aspergillus* spp.), blue mould rot (*Pennicillium* spp.), white rot (*Sclerotiorum cepivarum*) and smudge (*Colletotrichum circinans*) (Jones and Mann 1963).

Different parts of the bulb may be attacked, from the base to the neck. Some rots produce lesions on the outer scales while others are not visible externally. Affected tissues are water soaked and in advanced stages, these are shrunken and brownish. Under dry conditions, decayed tissues are dry and papery. Mycelial growth often accompanies the affected areas. Some fungi may not produce decay, but may induce discolourations or blemishes, which lower the market value of onions (Pantastico 1975).

The occurrence and magnitude of losses due to pathogenic micro-organisms are very variable and dependent on several factors. As many post harvest pathogens are wound parasites, one of the major factors governing the incidence and magnitude of such losses is the physical condition of the produce. This should be free of injuries for longer storage life.

Post harvest losses caused by diseases can also be reduced by adhering to good phytosanitary practices, such as the elimination of plant debris and the cleansing and sterilising of implements, boxes, buildings, etc. Also, losses can be reduced in certain cases by the direct application of pesticides to the produce (Booth 1974). However, before any chemical is used as a post harvest treatment of onions or other vegetables it must be thoroughly screened for absence of mammalian toxicity, and then only used in accordance with the established food-additive regulations of the country concerned. Chemical treatments may be classified by method of application into, fumigants, treated wraps, dips, sprays and dusts.

In addition to post harvest chemical treatments certain post harvest diseases may be controlled by pre-harvest crop applications of protectant or eradicant pesticides. Thus, for successful disease control, a thorough knowledge is necessary of the pathogen(s) in the host and the host/pathogen reacting so that control methods may be optimally defined and timed.

One of the most effective and simple means of reducing post harvest physiological and pathological losses of onions is by curing. Curing is a wound healing process during which general skin strengthening also occurs. The process is stimulated by conditions of relatively high temperatures and humidities. Onion curing improves skin colour and also appears to be accompanied by the development of fungicidal compounds in the skins (Booth and Coursey 1972).

Onions are considered suitable for storage when the neck is tight and the outer scales are dry and rustle when handled. This condition is generally reached with a weight loss in the order of 3% to 5%. In a comparison of field curing (Windrows), artificial curing (16 hours at 46°C), and 'non cured' bulbs, Hoyle (1948) found that both curing methods reduced weight losses in storage compared with 'non cured' bulbs. Although Hoyle found no significant statistical differences between field and artificial curing, he considered field curing to be in general unsatisfactory and artificial curing to have the advantages of being independent of weather conditions and usually quicker.

4.3 Nitrogen Nutrition and Bulb Storage

There is a common opinion that high doses of N have a bad effect on the storage of onion bulbs, but little experimental work was performed to justify such a claim. Sypien *et al* (1973) showed that the application of relatively high doses of N as a

top dressing had a rather negative effect on the keeping quality of onion bulbs. The storage life result was strongly correlated with the thickness of the neck, with thin-necked bulbs giving a better storage.

Riekels (1977) noted that the storage life of onions as indicated by sprouting of the bulbs was shorter with high rates of N than with no N or low N rates for both irrigated and non irrigated onions, but the response was less without irrigation. Kepka and Sypien (1970) did not show any regularity in the effect of N fertilization on the storage of onions. The differences between the fertilizer variants were found to be small, changeable and insignificant. They noted that some other factors could influence the storage results more than N fertilization. It was evident that very low percent of marketable bulbs after storage and high percent of the sprouted bulbs was probably caused by a very late date of harvest of the onions. Riekels (1977) suggested that the onions grown with low N and reported to have a better storage life than high N ones may have entered dormancy later, assuming the period of dormancy is somewhat constant for a given cultivar. However, limiting N to prolong the storage life of onions is not desirable because of simultaneous poor yields and later maturity.

Finally, the storage life of onions depends on many factors, but probably the most important is cultivar. Certain characteristics tend to indicate superior storage quality, such as a high degree of pungency, high soluble and total solids contents, and globular shape (Ryall and Lipton 1978). Within a given cultivar, maximum storage life can be achieved by proper curing, storing only well-matured onions, treating them with a sprout inhibitor, such as maleic hydrazide, during maturation and providing optimum storage conditions.

SECTION B

EXPERIMENT 1 : GREENHOUSE TRIAL

CHAPTER 5

MATERIALS AND METHODS

5.1 GENERAL

The experiment was conducted in a glasshouse at Massey University's Plant Growth Unit. The glasshouse, 9 m x 24 m in size, is a modern aluminium structure equipped with thermostatically controlled heaters and ventilators. The air temperature was maintained between 20 and 25°C throughout the experiment.

A modified UC compost was used as media. This consisted of equal parts by volume of Hauraki peat and fine washed sand with the following plant nutrients, except N, added and thoroughly mixed together:

Potassium sulphate	- 30 g/100 l	peat:sand
Superphosphate	- 150 g/100 l	" "
Dolomite lime	- 450 g/100 l	" "
Ground limestone	- 150 g/100 l	" "
Trace elements (Frit FTE 36)	- 15 g/100 l	" "

Plastic pots (13 cm) with drainage holes at the base were filled with the media and arranged according to treatments on trolley tables in the glasshouse.

The local cultivar of *Allium cepa* L., "Pukekohe Long Keeper" (PLK) from Arthur Yates Ltd was used in the study. The seeds were treated with Captan^{R} to prevent "damping-off" diseases. Sowing was on 13 September 1979 and the pots were watered with tap water as necessary until emergence. Double the seedlings required per pot per harvest date was the number of seeds sown per pot. The seeds germinated in 7 to 9 days and shortly after, were thinned according to Table 1.

TABLE 1

THE SAMPLING PROCEDURE FOR EACH HARVEST

HARVEST NUMBER	NUMBER OF POTS SAMPLED	NUMBER OF PLANTS/POT	TOTAL NUMBER OF PLANTS HARVESTED
1	4	20	80
2a	3	15	45
2b	3	15	45
3a	3	10	30
3b	3	10	30
4a	3	6	18
4b	3	6	18
5a	3	4	12
5b	3	4	12
6a	4	2	8
6b	4	2	8
7a	4	1	4
7b	4	1	4
8a	4	1	4
8b	4	1	4
9	20	1	20*

* *Some used for bulb diameter, yield and quality measurements.*

5.2 EXPERIMENTAL DESIGN

A split plot randomised complete block design with three replicates (blocks) was used. The main plots were six N plates and the sub-plots were nine harvest dates. The N levels were selected after a preliminary investigation in which onions were grown in the modified UC media for 10 weeks using various N rates. This showed that 0 to 100 ppm N levels caused deficiency in N and 200 to 300 ppm N levels appeared to be sufficient for onion plant growth. Thus the following N treatments were used in the real experiment:

N LEVELS -	N_o	N_1	N_2	N_3	N_4	N_5
ppm N	0	100	200	250	300	400

5.3 SAMPLING METHOD

Whole plant samples were harvested from each treatment and block, every 14 days after emergence up to full maturity (nine harvest dates). The first and last harvest dates each consisted of a single sample but the seven intermediate harvests each comprised two samples. The number of pots and the number of plants per sample varied for each of the nine harvests and are shown in Table 1. This was to provide sufficient number of plants in a sample for analysis and also to avoid competition as the plants grow bigger. During each harvest the plants were carefully removed with roots intact from the pots by soaking the media in water and tipping it out. The roots were then washed free of sand and peat and some of the peat still tightly held by the roots was carefully removed by hand.

5.4 NITROGEN STOCK SOLUTION AND FEEDING

Calcium nitrate was used as the nitrogen source in the experiment. Stock solution of N was prepared using calcium nitrate fertilizer and tap water. The N treatments were started 7 days after emergence. When feeding, each level of N, except No, was prepared from the stock solution as a liquid feed and

this was surface watered to the plants with a watering can every day. Between N feeds, surface irrigation with tap water was given as necessary to keep the media moist. Also, every week the media was flooded with tap water to avoid the build up of excessive soluble salts that could have affected plant growth.

5.5 GROWTH PARAMETERS

The following growth measurements were made on each sample:

(i) Plant Fresh Weight - weighed whole plants with roots intact.

(ii) Leaf Number - total number of visible green leaves.

(iii) Leaf Area - the Lambda Leaf Area Machine was used. The total green leaves in a sample were each flattened and fed into the machine and the reading recorded was multiplied by two to obtain the area of the cylindrical total blade surface.

(iv) Dry Weight - the whole plants in each sample were separated into leaves, bulbs and roots and dried separately in an electric oven at 75°C for 24 hours or more as necessary. In the early harvest dates these plant parts were put into separate glass jars sprayed with a silicon aerosol to prevent the plant material sticking on the glass.

As the plants increased in size, so the jars were replaced by paper bags. After drying, the samples were cooled in a dessicator and the dry weights of the plant parts determined.

5.6 Plant Tissue Analysis

Total N and NO_3-N concentration of leaves, bulbs and roots were determined for each sample using conventional laboratory techniques. Tissue NO_3-N in the fresh onion bulb was determined for each sample using 'Merckoquant' test strips.

5.6.1 Laboratory Analyses

The dried plant parts of leaves, bulbs and roots in a sample were each ground to about 200 mesh in a Wiley mill and stored in clean bottles with stoppers. Before starting the laboratory analyses the powders of the tissues were again dried at 70°C for 24 hours in order to remove moisture picked up during storage. These were then cooled in a dessicator and sub-samples weighed out for analysis.

(A) Total N

A sub-sample of 0.15 to 0.2 g (depending on dried material available) of the dried plant part was digested with 1 litre of concentrated sulphuric acid and 100 g of potassium sulphate, using 1 g of selenium as catalyst. The mixture was heated in a kjeldahl digestion block until the solution turned clear from dark brown (about 4 hours). The clear solution was cooled and diluted to 50 ml with distilled water. Total N in the sample was then determined with a Technicon Auto Analyser II.

(B) NO_3-N

A sub-sample of 0.1 g dried tissue was weighed into a small flask. Nine millilitres of silver sulphate (Reagent 2, Appendix I) was added and the flask quickly swirled. Then 1 ml sodium phosphate (Reagent 3) was immediately added. The mixture was allowed to stand for 2 hours and then filtered. Two millilitres of the filtrate was measured into a 15 ml centrifuge tube, then added 2 ml copper sulphate solution (Reagent 1), mixed, added 6 ml distilled water and approximately 0.5 g Reagent 4. This was mixed and allowed to stand for 1 hour, then centrifuged at 4000 r.p.m.

Two millilitres phenol sulphonic acid (Reagent 5) was measured into a boiling tube, directly onto the bottom. Then 2 ml of the supernatant added by drops from above directly onto the reagent, swirling carefully after the addition of each drop. This was cooled and 25 ml ammonium hydroxide (Reagent 6) added cautiously with stirring. It was cooled again and absorbance read with a Varian Techtron Spectrophotometer, Model 635, and with the instrument set at zero with a blank.

Aliquots of standard solution (Reagent 7) from 1 to 4 ml were used and the above procedure beginning with the addition of copper sulphate followed (Ward and Johnston 1960).

5.6.2 Rapid Tests (SAP NO_3-N)

Tissue NO_3-N in the fresh onion bulb was measured using Merckoquant strips (described in the literature review) for each sample. Preliminary investigations with leaf blades ran into problems with chlorophyll in the leaves masking the colour change. The bulb was found to be better than the leaves with the strips as sap extraction was easier with the bulbs and no masking of colour occurred. Also, the NO_3 in the sap appeared

to be higher in the bulb than in the leaves.

Sap was extracted from the bulbs by cutting the bulbs transversely in the middle and squeezing the sap out. A strip was briefly dipped in the sap and checked for colour change after 2 minutes. In the early harvests when nitrate in the fresh bulbs was very high and the readings exceeded the maximum colour standard (500 ppm NO_3) of the strips, the time in seconds for the colour to develop to that of the 500 ppm NO_3 standard on the tube was recorded. From this the high NO_3 concentrations in the fresh bulbs were estimated.

CHAPTER 6

RESULTS AND DISCUSSION

6.1 General Observations

The nitrogen in the media appeared to be adequate for the emerging seedlings up to when the nitrogen treatments were started 7 days after emergence. However, at the first harvest date (14 days after emergence), the seedlings of the no nitrogen treatments (No) showed signs of nitrogen deficiency, i.e. yellowish-green patches appeared on the leaves.

Throughout the growth period from first harvest, the leaves of the low N treatments (No, N1) were yellowish-green whilst the leaves of the high N (N2, N3, N4, N5) treated plots were dark green. This suggests that whilst the low N treated plots were N deficient, the high N plots had sufficient N during the growing period. The leaves of No treatment particularly showed serious deficiency, with very small, pale leaves and in some cases non-existent. In fact some plants from treatment No were lost because of acute N deficiency. However, some leaves from No plots later in growth picked up, probably due to delayed decomposition of the peat which released some N to the plants.

The tops of the high N treatments were first observed to fall, thus signalling maturity of the bulbs.

Bulbing started about 56 days (Harvest 4) after emergence. In the early stages of growth there was a slight swelling of the false stem but this was not regarded as bulb development since it can occur even under short photoperiods (Butt 1968). Bulbing ratio was used to assess bulb development. It is the relationship between the greatest diameter near the base and the minimum neck diameter. Mann (1952) reported that any ratio above 2 indicates definite bulbing. The No treatments never produced decent sized bulbs.

Apart from No treatments, the roots of the lower N levels appeared to be greater than the roots of the higher N levels.

Figure 2 shows photos of the sequence of onion growth from harvest 2 (28 days after emergence) to harvest 7 as influenced by N fertilizer levels.

6.2 Growth Characteristics

6.2.1 Fresh Weight per Plant

The fresh weight per plant increased with time for all treatments (Fig. 3). In all the growth stages up to the final harvest, the high N treatments (N2, N3, N4, N5) had larger fresh weight per plant than the low N (No, N1) treatments. The No treatments were very much lower in whole plant fresh weight than the other N treatments throughout the crop growth period. The high N treatments (N2, N3, N4, N5) had similar fresh weight per plant for most of the growth stages. However, as maturity approached, the rate of increase in plant fresh weight for N5 was slower than for N2, N3 and N4 probably due to earlier maturity.

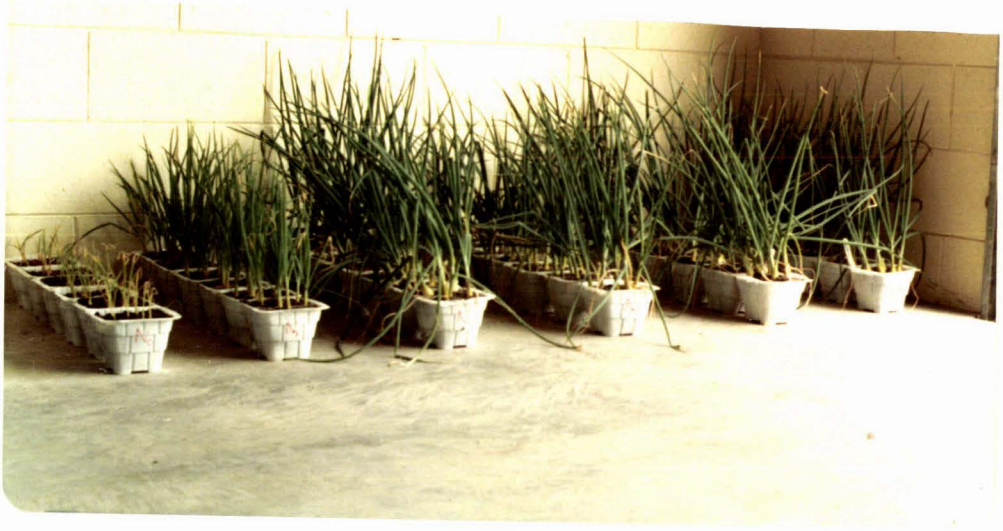
6.2.2 Dry Weight per Plant

The total plant dry weights of all the treatments followed closely that of the fresh weight (Fig. 4). The total dry weight per plant was obtained by adding the dry weights of the roots, leaves (including neck) and bulb of the plant. For all treatments the total plant dry weight increased with time. In nearly all the growth stages (harvest dates) the high N treatments had higher dry weight per plant than the low N treatments (No, N1). Again the No treatments were very much lower in dry weight than all the N treated plots especially in the middle and later stages of growth. The high N treatments had similar dry weight per plant in most of the harvest dates. It was only in the

FIG. 2. Visual appearance of the onion plants as influenced by N rates at different harvest dates.

No N1 N2 N3 N4 N5

(HARVEST 2)



(HARVEST 4)

(HARVEST 5)

(HARVEST 6)

(HARVEST 7)

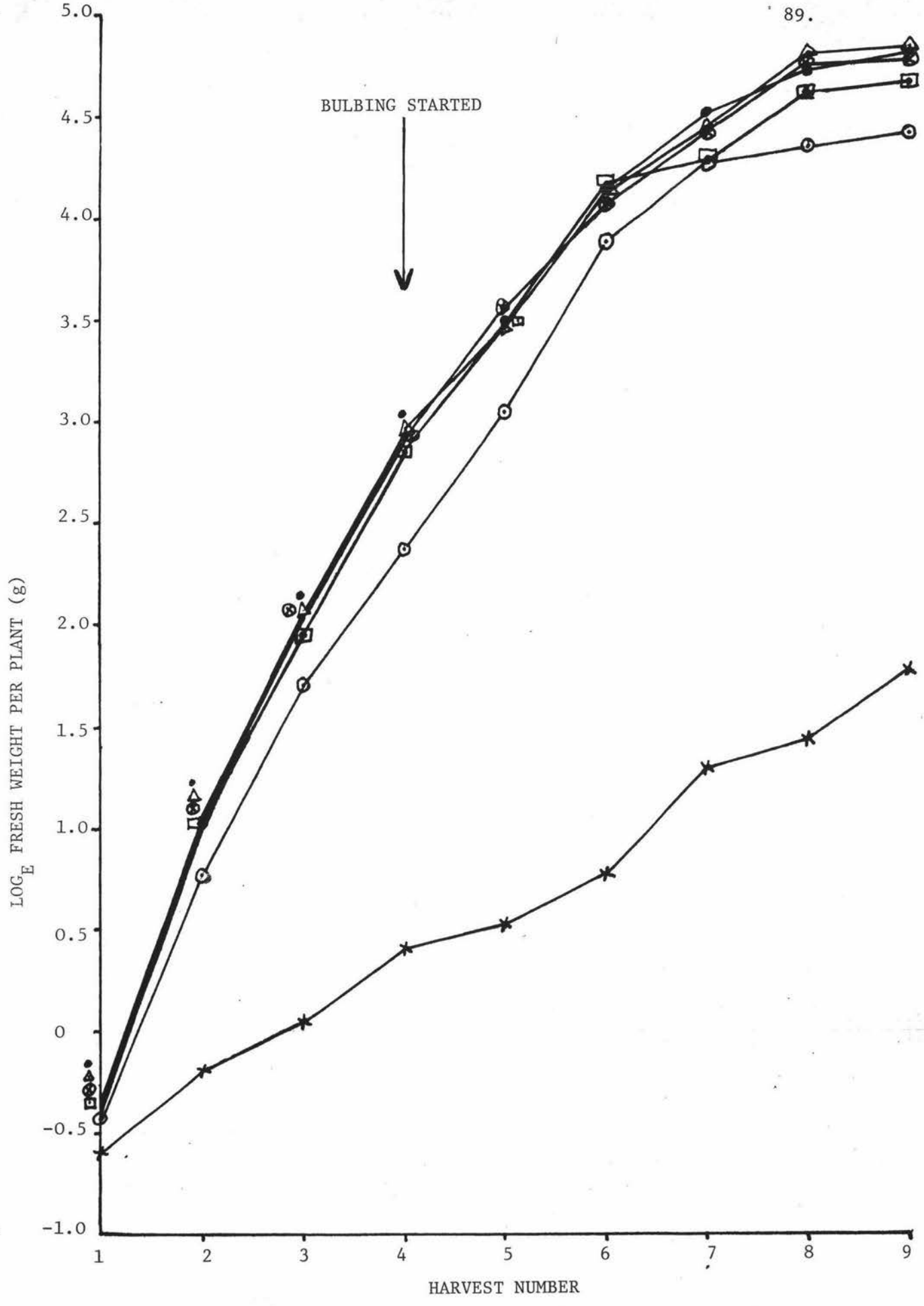


FIG. 3. Effects of nitrogen fertilizer on fresh weight per plant.

×—×No, ○—○N1, △—△N2, ●—●N3, ⊗—⊗N4, □—□N5.

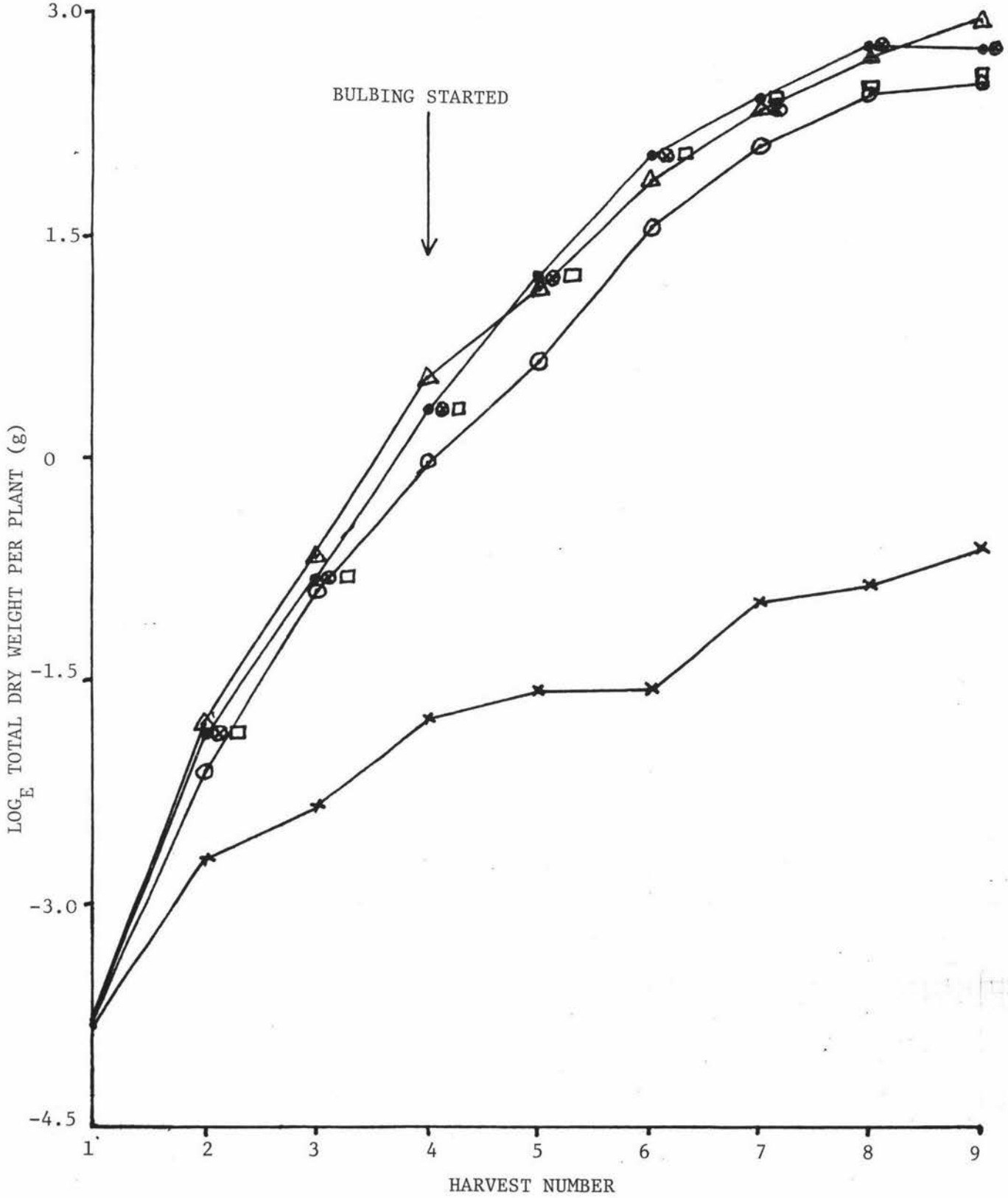


FIG. 4. Effects of N fertilizer on dry weight per plant.

×——× No, ○——○ N1, △——△ N2, ●——● N3, ⊗——⊗ N4, □——□ N5.

final stages of growth that N5 was slightly lower in dry weight than N2, N3, and N4, probably because of earlier maturity and senescence of N5 plants.

6.2.3 Root Dry Weight per Plant

Apart from No, root dry weight per plant was heavier with the lower N treatments (Fig. 5). All the N added treatments increased in root dry weight per plant until a peak was reached 12 weeks after emergence, then decreased with age of the plant. The rate of decline was sharper with the higher N fertilizer levels, probably due to earlier maturity resulting in more roots lying in the higher N rates. Treatments N4 and N5 had similar root dry weight throughout the growth period. The very deficient No plots had very much lower root dry weight per plant than the other treatments in all the growth stages. The pattern of growth was also less consistent, reaching maximum 10 weeks after emergence, declined slightly, then started increasing slowly again up to final harvest.

6.2.4 Bulb Dry Weight per Plant

As the onion bulb is the plant part that interests growers when measuring the yield of the crop, it is therefore realistic to follow the changes that may occur in this organ as regards N treatments during growth. Figure 6 shows the pattern of bulb growth as affected by N fertilizer throughout the crop growth period. Bulb dry weight increased with age for all treatments. In the very early growth stages, bulb dry weights of the low N treatments (No and N_1) were slightly higher than the high N treatments' earlier bulb formation. However, this was during the swelling of the neck base when proper bulb development had not yet started. By the time real bulb development started the high N treatments had higher bulb dry weight than the low N treatments and this continued throughout the growth period.

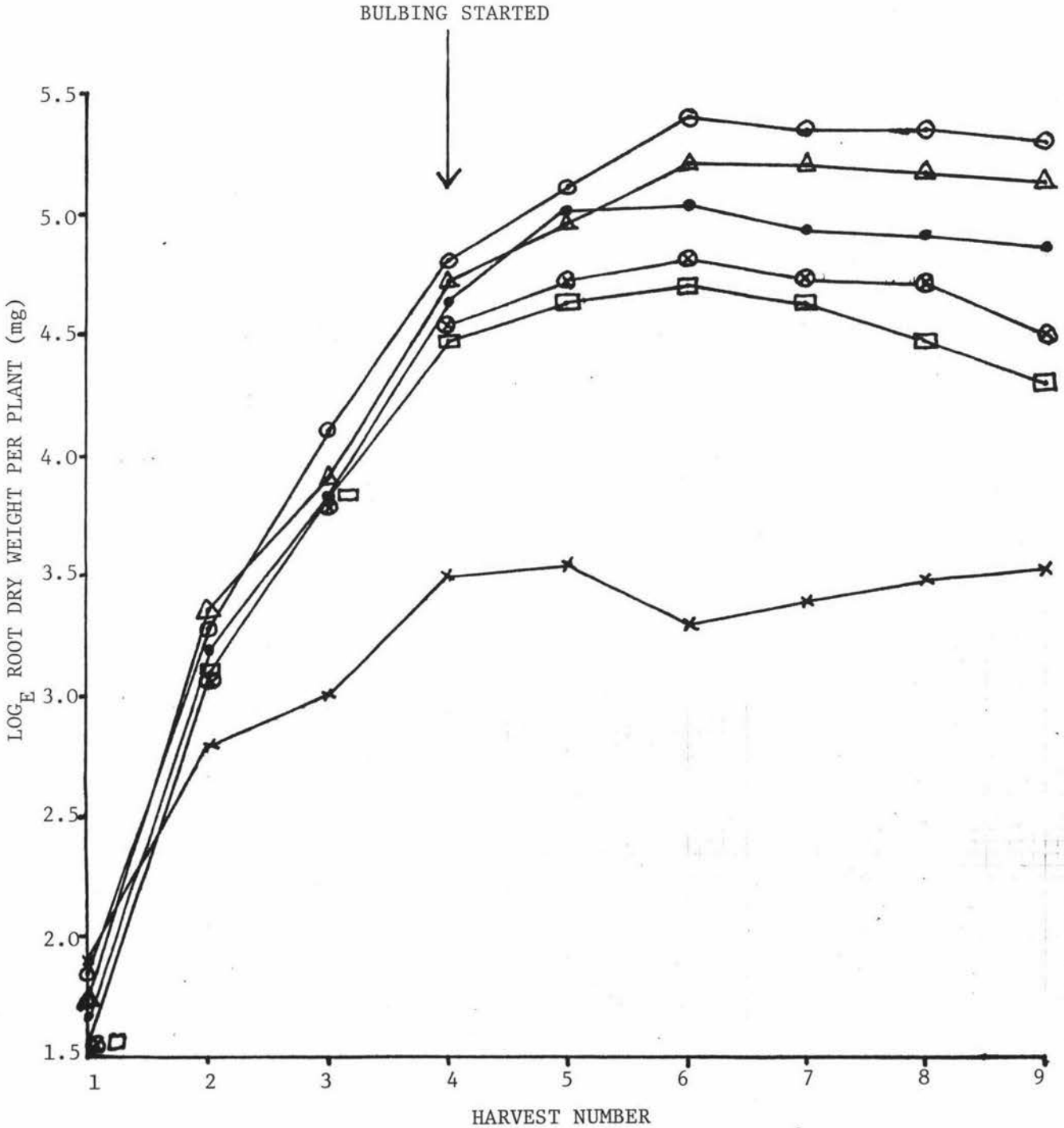


FIG. 5. Effects of N fertilizer on root dry weight per plant.

No, N1, N2, N3, N4, N5.

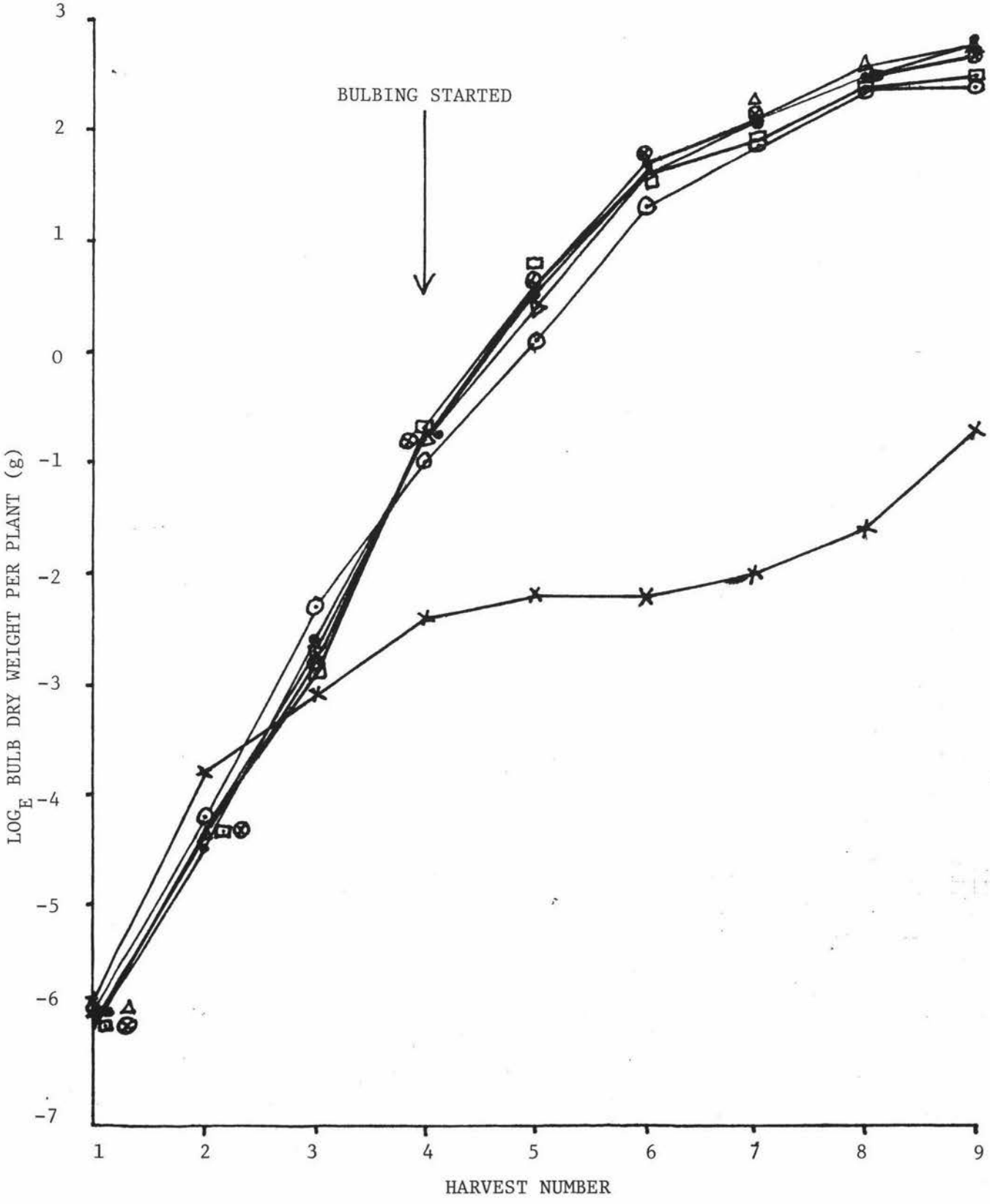


FIG. 6. Effects of N fertilizer on bulb dry weight per plant.

No, N1, N2, N3, N4, N5.

Treatment No was very much lower in bulb dry weight than all the plots with N added when bulb development was in progress. The high N treatments had similar bulb dry weight during most of the earlier growth period but as maturity approached N5 was lower than the others. The maximum bulb dry weight was found to be highest for No and N3 at the final harvest. The very high N rates (N4 and N5) matured earlier before the bulbs developed fully.

6.2.5 Number of Green Leaves per Plant

The number of green leaf blades per plant increased with age until maximum was reached then decreased (Fig. 7). The high N rates had more leaves per plant than the low N rates for most of the harvest dates. The high N treatments reached maximum green leaf number per plant 10 weeks after emergence. The low N levels (No and N1) however, attained maximum number of leaves later with N1 12 weeks and No 14 weeks after emergence. Thus it is apparent that the higher N levels attained maximum number of leaves earlier than the low N levels. There was no significant increase in the number of green leaves for the No treatment in the early growth stages up to 12 weeks after emergence. However, some N from the newly decomposed peat provided a slight increase in leaf number after this growth period. The number of green leaves per plant declined much more markedly with the high N rates than with the low N rates after reaching maximum. The sharp decline is associated with bulbing which inhibited leaf emergence and the dying of older leaves as maturity approached.

6.2.6 Total Green Leaf Area per Plant

The total green leaf area to some extent followed a similar growth pattern to the total number of green leaves. The green leaf area increased as the plants advanced in age till a peak

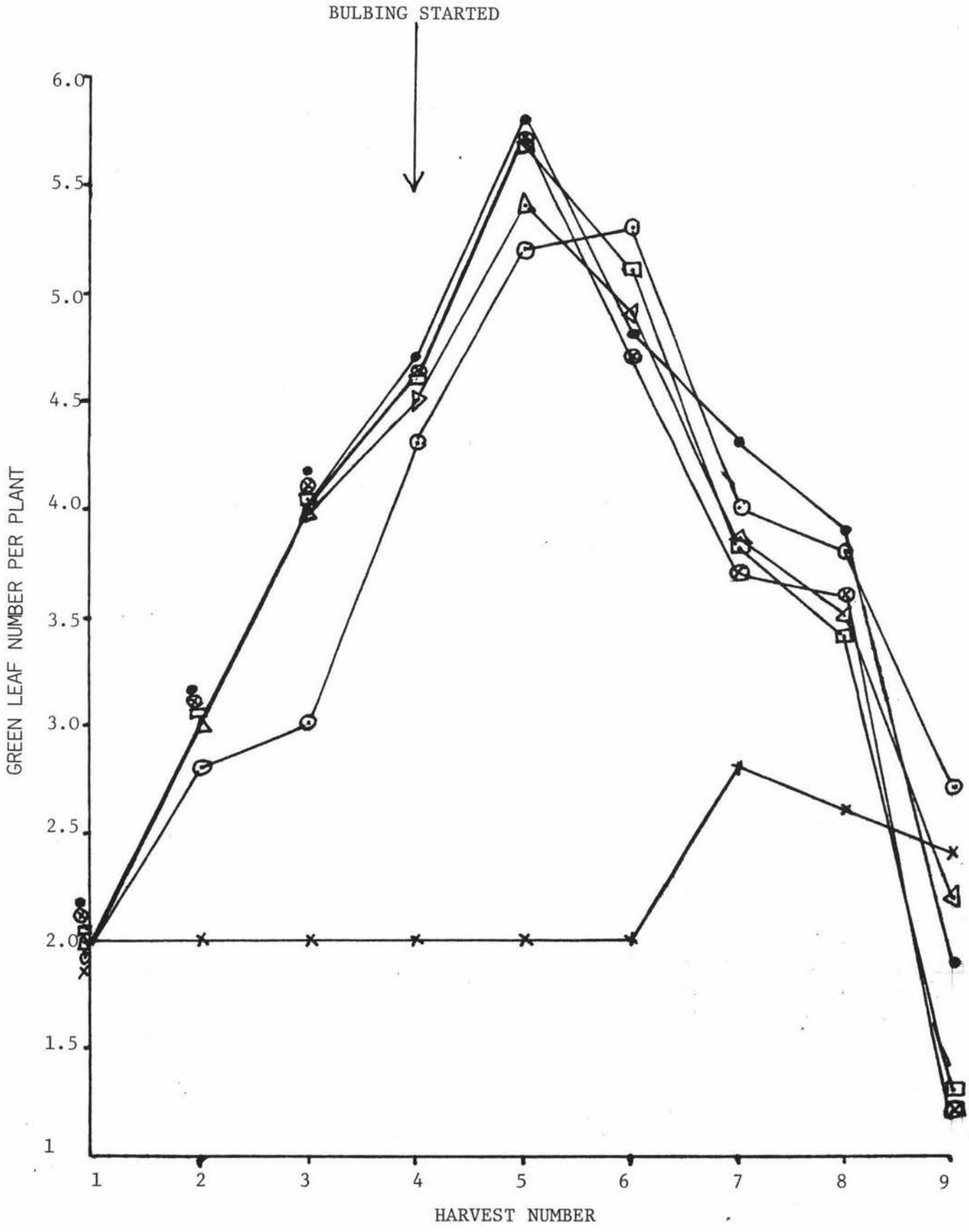


FIG. 7. Effects of N fertilizer on green leaf numbers per plant.

No, N1, N2, N3, N4, N5.

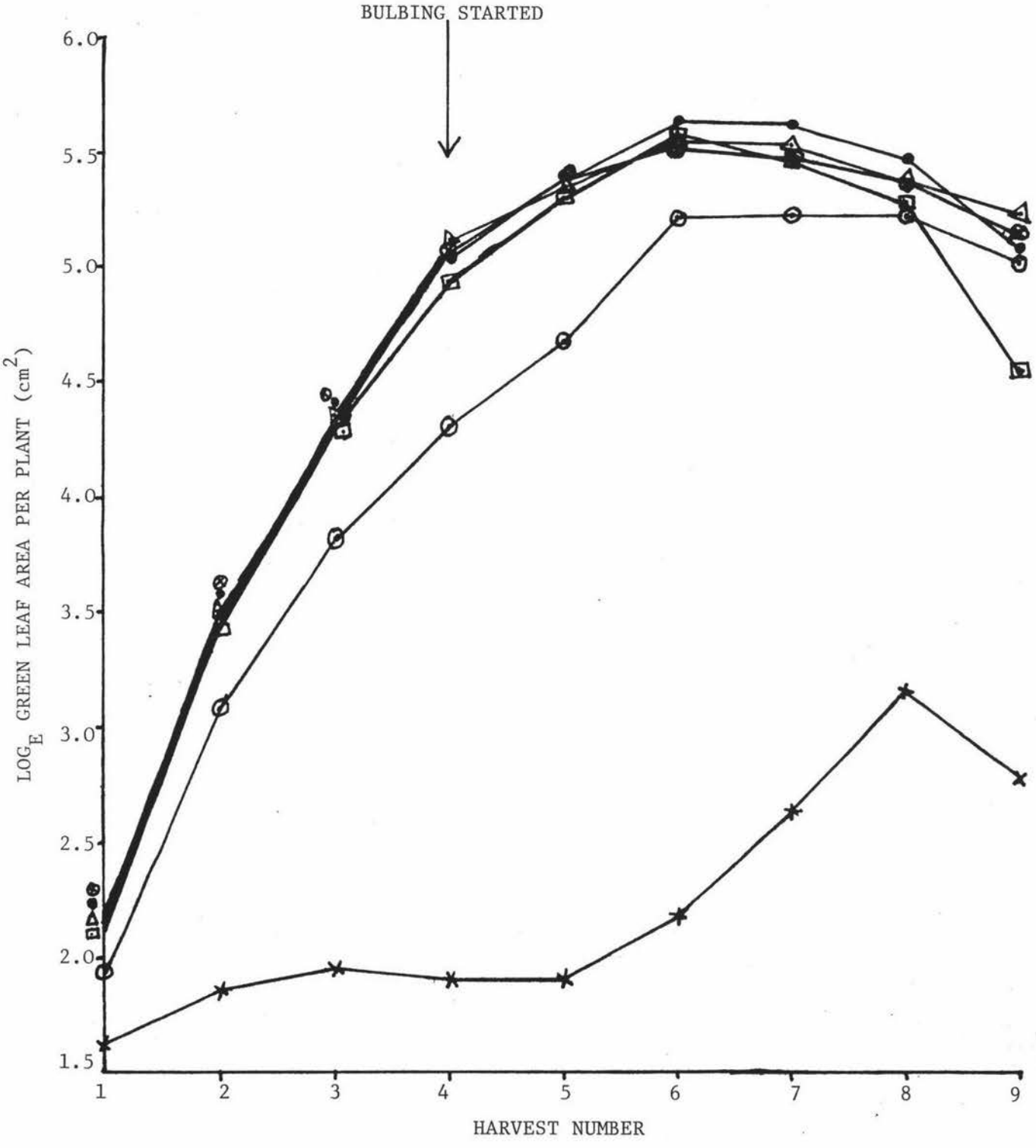


FIG. 8. Effects of N fertilizer on green leaf area per plant.

No, N1, N2, N3, N4, N5.

was reached 12 weeks after emergence for N1 to N5 and 16 weeks after emergence for No, then declined (Fig. 8). The decline is attributed to the depression of new leaf emergence resulting from bulb development, and also to increased rate of leaf senescence as plants approached maturity. Treatment N5 declined much faster than the other N treatments because of earlier maturity resulting in earlier leaf senescence. The high N treatments (N2, N3, N4, N5) had similar leaf area through most of the growth period. In general, the total green leaf area per plant was higher with the high N treatments than the low N treatments (No and N1). The No treatment had significantly very small leaf area throughout the growth period.

6.2.7 Growth Analysis

The growth analysis parameters as influenced by N levels are shown in Table 2. In general, all the plots with N added had a significantly higher mean total RGR, bulb RGR, NAR, LAR, LWR and SLA than plots with no N added. The results of the nitrogen-harvest date interactions for all the growth analysis parameters are shown in Appendices II to VII. When treatment No is excluded from the analysis of variance only LAR and LWR showed significant interaction between harvest date and N rates.

The mean RGR, LAR, LWR and SLA decreased with time but NAR was less consistent (Table 3). However, NAR was not significantly different between harvest dates in the early growth stages but with later harvests, NAR was much more variable and significant differences were recorded between harvest dates. Thus NAR was only constant with ontogeny during the early growth stages.

In most growth analysis studies, RGR is estimated for the entire plant. Since the yield of most vegetable crops is not usually regarded in terms of weight of the whole plant, but a particular part of the plant, for instance the onion bulb, it seems worthwhile to also determine the RGR of such parts as

influenced by different treatments. In this study whole plant RGR was found to be closely related to bulb RGR at various harvest dates.

RGR is defined by Briggs *et al* (1920) as the product of NAR and LAR. Thus increases in RGR caused by N levels will be dependent on the changes induced in NAR and LAR. To this end, increases in RGR due to N response were found to be largely determined by LAR (Table 2). The high N treatments (N2, N3, N4, N5) had significantly larger LAR than the low N treatments (No, N1).

LAR is defined as the product of LWR and SLA. However, with regards to the response of onion plants to N fertilizer, LAR increases appear to be mainly due to increases in LWR.

TABLE 2

EFFECTS OF NITROGEN TREATMENTS ON $\overline{R.G.R.}$, $\overline{N.A.R.}$, $\overline{L.A.R.}$, $\overline{L.W.R.}$ AND S.L.A. OF PLK ONIONS OVER THE WHOLE GROWTH PERIOD.

	TOTAL RGR $g\ g^{-1}\ week^{-1}$	BULB RGR $g\ g^{-1}\ week^{-1}$	NAR $g\ m^{-2}\ week^{-1}$	LAR $m^2\ g^{-1}$	LWR	SLA $m^2\ g^{-1}$
No	0.1640b *	0.2893c	26.36b	0.00576c	0.3383c	0.01623b
N1	0.3722a	0.5238b	58.86a	0.00756b	0.3800b	0.01764a
N2	0.4079a	0.5494ab	58.62a	0.00920a	0.4362a	0.01835a
N3	0.4195a	0.5820a	59.42a	0.00928a	0.4383a	0.01783a
N4	0.4096a	0.5717a	57.45a	0.00944a	0.4478a	0.01795a
N5	0.3716a	0.5159b	51.62a	0.00880a	0.4302a	0.01761a

* *Mean separation is by Duncan's New Multiple Range Test. Means in columns having the same letters are not significantly different at P = 0.05.*

TABLE 3

EFFECTS OF HARVEST DATE ON MEAN R.G.R., N.A.R., L.A.R., L.W.R. AND S.L.A. OF PLK ONIONS

	HARVEST							
	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9
TOTAL RGR $g\ g^{-1}\ week^{-1}$	0.7888a*	0.5064b	0.4781b	0.3288c	0.3434c	0.1858d	0.1872d	0.0412e
BULB RGR $g\ g^{-1}\ week^{-1}$	0.8515a	0.7596b	0.8060ab	0.5641c	0.4832d	0.2350e	0.1998ef	0.1437f
NAR $g\ m^{-2}\ week^{-1}$	37.42de	32.01de	44.59d	45.64d	74.57b	59.86c	94.73a	27.62e
LAR $m^2\ g^{-1}$	0.02181a	0.01571b	0.01040c	0.00698d	0.00457e	0.00316f	0.00238fg	0.00172g
LWR	0.6962a	0.6826a	0.5938b	0.4765c	0.3268d	0.2310e	0.1723f	0.1153g
SLA $m^2\ g^{-1}$	0.03108a	0.02283b	0.01709c	0.01441d	0.01402d	0.01369d	0.01384d	0.01384d

* *Mean separation is by Duncan's New Multiple Range Test.*
Means in rows having the same letters are not significantly different.

6.2.8 Bulb Size and Bulb Maturity

Table 4 shows differences in bulb weight, bulb diameter and bulb maturity in relation to N levels. The high N levels had heavier bulb weight, larger bulb diameter and matured earlier than the low N levels. In general, bulb size and bulb maturity for the high N treatments (N2, N3, N4, N5) were significantly different to the low N levels. The bigger bulbs produced under higher N levels may be attributed to the greater number and thickness of swollen leaf sheaths and scales in such cases caused by the accumulation of photosynthates from leaves. The decrease in bulb weight and bulb diameter of the very high N rates (N4 and N5) was due to earlier bulb maturity resulting in shorter bulbing period.

TABLE 4

Effects of N on bulb weight, bulb diameter and bulb maturity of PLK Onions at final harvest.

N LEVELS	MEAN BULB WEIGHT (g)	BULB DIAMETER (mm)	BULB MATURITY (% TOPS FALLEN)
No	12.50c*	16.67c	0c
N1	83.27b	48.42b	69.33b
N2	112.56a	58.17a	90.33a
N3	117.11a	57.50a	93.00a
N4	106.00a	56.17a	97.33a
N5	100.41ab	54.92a	100.00a

* *Mean separation is by Duncan's New Multiple Range Test. Means in columns having the same letters are not significantly different at P = 0.05.*

6.3 Plant Tissue Analysis

6.3.1 Nitrate-Nitrogen (Laboratory Analysis)

Nitrate-nitrogen distribution in the roots, bulbs and leaves of the onion plant as influenced by N fertilizer levels throughout the growth period is shown in Figures 9, 10 and 11. It could be observed in all three plant parts that low N treatments (No, N1) had lower NO_3-N content than high N treatments (N2, N3, N4, N5) in all growth stages. In general, the NO_3-N content increased with increased nitrogen fertilizer.

During the seedling stage, the NO_3-N in the roots, bulbs and leaves were very high for all N levels. However, as development progressed the NO_3-N contents in the leaves and bulbs decreased sharply from the seedling stage up to the commencement of real bulbing (8 weeks after emergence). The NO_3-N content in the roots declined gradually with plant age. As bulbing progressed NO_3-N content in the leaves and bulbs increased slightly but declined again as maturity was approached.

In general, the NO_3-N content in the roots was much higher than the NO_3-N content in the bulbs and leaves throughout the growth period (Fig. 12). The leaves and bulbs had similar NO_3-N content with the bulbs slightly higher for most of the growth stages. The very high levels of NO_3-N in the roots in comparison to the leaves and bulbs would suggest that nitrate is reduced in the roots in onions. The roots (Fig. 9) showed much more distinctly than the bulbs (Fig. 10) or leaves (Fig. 11) that NO_3-N content increased with increased N level during onion growth. Thus, the roots appear to give a better indication of the nitrogen status of an onion crop than the leaves or bulbs when NO_3-N content of the plant is monitored. However, its not practically easy to sample roots in the field and so sampling leaves and bulbs may be favoured by growers. However, with the low NO_3-N concentration in the leaf blades and bulbs from bulbing to final harvest very sensitive methods of analysis will be required for monitoring the NO_3-N concentrations in these organs.

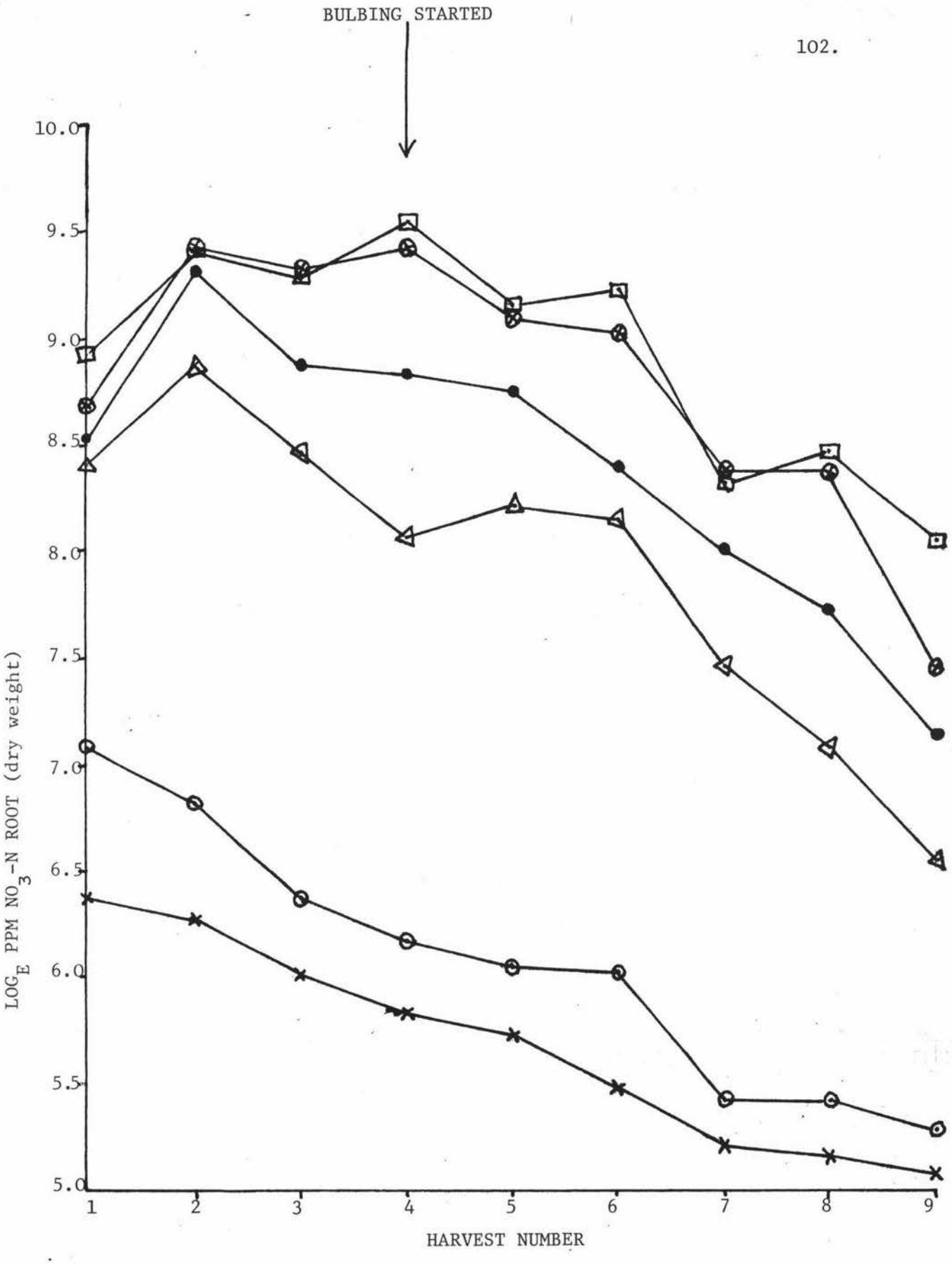


FIG. 9. Effects of N fertilizer on root NO_3-N concentration.

No, N1, N2, N3, N4, N5.

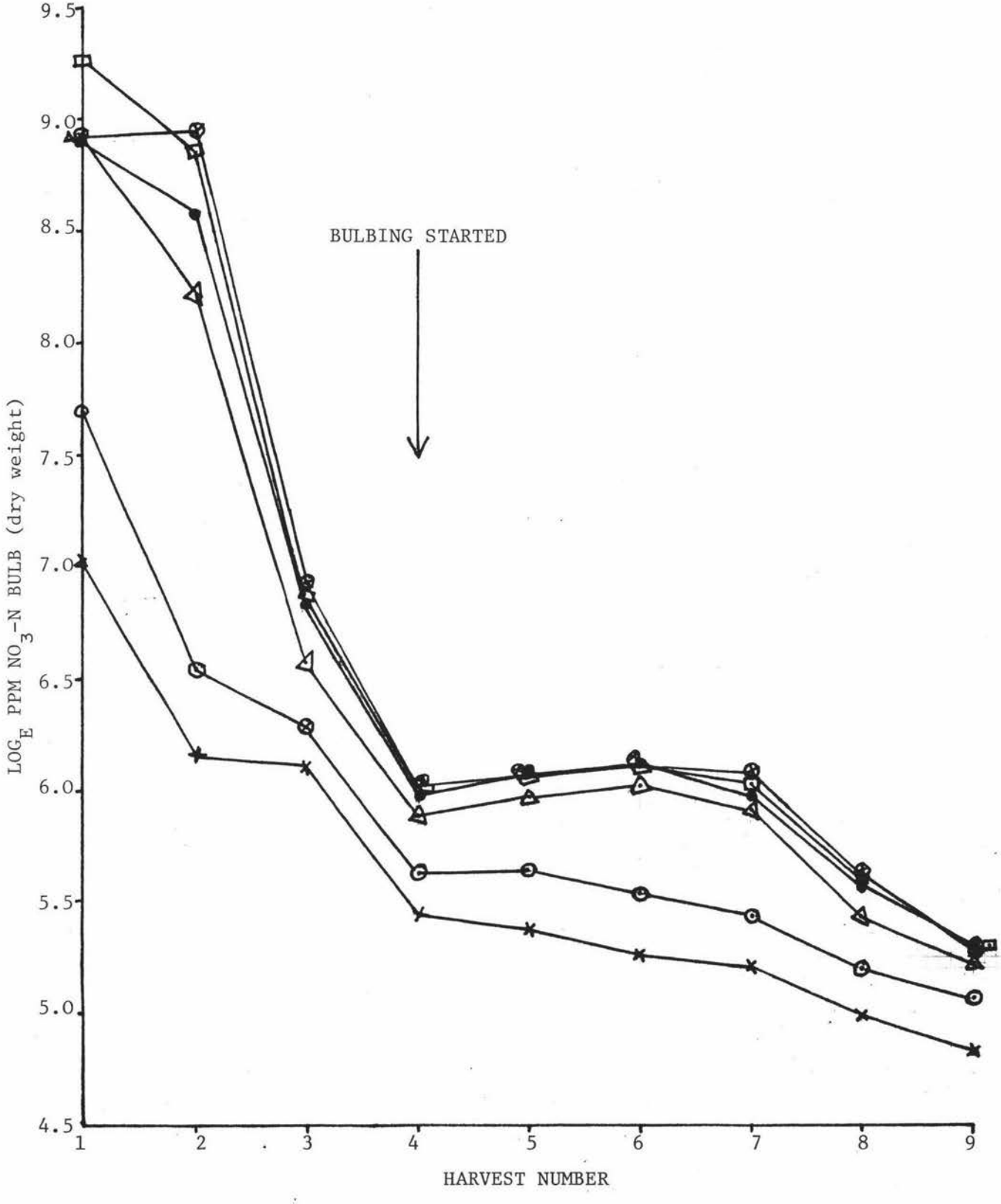
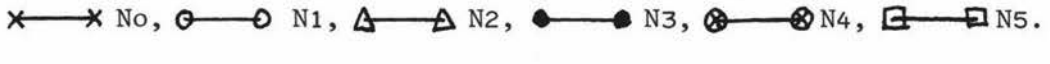


FIG. 10. Effects of N fertilizer on bulb NO_3- N concentration.



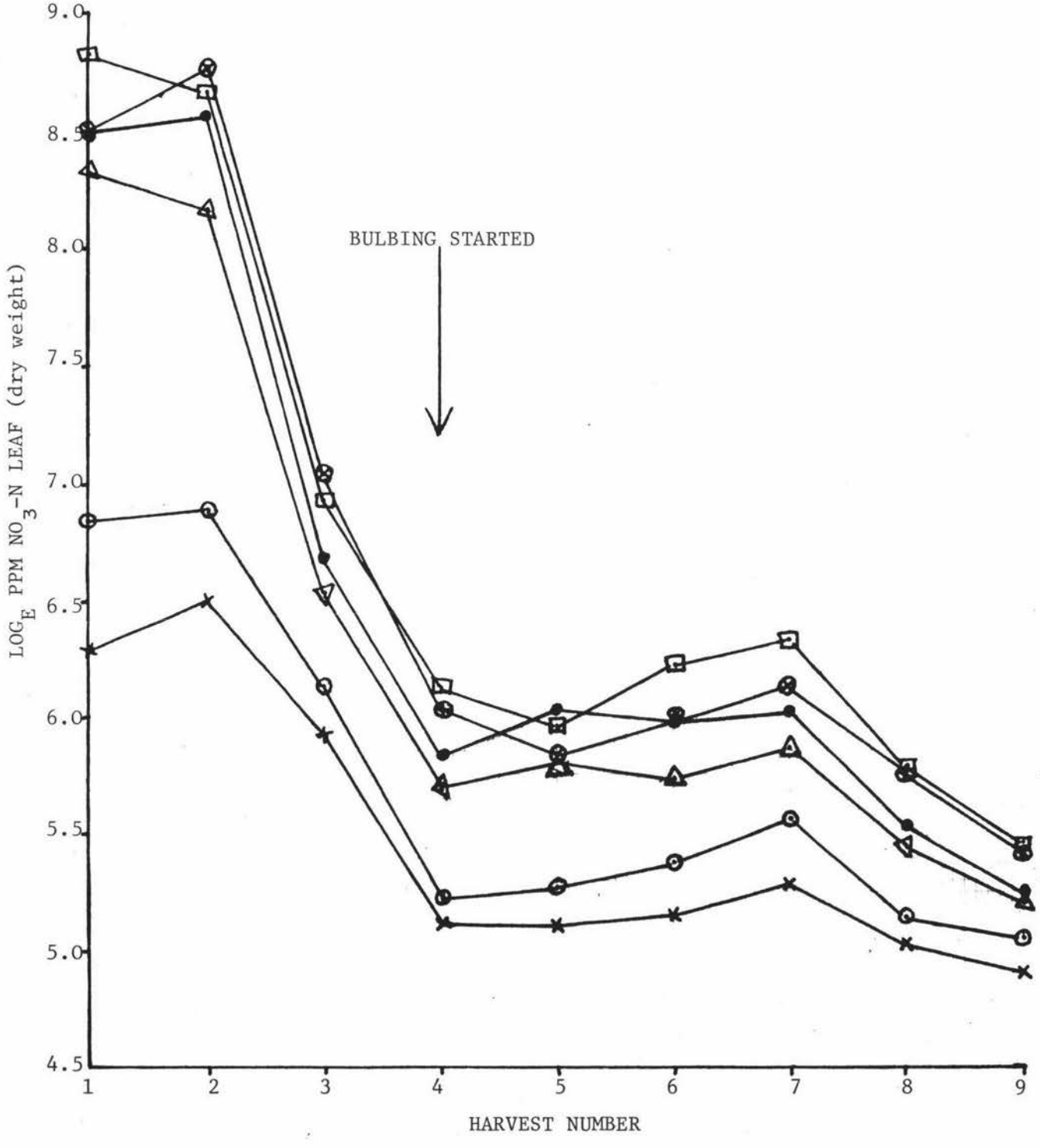


FIG. 11. Effects of N fertilizer on leaf NO_3-N concentration.

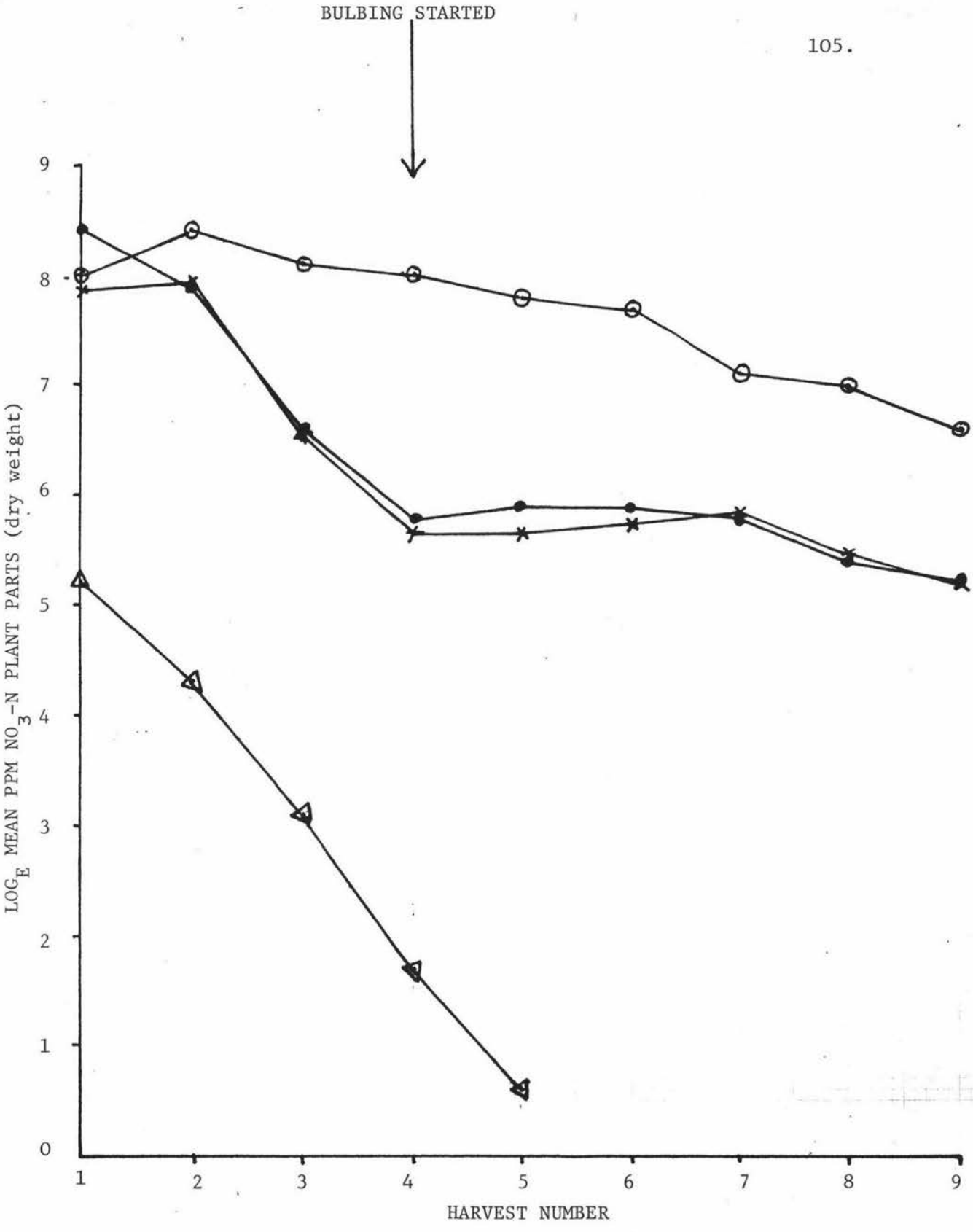


FIG. 12. Distribution of NO_3-N in the plant parts.

leaf, root, bulb, fresh bulb.

The relationship between S (= actual RGR/RGR of non deficient plants) and the NO_3-N concentration of leaves, bulbs and roots is shown in Figures 13, 14, 15, 16 and 17. From the curves obtained the critical nitrate-nitrogen concentrations of onions in the three plant parts sampled were worked out, assuming that the critical concentration for NO_3-N is that concentration which produced 90% of the maximum growth (Ulrich and Hill 1967).

Two critical NO_3-N concentration curves were drawn for leaves (Figs 13 and 14) and bulbs (Figs 15 and 16) because of the marked difference in NO_3-N concentration between the early harvests and the late harvests. This should give a more accurate indication of the N fertilizer status of an onion crop at different stages of growth. Hence the critical NO_3-N concentration for leaves was established at 850 ppm NO_3-N dry weight very early in the season (up to 6 weeks after emergence) and 210 ppm NO_3-N dry weight later in the season, from start to real bulbing to final harvest. Similarly, that for bulbs ranged from 800 ppm NO_3-N dry weight early in the season to 275 ppm NO_3-N dry weight later in the season. The critical NO_3-N concentration for roots is much more consistent with growth stage and it has been established at 800 ppm NO_3-N dry weight basis throughout the growth period.

6.3.2 NITRATE-NITROGEN (RAPID TESTS)

Figure 12 shows the mean NO_3-N concentration in the fresh onion bulb at various N levels measured with 'Merckoquant' strips. With the high N treatments (N2, N3, N4, N5), only the first five harvests produced readings with the 'Merckoquant' strips, the rest of the harvests recorded zero readings. Treatment No recorded zero readings throughout the growth period whilst treatment N1 only produced readings in the first two harvests (Table 5).

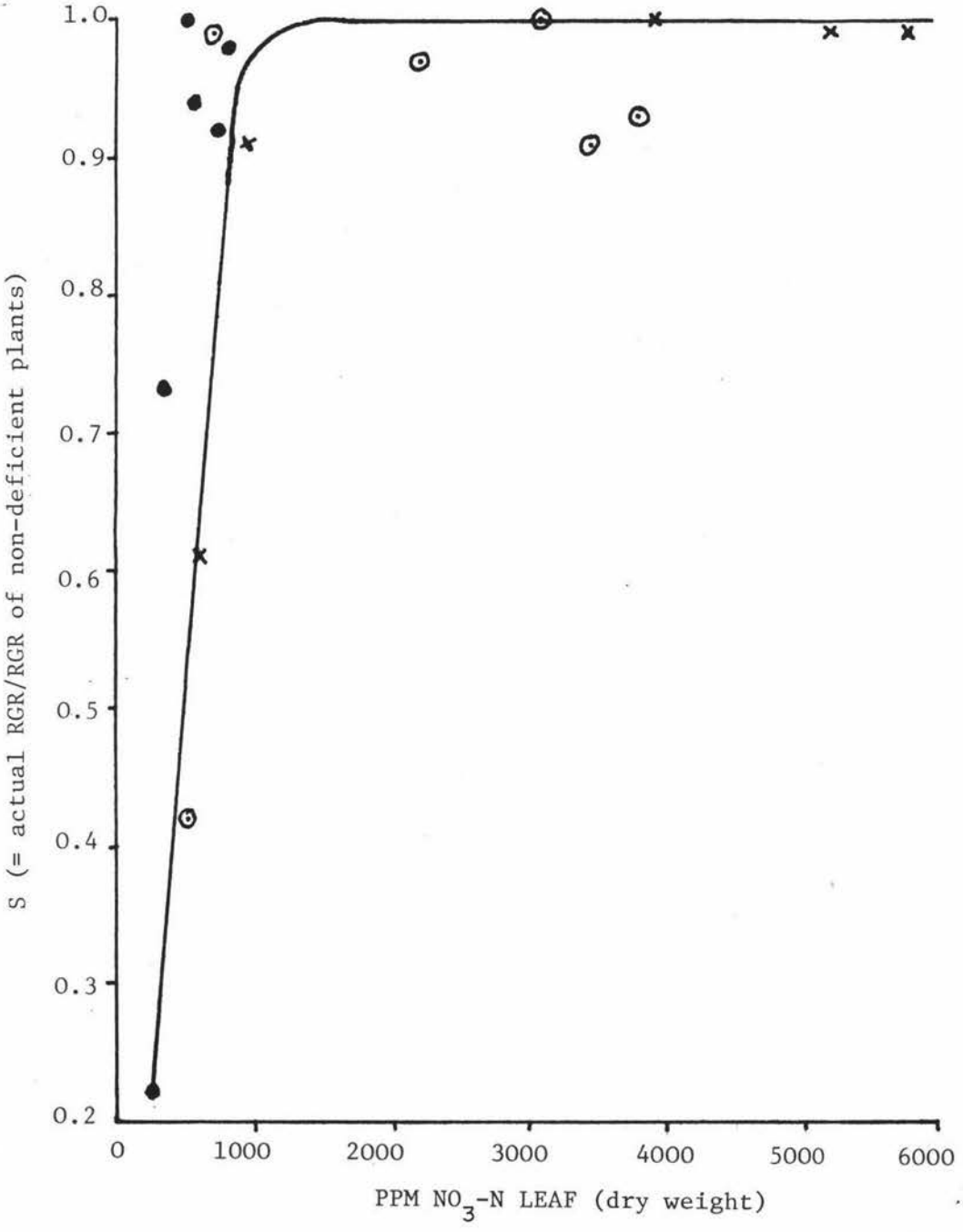


FIG. 13. Relative growth rate of PLK onions as related to the NO_3-N concentration in the leaf during the early stages of growth.

×——× H1, ○——○ H2, ●——● H3.

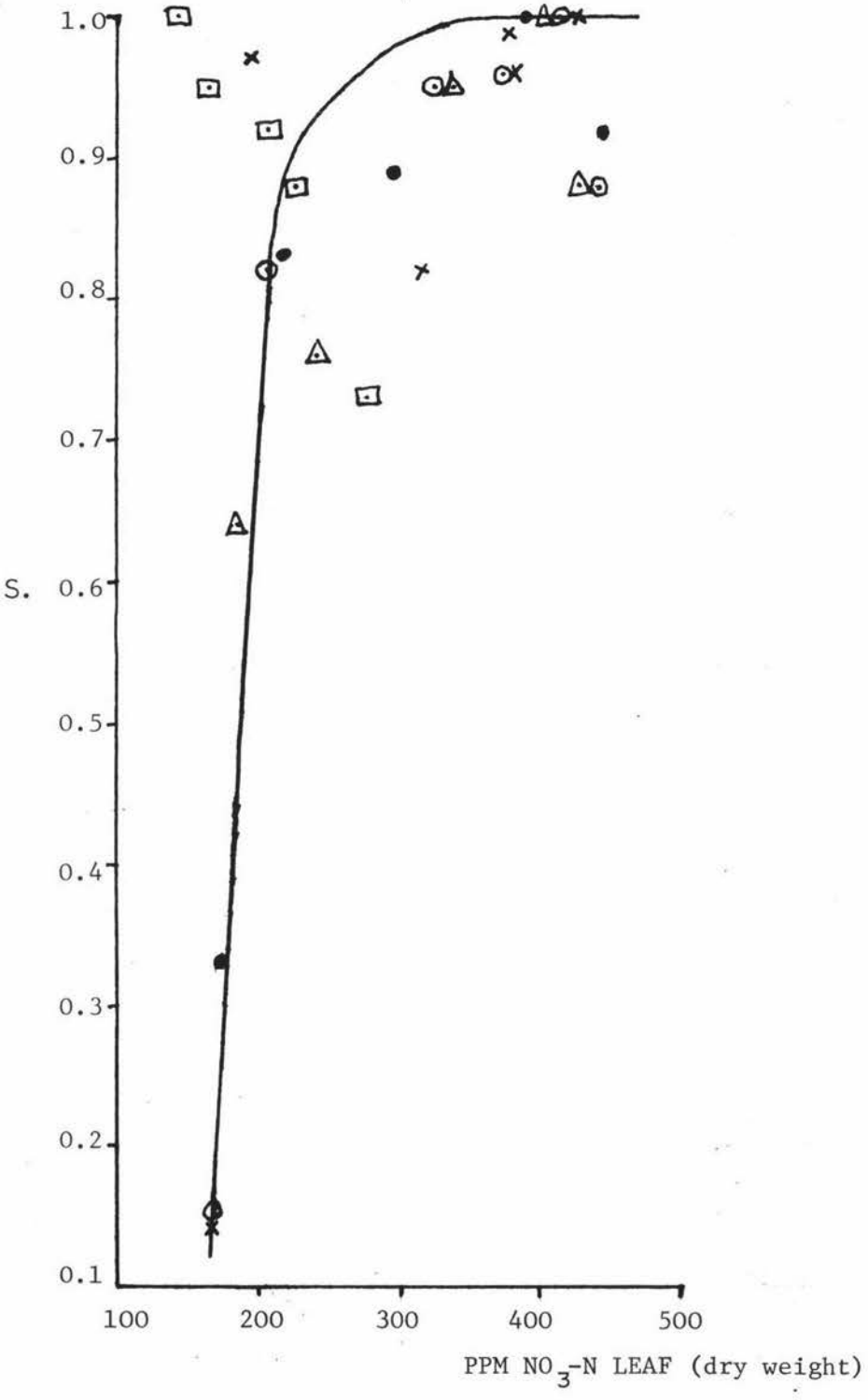


FIG. 14. Relative growth rate of PLK onions as related to the NO_3-N concentration in the leaf during the later stages of growth.

H4, H5, H6, H7, H8.

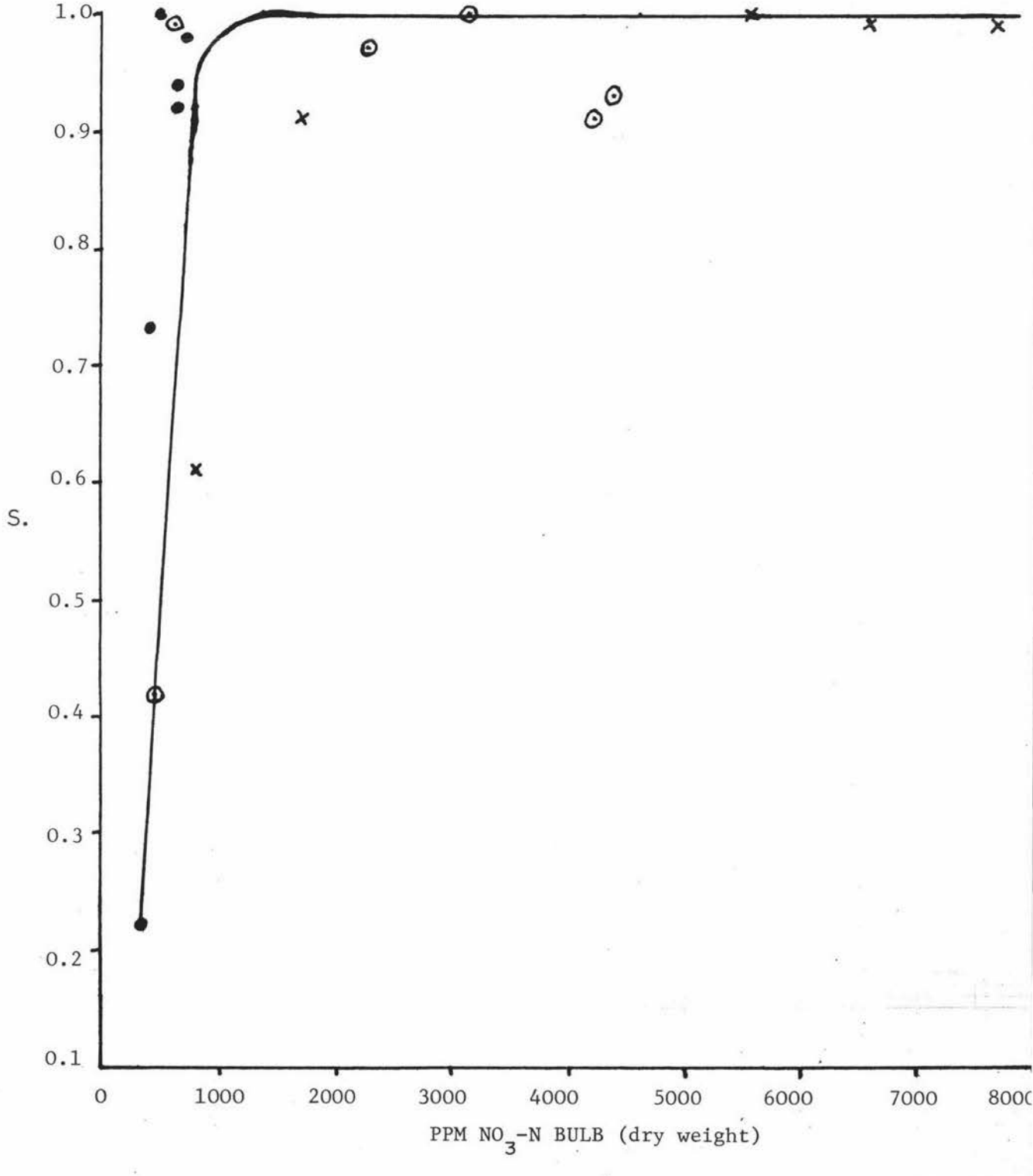


FIG. 15. Relative growth rate of PLK onions as related to the NO_3-N concentration in the bulb during the early growth stages.

H1, H2, H3.

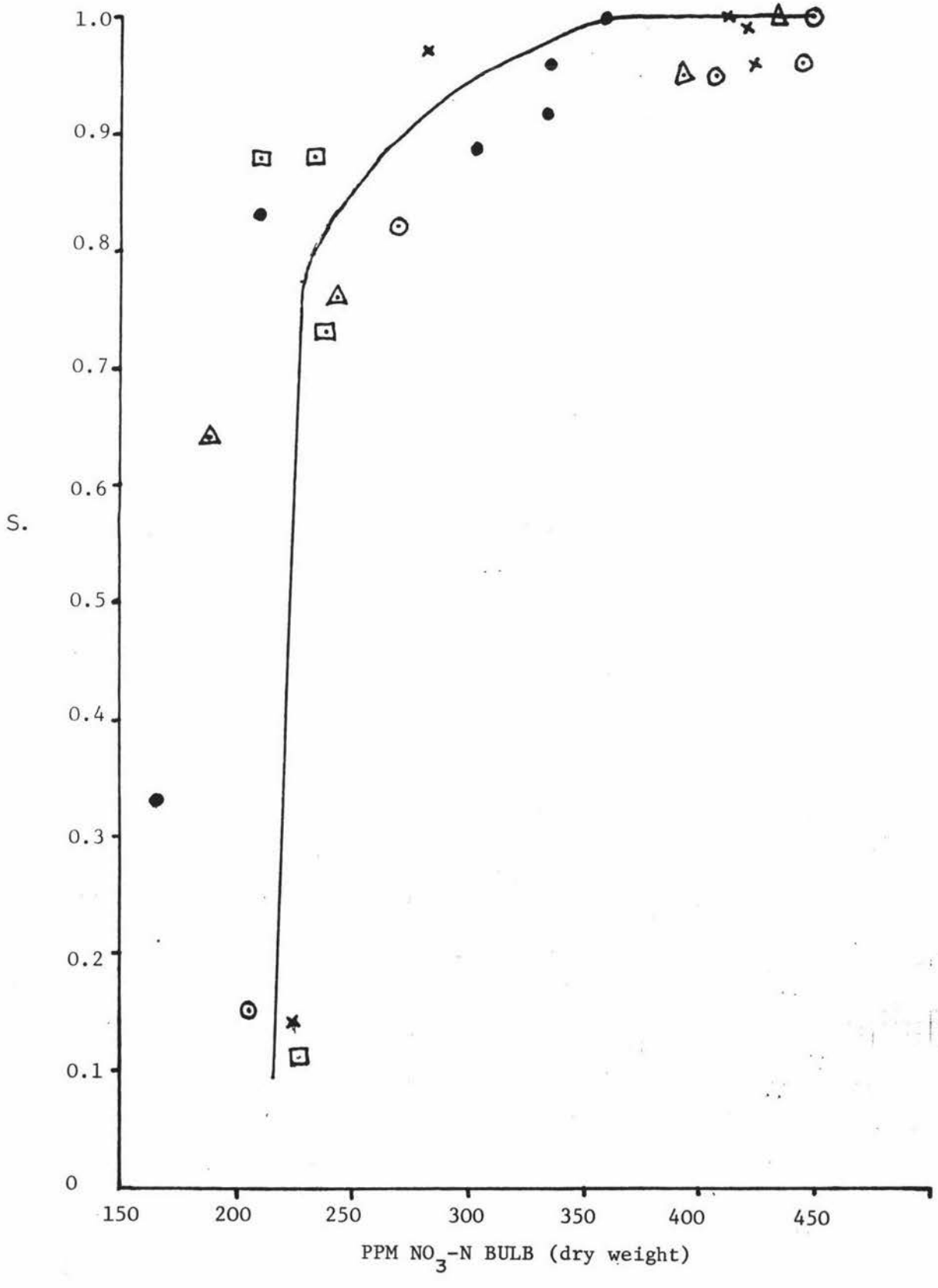


FIG. 16. Relative growth rate of PLK onions as related to the NO_3-N concentration in the bulb during the later growth stages.

H4, H5, H6, H7, H8.

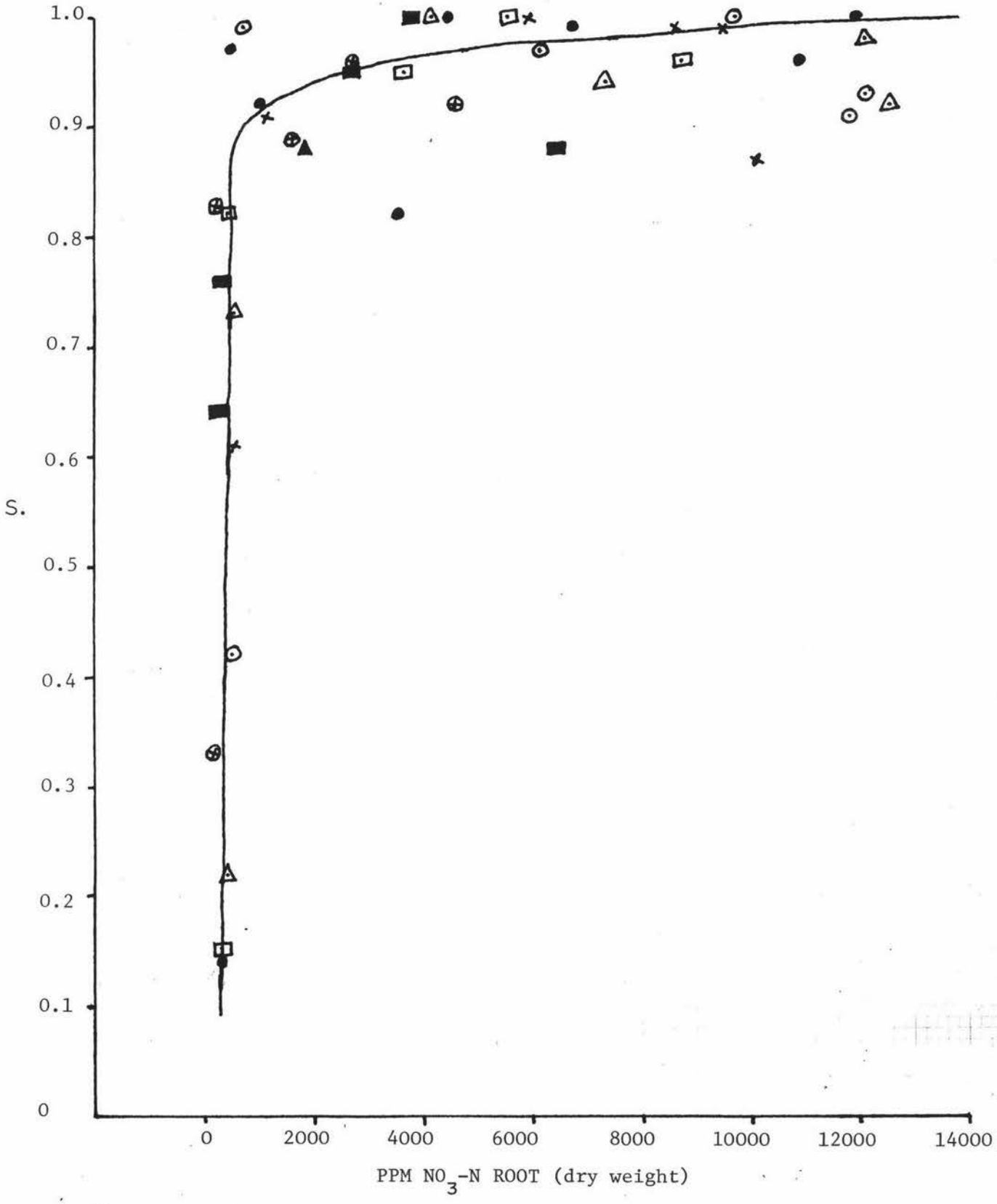


FIG. 17. Relative growth rate of PLK onions as related to the NO_3-N concentration in the root.

H1, H2, H3, H4, H5, H6, H7, H8.

TABLE 5

EFFECTS OF N TREATMENTS ON PPM NO_3-N CONTENT OF FRESH PLK ONION BULBS AT DIFFERENT STAGES OF GROWTH.

NITROGEN LEVELS	HARVESTS				
	H1	H2	H3	H4	H5
No	0	0	0	0	0
N1	5.3	3.8	0	0	0
N2	189	57	23	7	2.3
N3	227	95	23	7	2.3
N4	227	114	34	7	2.3
N5	227	114	34	7	2.3

Table 5 shows a significant difference in NO_3-N content between the low N treatments and the high N treatments. However, it appears that the 'Merckoquant' strip can only be used to monitor NO_3-N in the fresh onion bulb early in the growth season and so may not be practically useful for determining N fertilizer requirements for onions. Perhaps the roots with high NO_3-N content would give a better result.

'Merckoquant' strips only measured the soluble nitrate (excluding organically combined nitrogen and ammonia) but the results presented are calculated in terms of nitrogen (N) rather than as nitrate (NO_3-).

6.3.3 TOTAL N

The total N distribution in the leaves, bulbs and roots of the onion plant at different growth stages for various levels of N (Figs 18, 19 and 20) follow a similar trend to the nitrate-nitrogen distribution. In general, total N content declined with plant age for all N levels. With all three organs, total N in the seedling stage was very high but declined sharply until real bulbing started then slowly increased as the bulbs were rapidly enlarging. As maturity was approached, total N in the leaves and roots decreased again but total N in the bulb continued to increase. The reason for such a trend can be explained by the fact that as maturity was approached the leaves and roots were senecing and dying whilst the bulbs were still expanding. Thus N in the leaves and roots was passed to the bulb, a source-sink relationship.

In general, total N in the leaves, roots and bulbs increased with increased N fertilizer. The low N treatments (No, N1) were distinctly lower in total N content than the high N treatments (N2, N3, N4, N5) for all three organs.

The leaves appeared to have a higher N content than the roots and bulbs with the bulbs having the lowest N content during most of the growing period (Fig. 21). This is in contrast to the NO_3-N curves where the roots were very much higher in NO_3-N than the leaves or bulbs (Fig. 12) throughout the growth period. The total N curves for leaves and roots closely follow each other but the bulbs follow a much lower pattern.

The critical total N concentrations of an onion crop in which leaves, bulbs and roots were sampled at various growth stages had been worked out from Figures 22, 23 and 24. These were established at 2.7% N dry weight for leaves, 1.6% N dry weight for bulbs and 2.1% N dry weight for roots. Monitoring total N in the leaves appears to give a better indication of the N status of an onion than would the bulbs or roots.

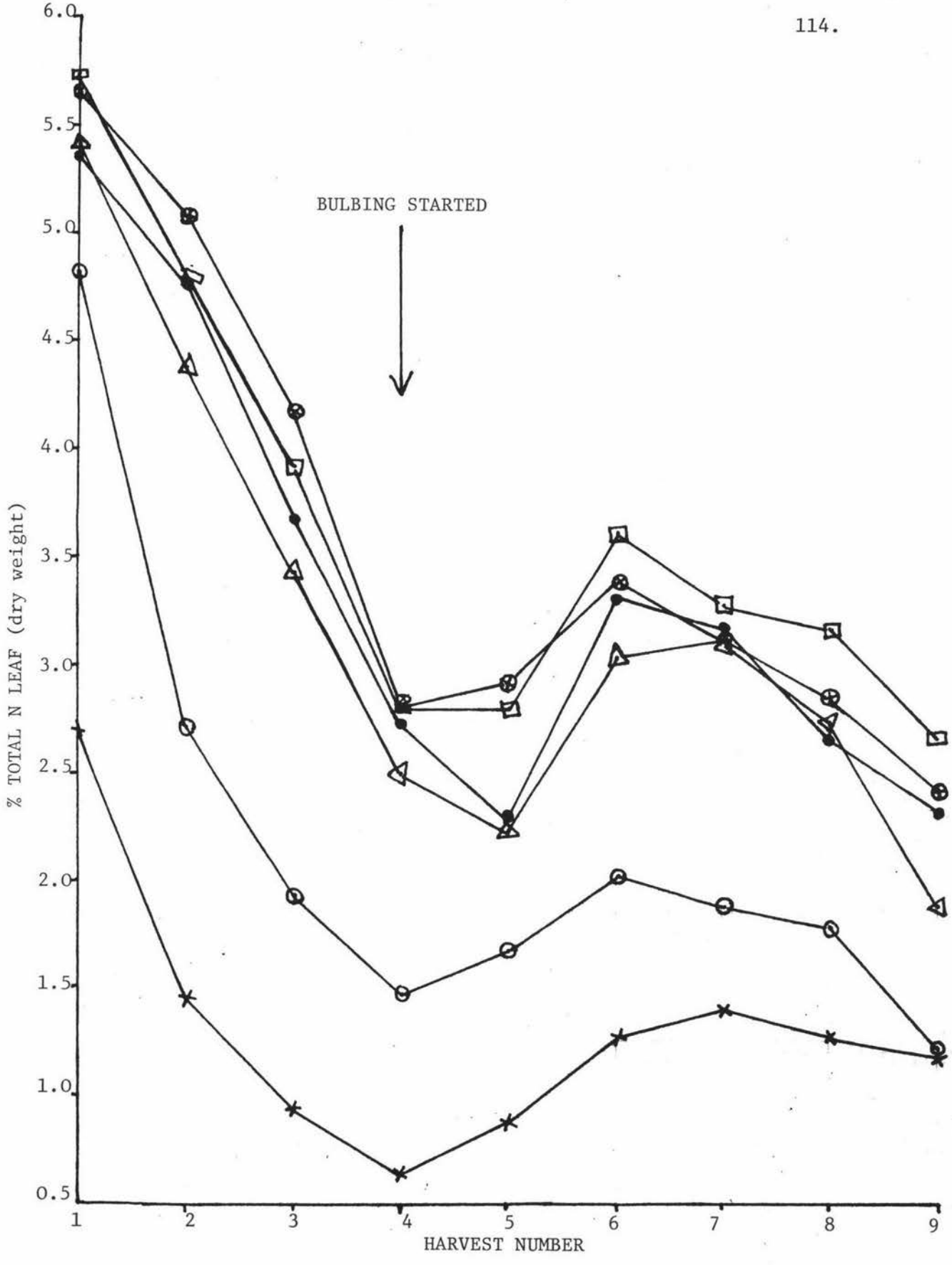


FIG. 18. Effects of N fertilizer on leaf total N concentration.

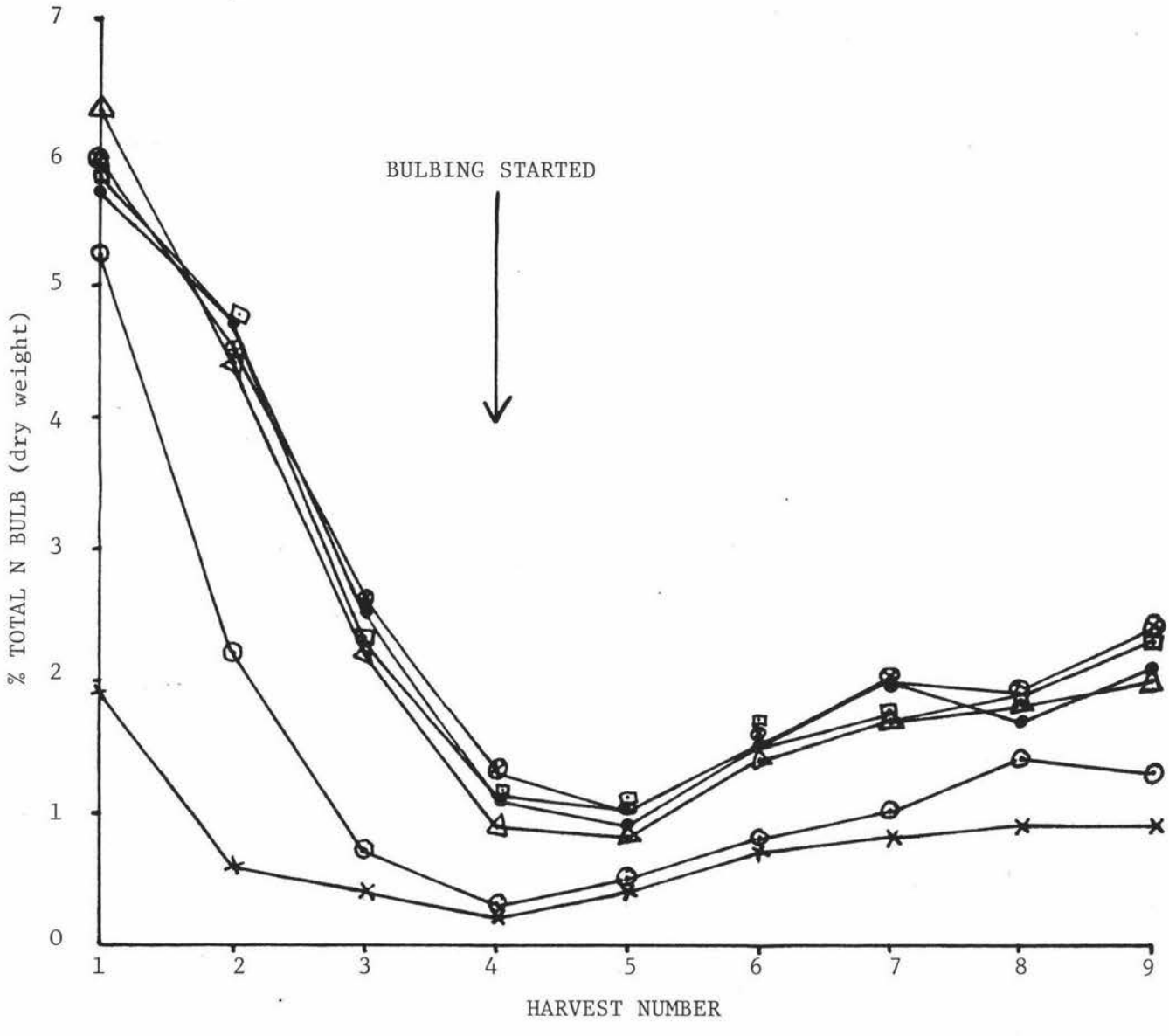


FIG. 19. Effects of N fertilizer on bulb total N concentration.

No, N1, N2, N3, N4, N5.

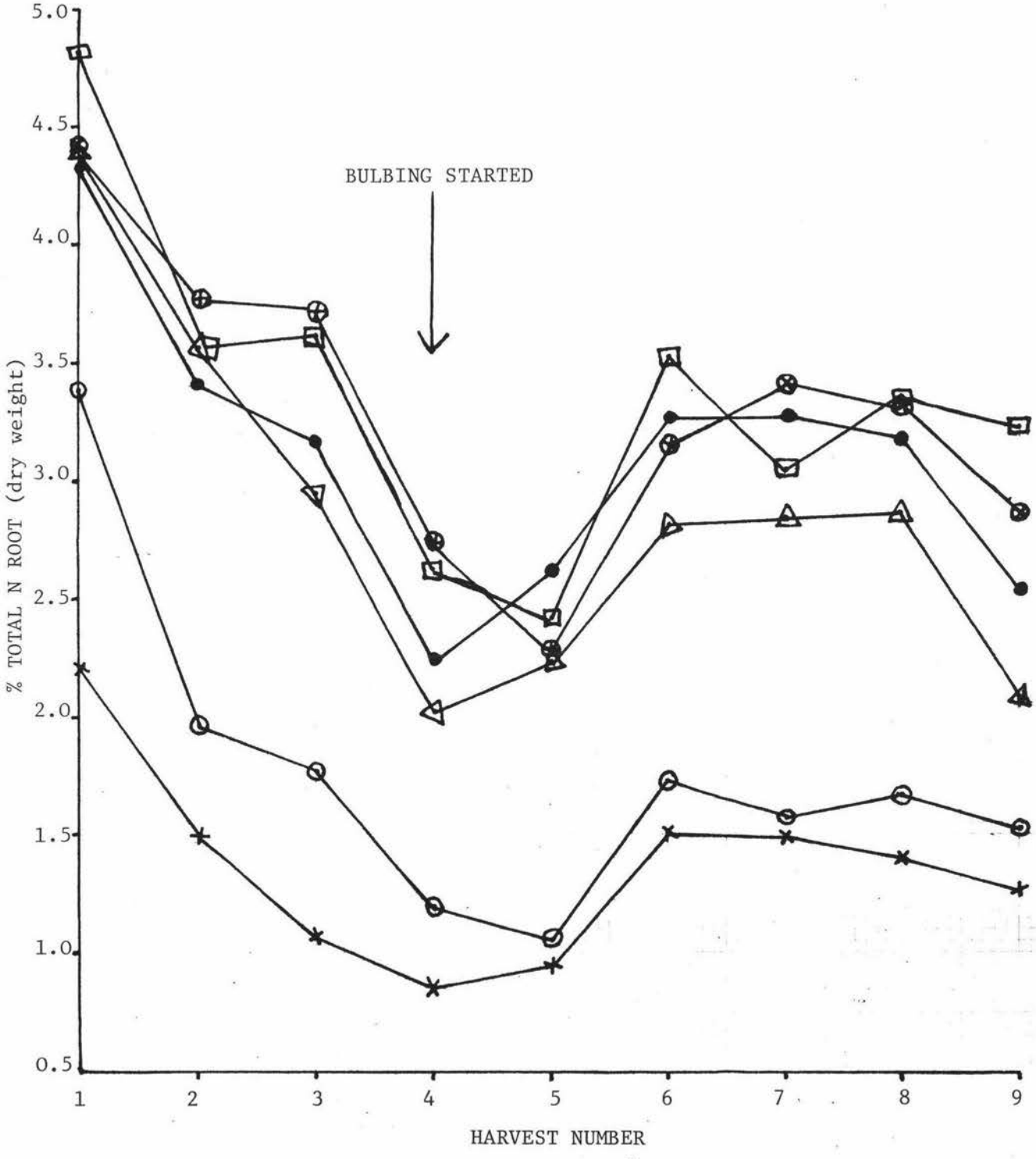


FIG. 20. Effects of N fertilizer on root total N concentration.

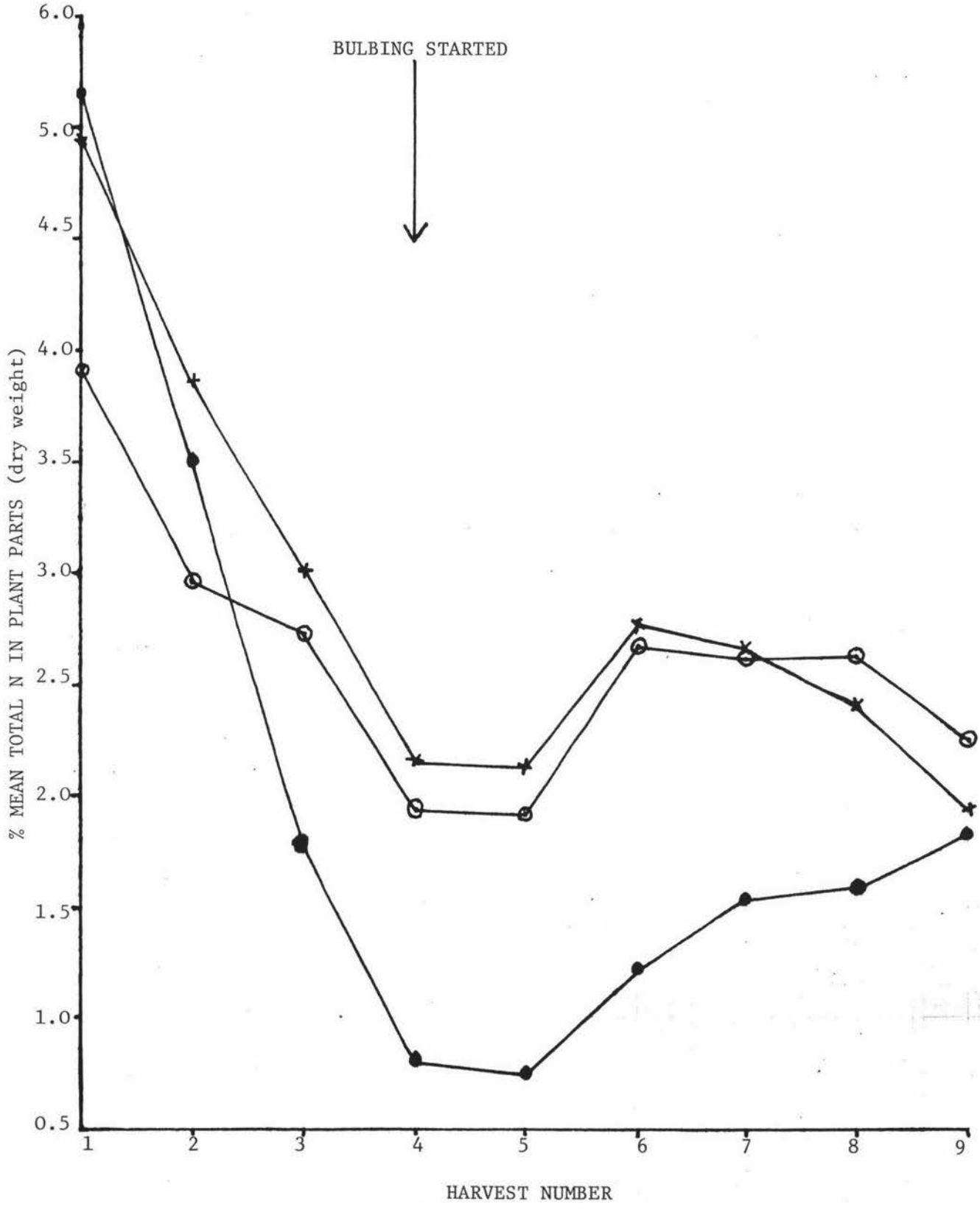


FIG. 21. Distribution of total N in the plant parts.

leaf, root, bulb.

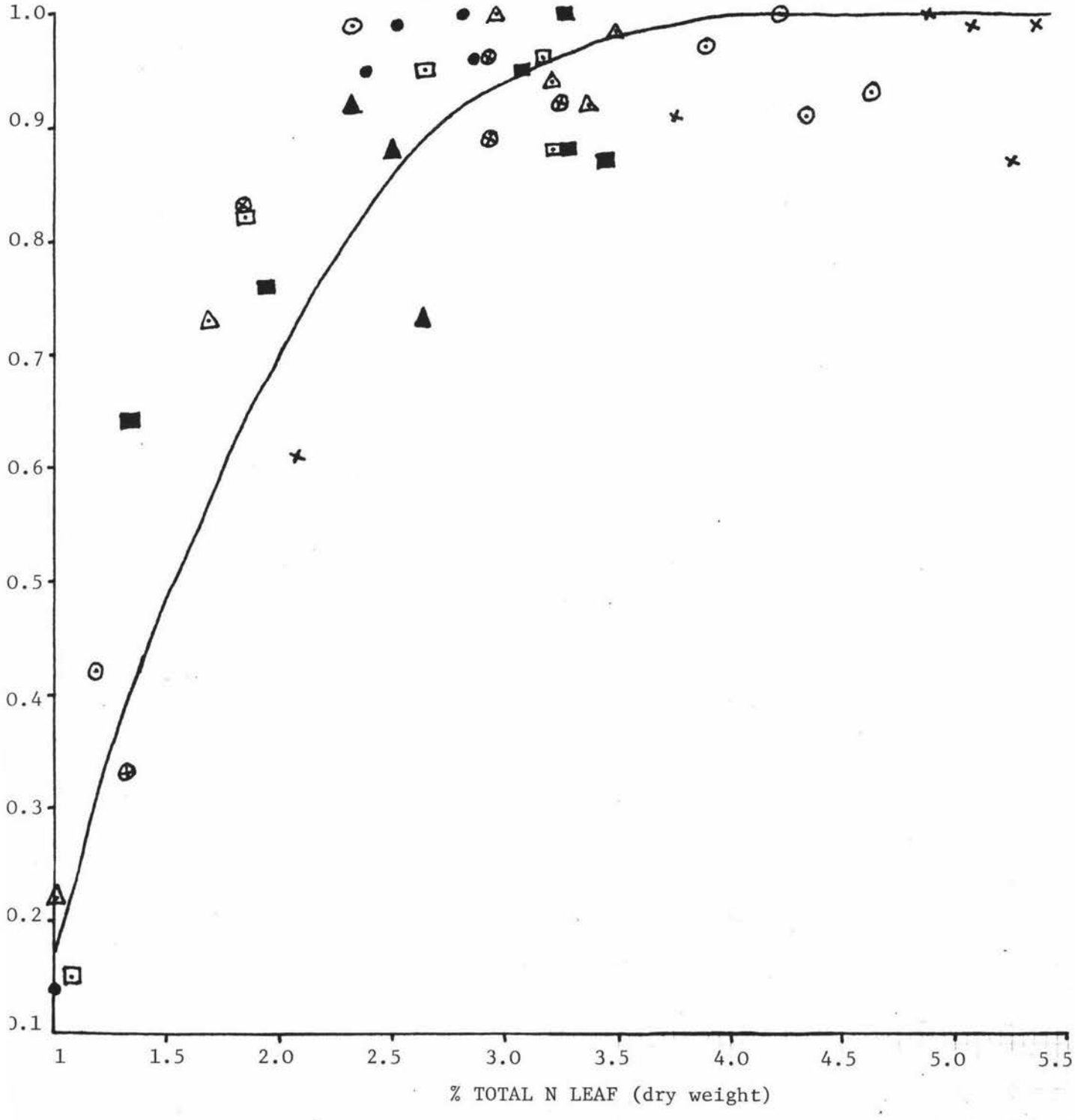


FIG. 22. Relative growth rate of PLK onions as related to total N concentration in the leaf.

H1, H2, H3, H4, H5, H6, H7, H8.

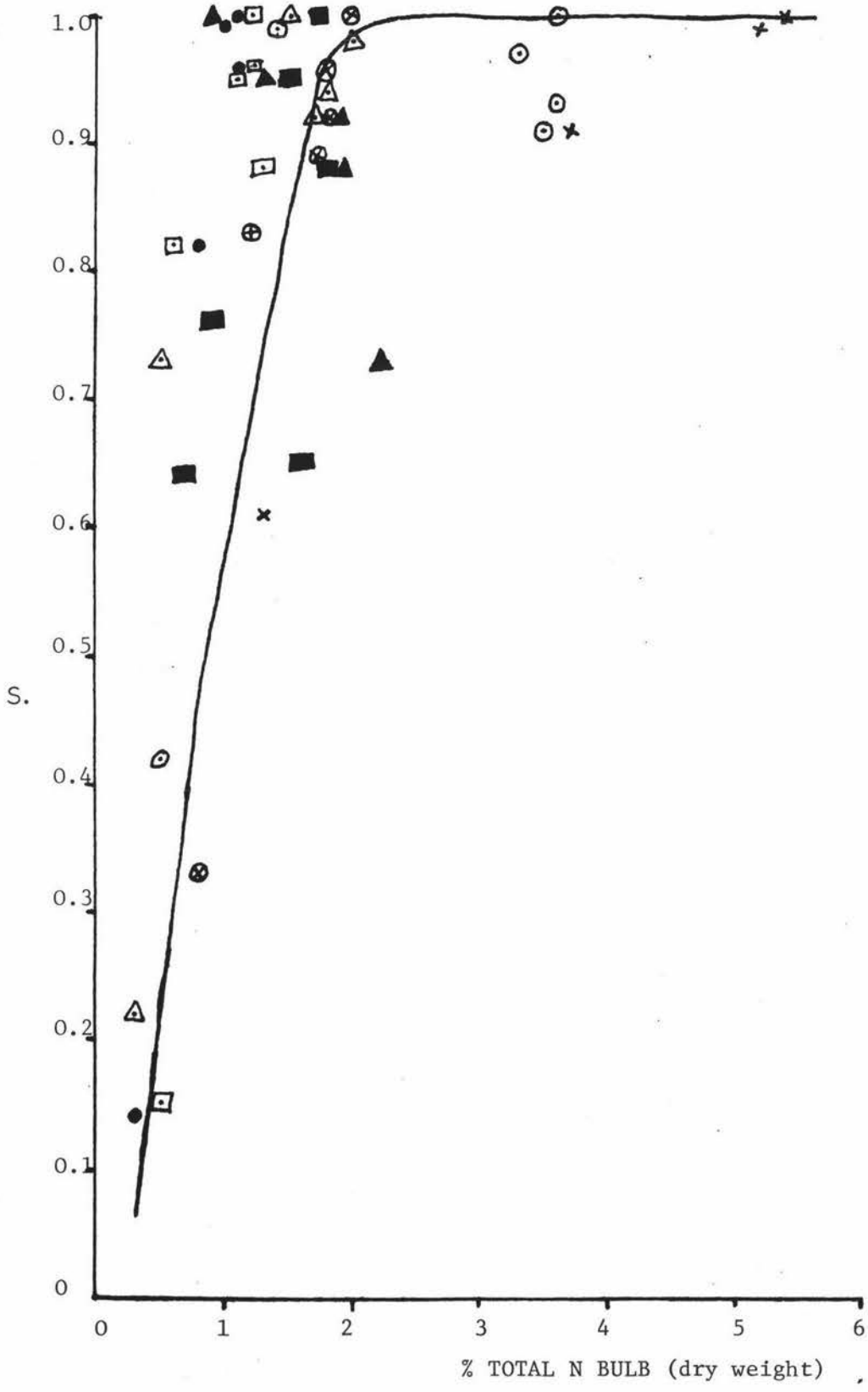


FIG. 23. Relative growth rate of PLK onions as related to total N concentration in the bulb.

H1, H2, H3, H4, H5, H6, H7, H8.

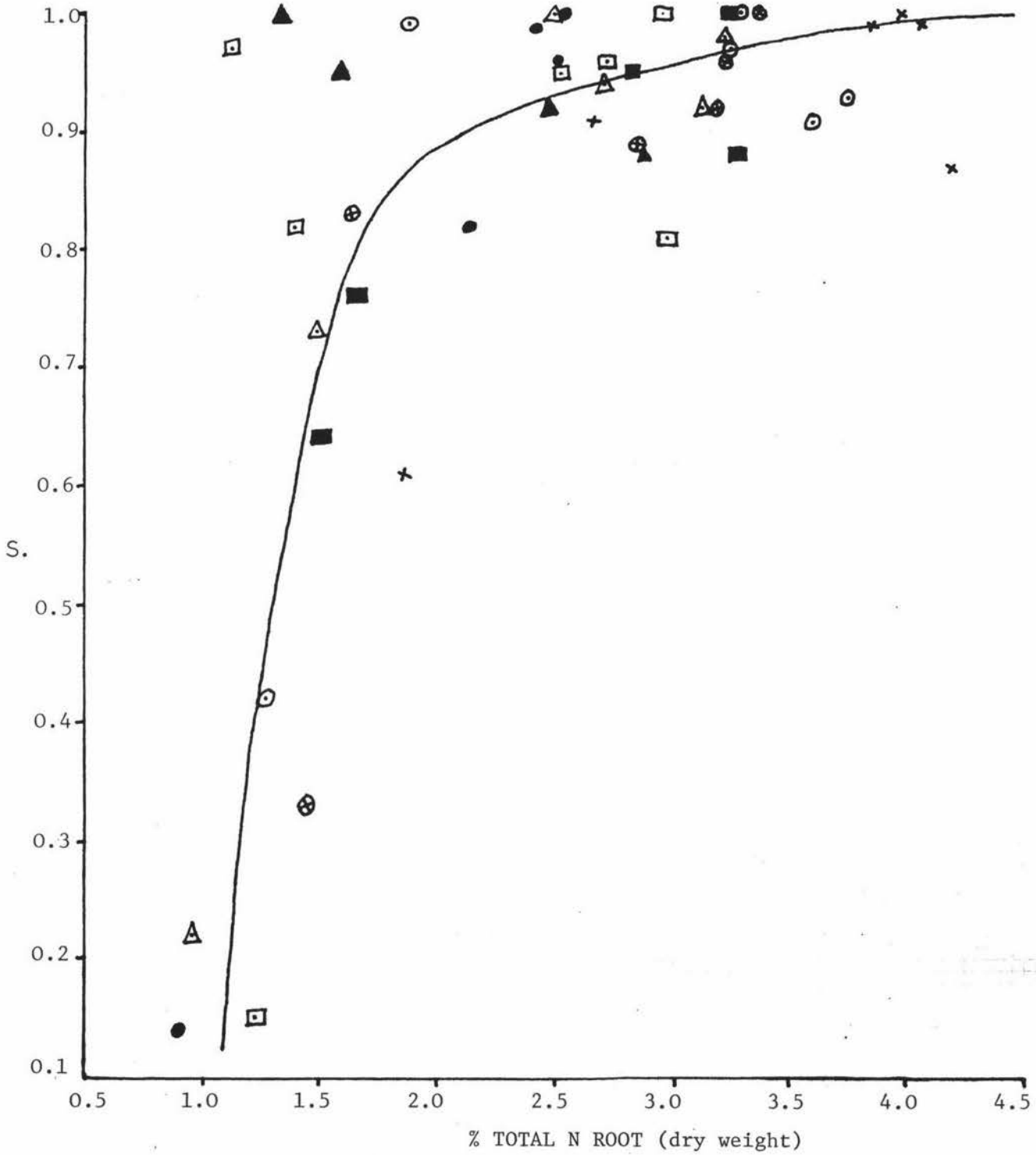


FIG. 24. Relative growth rate of PLK onions as related to total N concentration in the root.

H1, H2, H3, H4, H5, H6, H7, H8.

The NO_3-N and total N in the onion plant parts were found to be highly correlated. The bulbs (R = 0.85) showed a better correlation of total N and NO_3-N than the leaf (R = 0.75) or root (R = 0.59). However, because of the low NO_3-N concentrations in the onion plant, monitoring total N rather than NO_3-N appears to give a better guide to the N status of an onion crop.

SECTION C

EXPERIMENT 2 : FIELD TRIAL

CHAPTER 7

MATERIALS AND METHODS

7.1 GENERAL

The trial was carried out at Massey University's Department of Horticulture and Plant Health Experimental Field on a Manawatu silt loam soil. The trial area was rotary hoed and harrowed to give a fine tilth. Phosphorus, 200 kg P/ha, and potassium, 200 kg K/ha, were also incorporated into the soil. A slow release nitrogen fertilizer, sulphur coated urea with trade name Gold N, manufactured by Canadian Industries Limited, Ontario, was the source for the N treatments. The nitrogen fertilizer was placed 5 to 8 cm beneath the rows at sowing. The rows were 30 cm apart.

The cultivar Pukekohe Long Keeper (PLK) from Arthur Yates Limited was used in the trial. The seeds were treated with Thiram^{R} and Benlate^{R} to prevent fungal diseases. The seeds were sown by hand at a depth of about 15 mm directly over the N treated rows on 12 October 1979. The seeds germinated approximately 14 days after sowing. The seedlings were thinned to a spacing of 5 cm within rows in plots of 5.25 m^2. Guard rows were provided between plots.

Weeding was by hand. The crop was sprayed with Thiodan^{R} on 20 February 1980 to control thrip insects. Sprinkler irrigation supplemented rainfall when necessary.

7.2 EXPERIMENTAL DESIGN

A split plot randomised complete block design with three replicates was used in the trial. The main-plots were seven nitrogen levels and the sub-plots were four harvest dates. The following N rates were chosen:

N LEVELS	-	No	N1	N2	N3	N4	N5	N6
kg N/ha	-	0	50	100	150	200	250	300

7.3 Sampling Method

Plants were harvested from each treatment and block every 30 days starting 60 days after emergence up to full maturity (4 harvest dates). During each harvest a sample of 25 plants was carefully dug out (with most of their roots intact) from one of four sub-plots. The roots of each sample were washed free of soil and immediately taken to the laboratory for growth measurements, the same as those described in the first experiment.

7.4 Plant Tissue Analyses

The methods used were the same as those described in the first experiment.

7.5 Storage

Two batches of 40 good quality bulbs were selected from each treatment and block after the final harvest when the bulbs were fully mature. These were 'cured' in the glasshouse for two weeks. One batch of each treatment and block was placed in a cool storage room about 3°C and 75-85% RH. The other batch was placed in a controlled high temperature chamber about 30°C and 65-70% RH. The bulbs stayed under storage for four months after which they were examined for deterioration caused by weight loss, decay, sprouting and root growth.

CHAPTER 8

RESULTS AND DISCUSSION

8.1 GROWTH CHARACTERISTICS

The fresh and dry weight of the whole plant increased with time reaching maximum at the end of the growing period (Fig. 25). The growth in weight of the onion plant was very slow in the early stages. Approximately 60 days after emergence only 7-8 per cent of the ultimate plant fresh weight was produced in all N treatments. Most of the plant weight was produced thereafter when the bulbs were rapidly expanding and nearing maturity.

Entire plant fresh and dry weight increased with increasing N fertilizer up to 200 kg N/ha then decreased with further increases in N (Fig. 26). The high N treatments generally had larger fresh weight and dry weight than the low N treatments (Tables 6 and 7). All the plots with N added were significantly different to the plots with no N added. The relatively large fresh and dry weight in the low N plots could be attributed to the efficient supply of N to the plants by the slow release fertilizer and the fertile nature of the soil.

Bulb dry weight also increased with time and reached maximum at final harvest (Fig. 25). Bulb growth was very slow in the early stages of growth. Approximately 90 days after emergence only 2 to 3% of the ultimate bulb dry weight was produced. The bulb dry weight trend during the growing period closely followed the total plant dry weight curve. The bulb formed the predominant plant part as maturity approached. Most of the bulb was produced during the period when tops were drying and bulbs maturing. Bulb dry weight also increased with increasing N fertilizer up to 200 kg N/ha then decreased slowly with further increases in N (Fig. 26). Bulb dry weight also followed the same N response pattern as the entire plant dry weight.

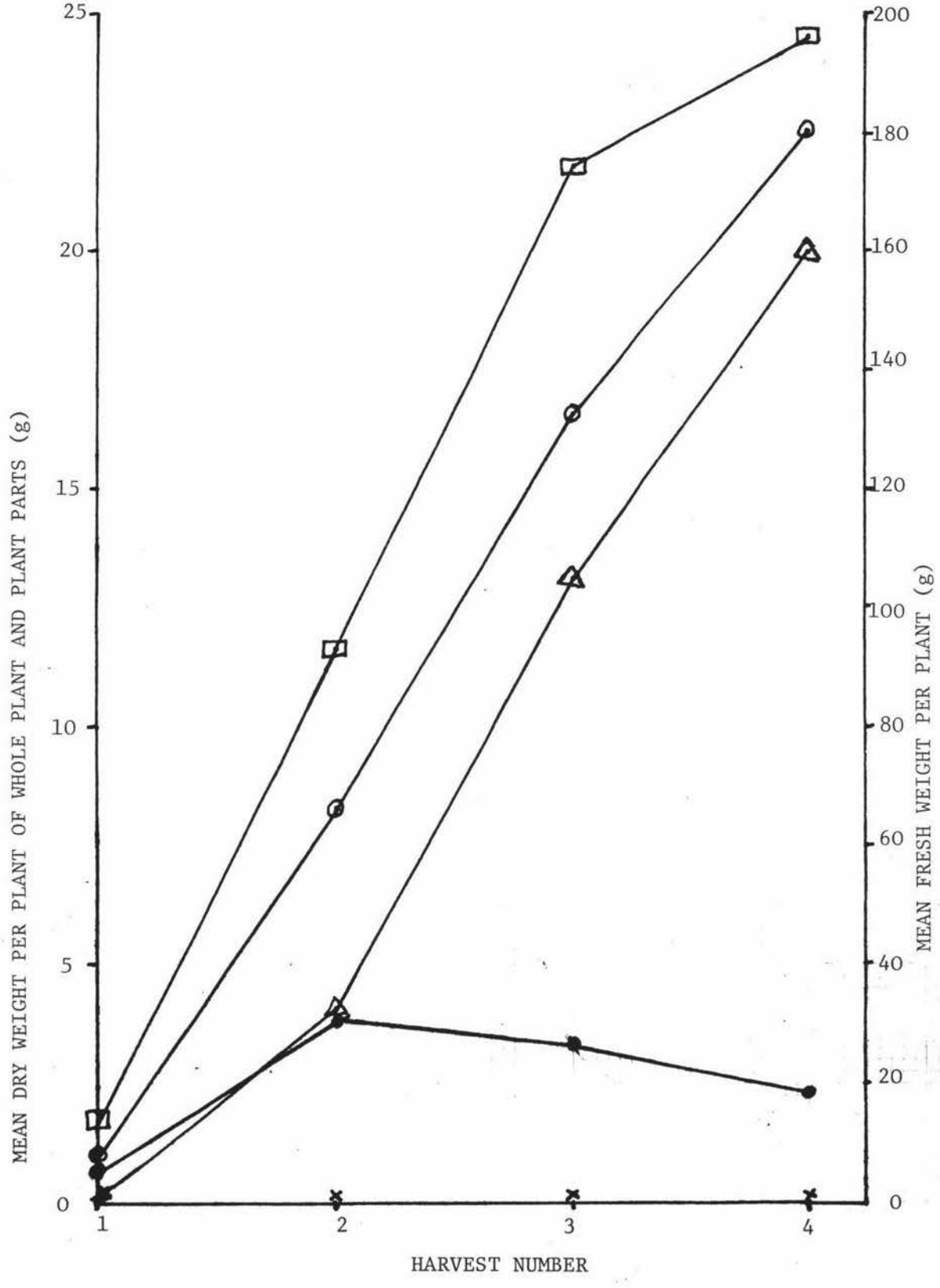


FIG. 25. Growth curves of PLK onions showing plant fresh weight (□—□), plant dry weight (○—○), bulb dry weight (△—△), leaf dry weight/plant (●—●) and root dry weight/plant (×—×).

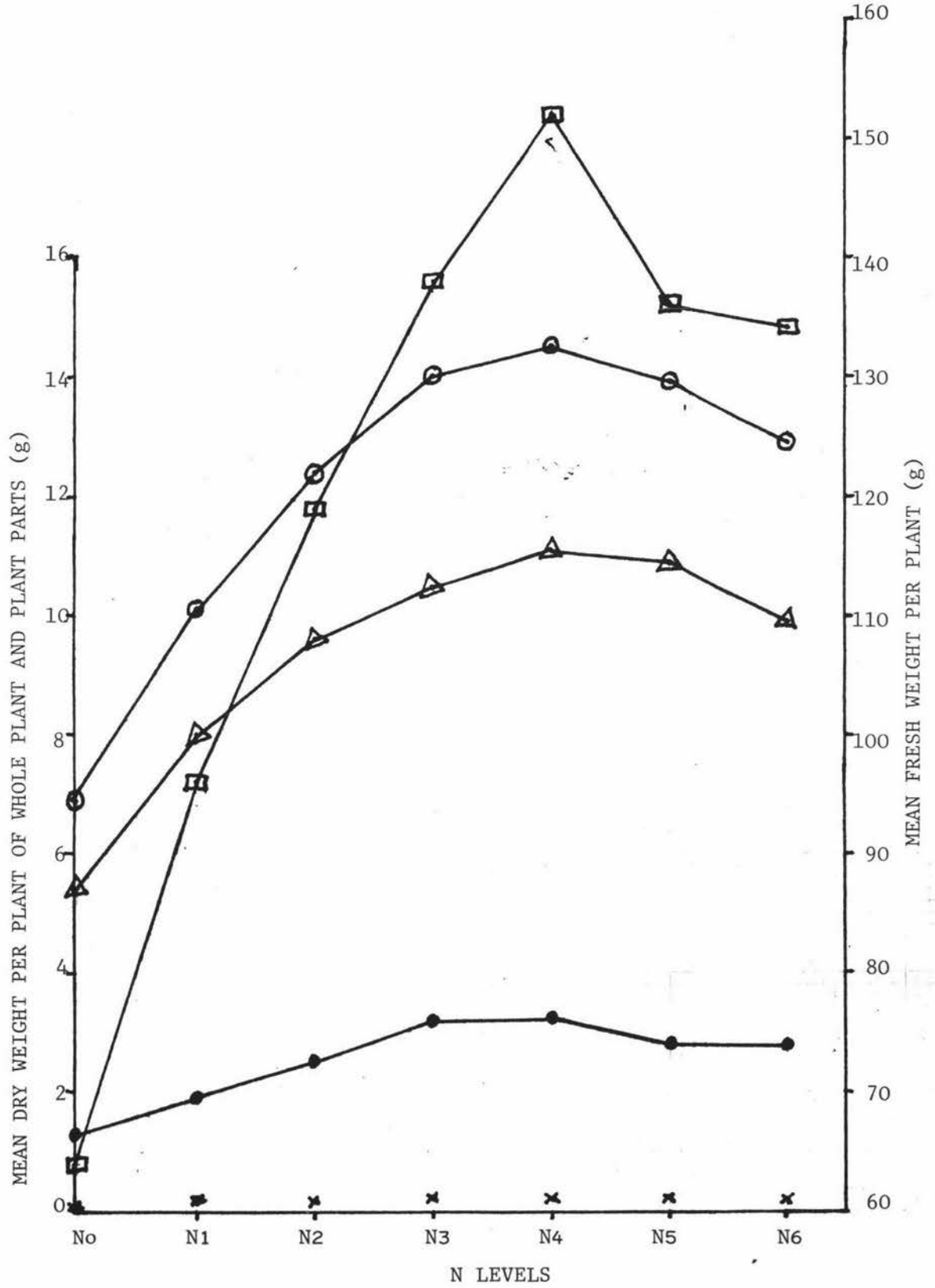


FIG. 26. Growth curves of PLK onions as influenced by N fertilizer levels. ⊡—⊡ plant fresh weight, ⊙—⊙ plant dry weight, △—△ bulb dry weight, ●—● leaf dry weight, ×—× root dry weight.

The total number of green leaves per plant increased with time until a peak was reached 90 days after emergence then declined (Fig. 27). In the early growth stages leaf emergence was high, hence the marked increase in leaf number. With the onset of bulbing however, leaf emergence was restricted and as maturity approached, the inhibitory effect of bulbing to leaf production and the dying of older leaves resulted in a decline in green leaf number.

Green leaf number increased with increasing N levels up to 200 kg N/ha then declined with further increases in N (Fig. 28). In general, high N treatments had more green leaves than the low N treatments during most of the growth stages.

Figure 27 shows the time trend of the total green leaf area per plant. This closely followed the same pattern as the green leaf number per plant. The maximum green leaf area per plant was recorded approximately 90 days after emergence. Similar to the green leaf number, the green leaf area per plant increased with age until it reached this maximum then declined. The leaf area appears to be closely related to leaf number. This is not surprising since leaf number and leaf size make up leaf area and it seems leaf number is a major determinant of leaf area in onions.

Leaf area increased with increasing N fertilizer up to 200 kg N/ha then declined with further increases in N (Fig. 28). The high N treatments generally had larger leaf area than the low N treatments, N being necessary for new leaf growth.

Root dry weight increased with time but as maturity approached declined slightly (Fig. 25). Apart from the lower root dry weight in treatment No, all the other N treatments had similar root dry weight per plant. Probably the difficulty in sampling all the roots per plant is the reason for differences between the N added plots not being pronounced.

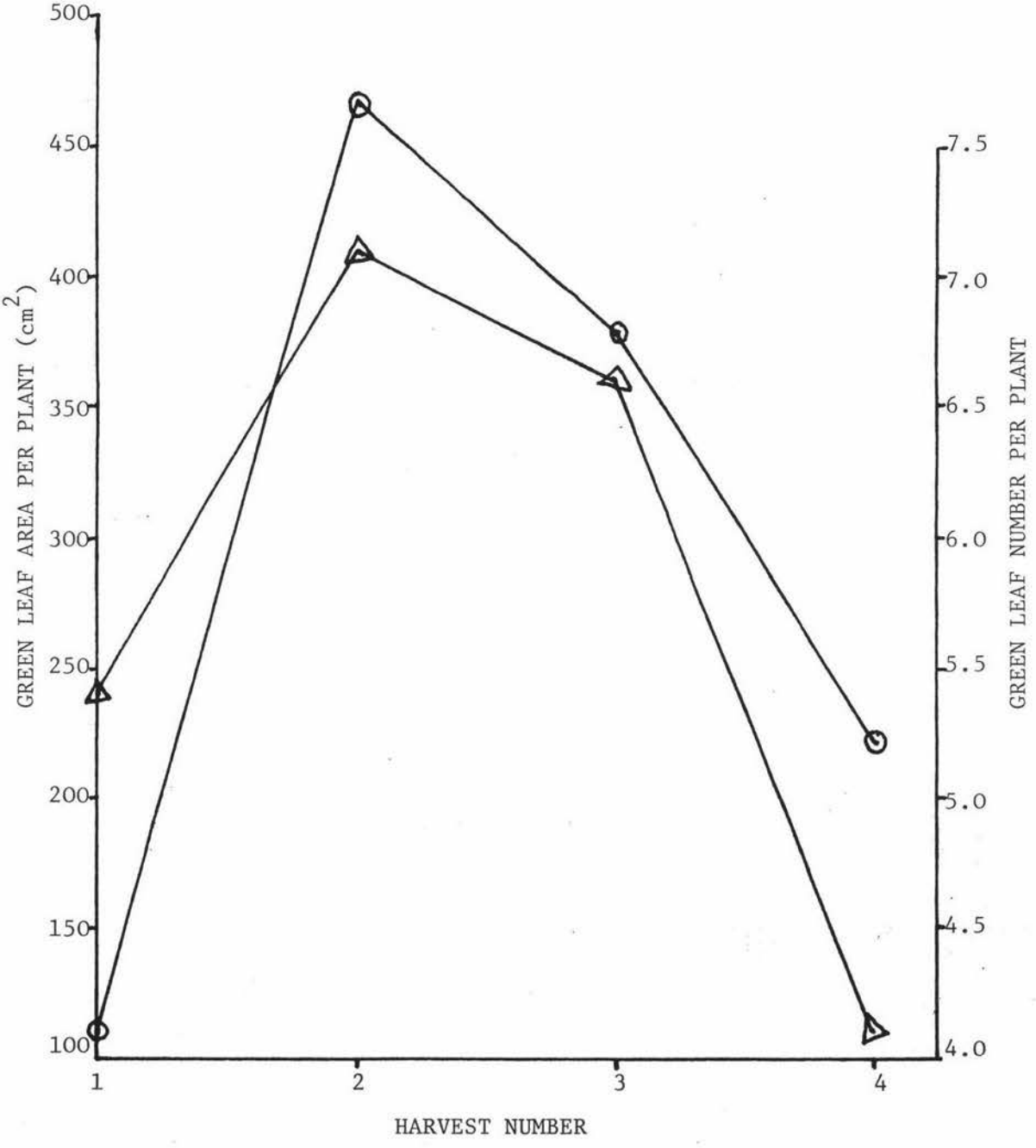


FIG. 27. Leaf growth curves of PLK onions showing green leaf area per plant (O—O) and green leaf number per plant (Δ—Δ).

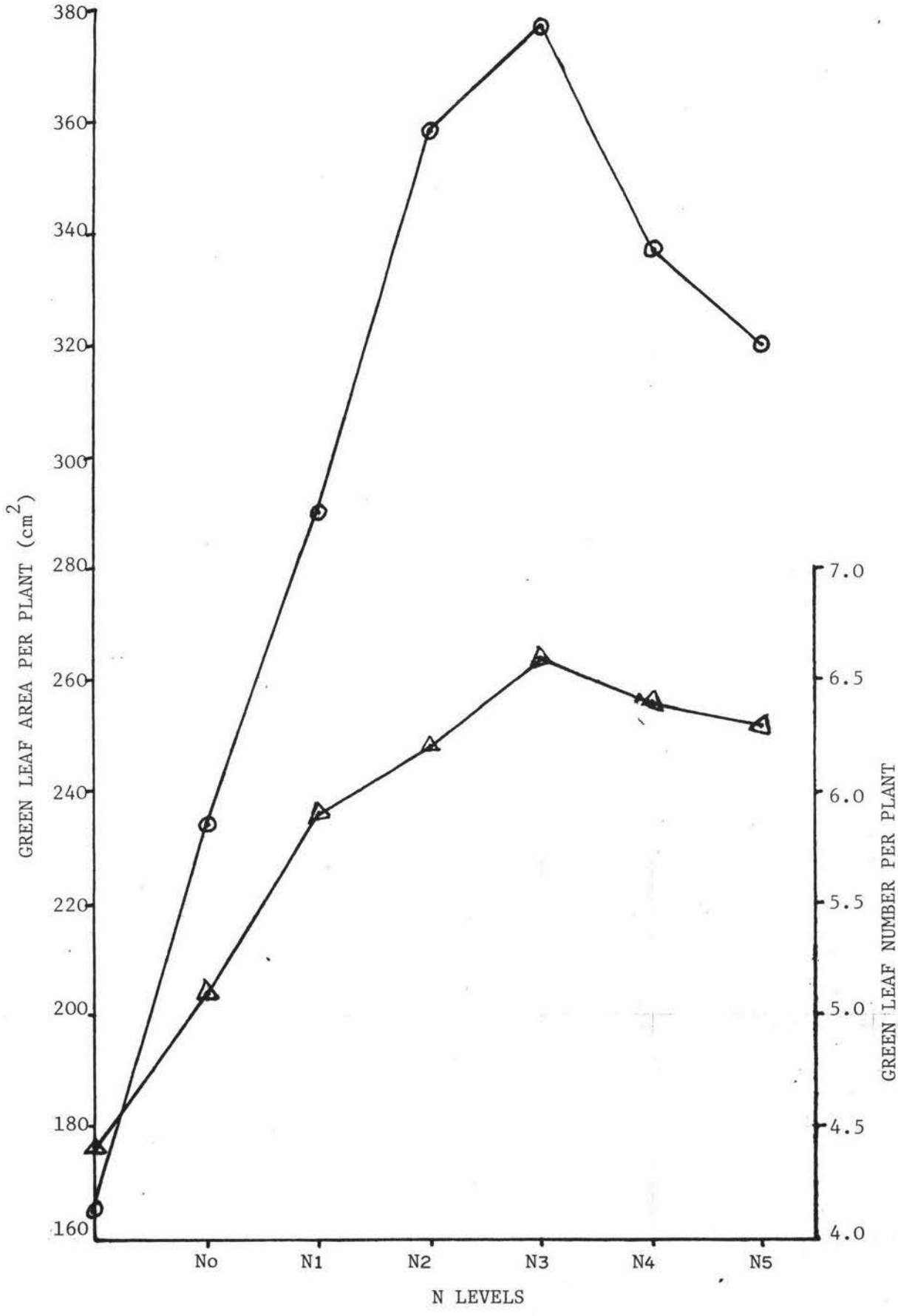


FIG. 28. Leaf growth curves of PLK onions as influenced by N levels.

⊖——⊖ green leaf area per plant, Δ——Δ green leaf number per plant.

Figure 29 shows response curves of fresh bulb diameter and fresh bulb weight as influenced by increasing N rates in the final harvest. Both bulb diameter and bulb weight increased with increasing N fertilizer up to 200 kg N/ha then decreased with further increases in N. The bulb weight and the bulb diameter appear to be closely related.

TABLE 6

EFFECTS OF N TREATMENTS ON LOG_e PLANT FRESH WEIGHT (g) OF PLK ONIONS AT DIFFERENT STAGES OF GROWTH.

NITROGEN LEVELS	HARVEST			
	1 (60 days after emergence)	2 (90 days after emergence)	3 (120 days after emergence)	4 (150 days after emergence)
No	1.93b	3.71b	4.53b	4.67c
N1	2.39ab	4.42a	4.95ab	4.97bc
N2	2.51a	4.43a	5.18a	5.28ab
N3	2.77a	4.65a	5.25a	5.44ab
N4	2.83a	4.68a	5.37a	5.58a
N5	2.67a	4.68a	5.33a	5.36ab
N6	2.64a	4.67a	5.29a	5.35ab

Mean separation is by Duncan's New Multiple Range Test. Means in columns having the same letters are not significantly different at P = 0.05.

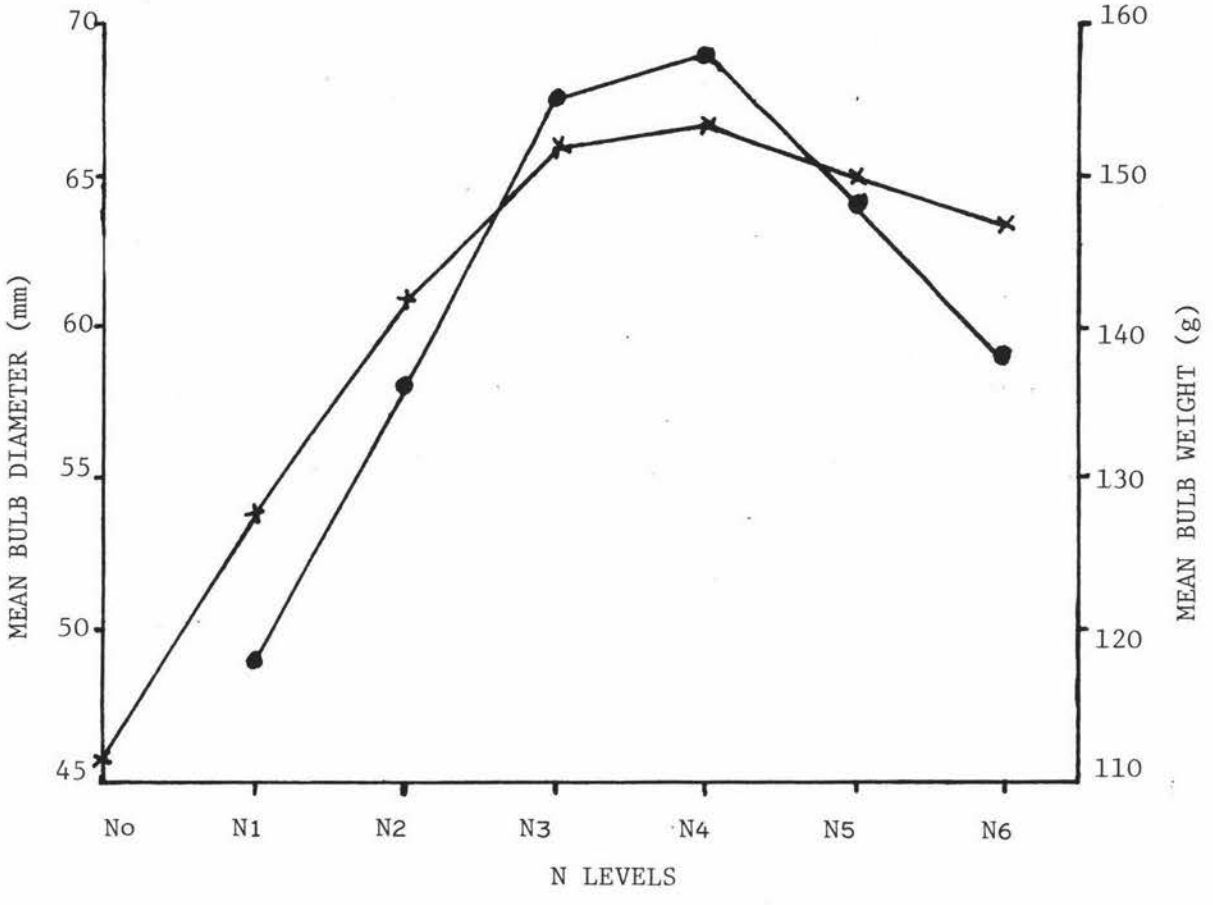


FIG. 29. The influence of N levels on bulb diameter (✕——✕) and bulb weight (●——●).

TABLE 7

EFFECTS OF N TREATMENTS ON LOG_e PLANT DRY WEIGHT (g) OF PLK ONIONS AT DIFFERENT STAGES OF GROWTH.

NITROGEN LEVELS	HARVEST			
	1	2	3	4
No	-0.6171b	1.44b	2.24b	2.53b
N1	-0.2071ab	2.03a	2.68ab	2.83ab
N2	0.0825a	2.03a	2.85a	3.13a
N3	0.1185a	2.17a	2.92a	3.29a
N4	0.1890a	2.26a	2.98a	3.30a
N5	0.1293a	2.26a	2.88a	3.29a
N6	0.0807a	2.21a	2.87a	3.14a

Mean separation is by Duncan's New Multiple Range Test. Means in columns having the same letters are not significantly different at P = 0.05.

8.2 PLANT TISSUE ANALYSIS AND N UPTAKE

8.2.1 NITRATE NITROGEN (LABORATORY ANALYSIS)

The relationship between the relative growth of onion plants and the NO_3-N concentration in the leaf blades, bulbs and roots of the plant at different stages of growth is shown in Figures 30, 31 and 32. Plotting the relative growth (the average dry weight of a treatment as a percent of the dry weight achieved in the maximum yielding treatment within the

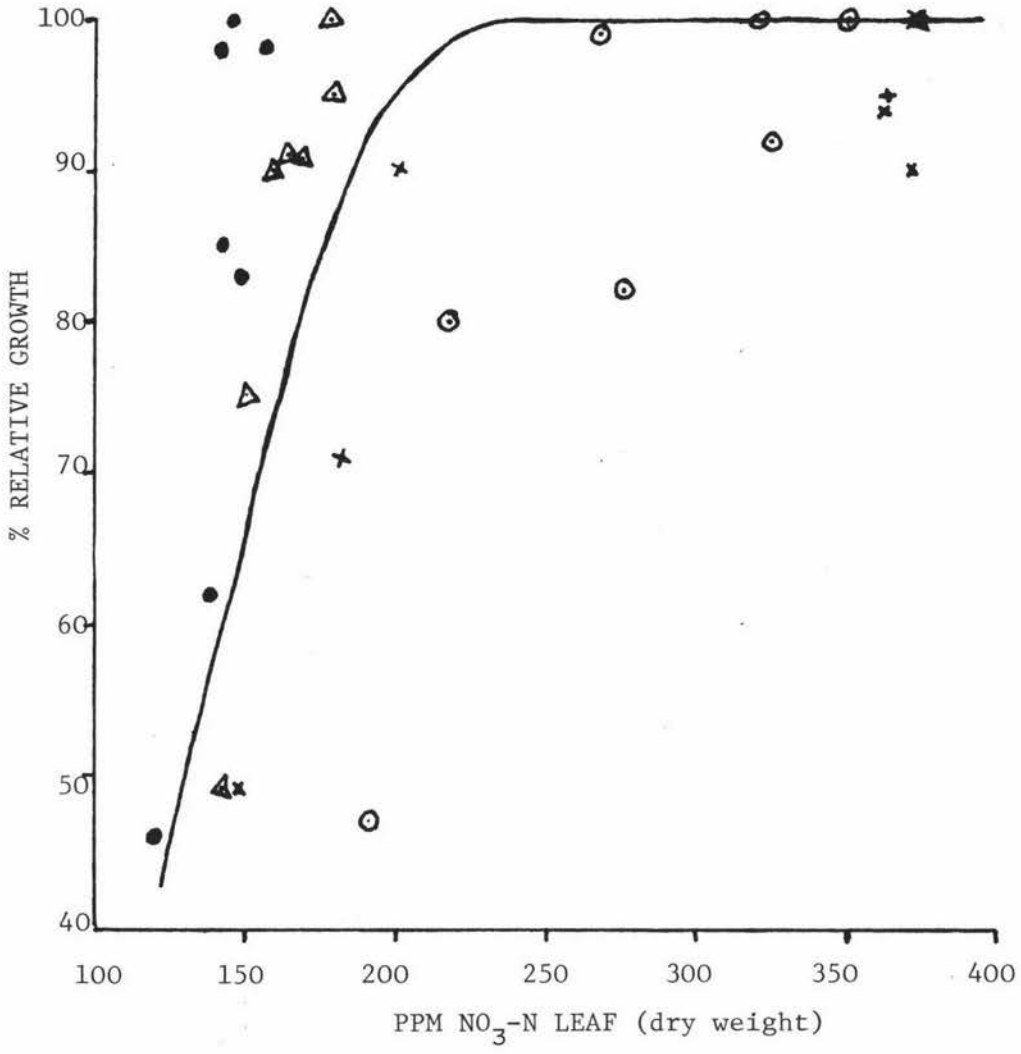


FIG. 30. Relative growth of PLK onions as related to NO_3-N concentration in the leaf.

H1, H2, H3, H4.

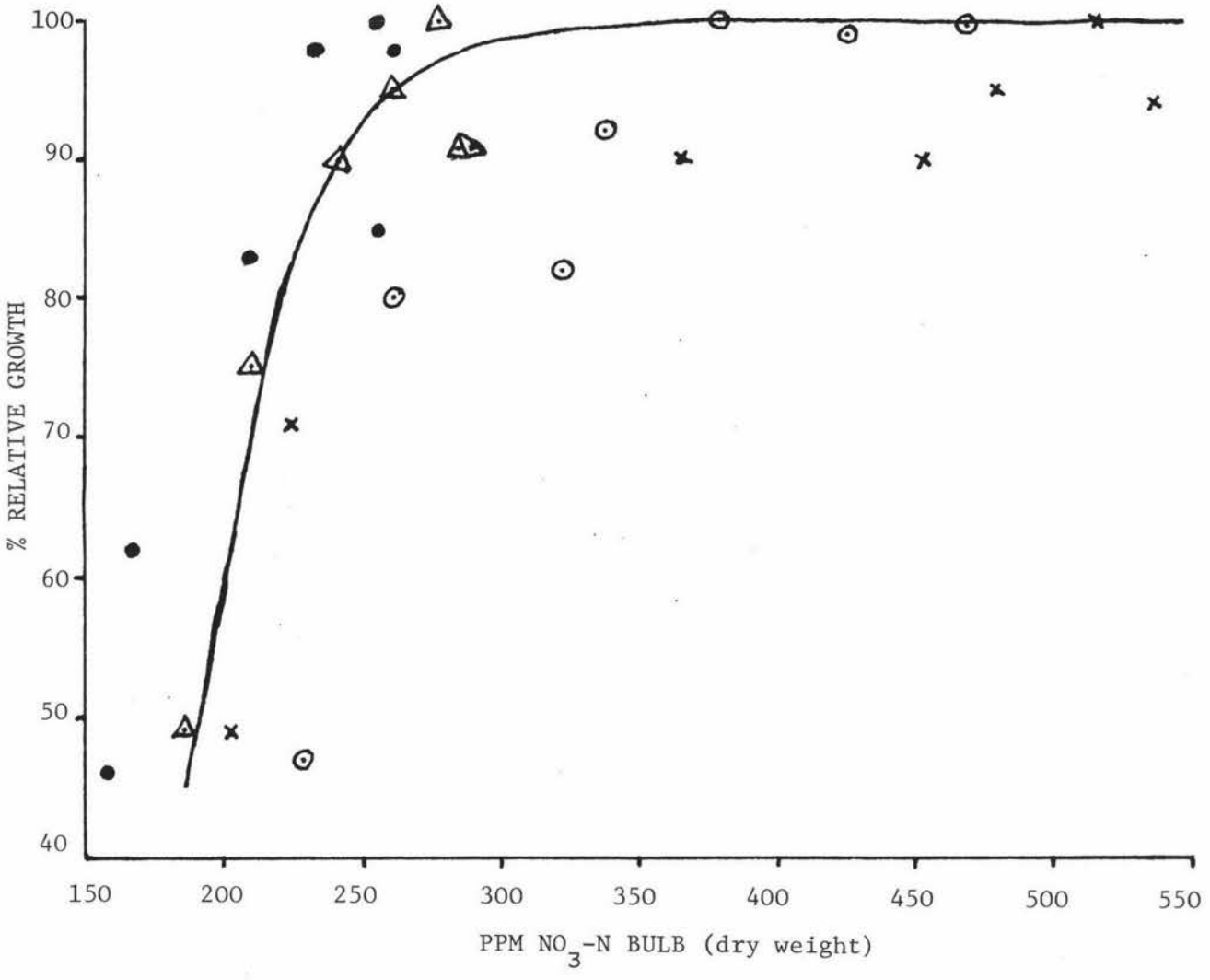


FIG. 31. Relative growth of PLK onions as related to NO_3-N concentration in the bulb.

X——X H1, O——O H2, Δ——Δ H3, ●——● H4.

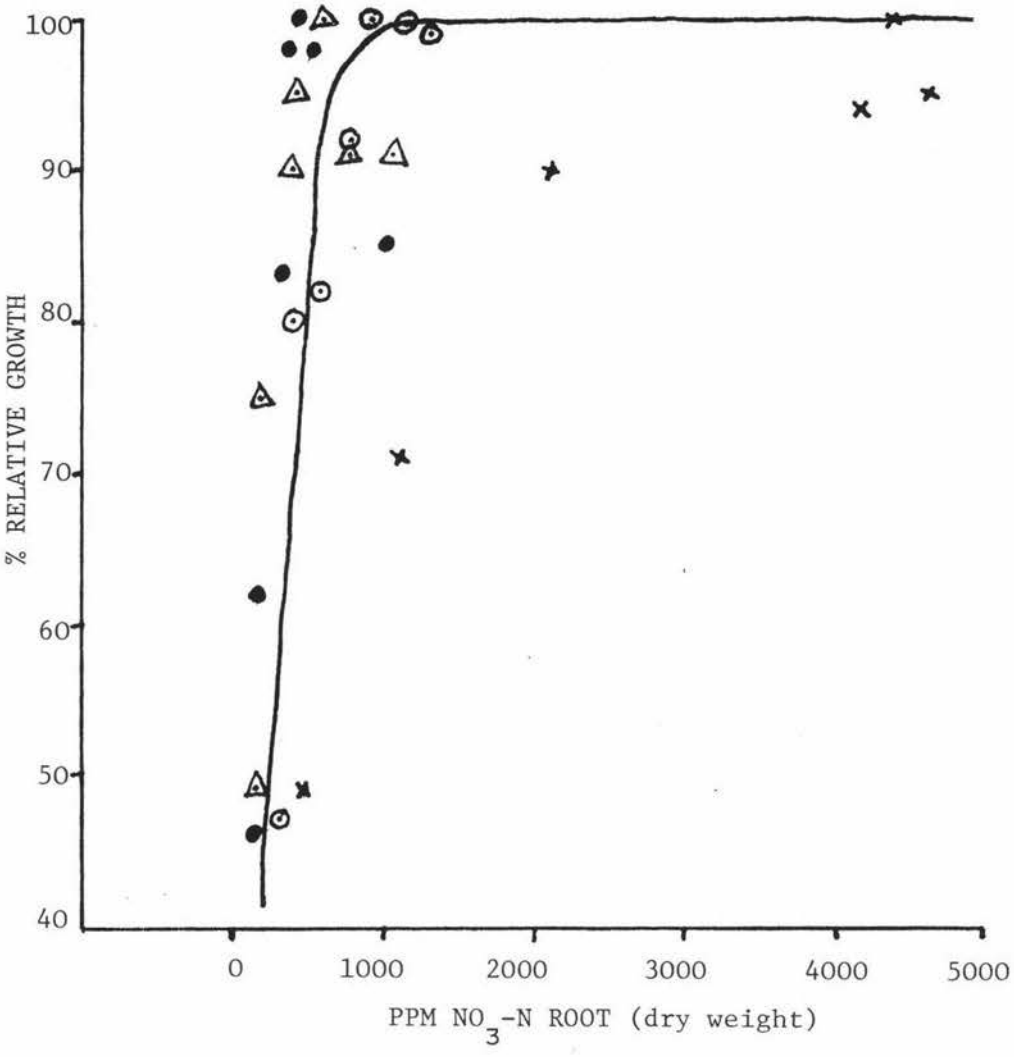


FIG. 32. Relative growth of PLK onions as related to NO_3-N concentration in the root.

H1, H2, H3, H4.

the same experiment) permitted the use of data from two or more growth stages in a single figure. From the curves obtained and assuming that the critical concentration for NO_3-N is that concentration resulting in a 10% restriction in growth, the critical NO_3-N concentration in leaves, bulbs and roots of onions from bulbing to final harvest was established at 190, 240 and 600 ppm NO_3-N dry weight respectively. The root appears to be a better part to sample for monitoring the N status of an onion crop than the other parts with regard to NO_3-N as the NO_3-N concentration in the leaf and bulb are too low (Fig. 33).

In general, NO_3-N concentration in the onion organs declined with age of the plant. The roots accumulated much more nitrate than the bulbs and leaves with the bulbs accumulating slightly more than the leaves. From start of bulbing, only minor changes in the NO_3-N concentration in leaves and bulbs occurred with time. The NO_3-N concentration in the roots, however, declined considerably with time from very high levels early in the season.

Figure 33 shows the $\log_e$ mean NO_3-N concentration of onion leaves, bulbs and roots at various N levels from 60 days after emergence to final harvest. In general, NO_3-N concentration increased with increasing N fertilizer in all the plant parts up to 250 kg N/ha then decreased with further increases in N.

8.2.2 NITRATE-NITROGEN (RAPID TESTS)

The NO_3-N concentration in the fresh onion bulb as recorded with 'Merckoquant' strips was very low (Table 8). Only the first harvest date (60 days after emergence) produced readings with the strips, the rest of the harvest dates recorded zero readings irrespective of the N fertilizer treatment. The No treatment recorded zero readings for all four harvest dates. This method appears to be less sensitive with low levels of NO_3-N in fresh bulb.

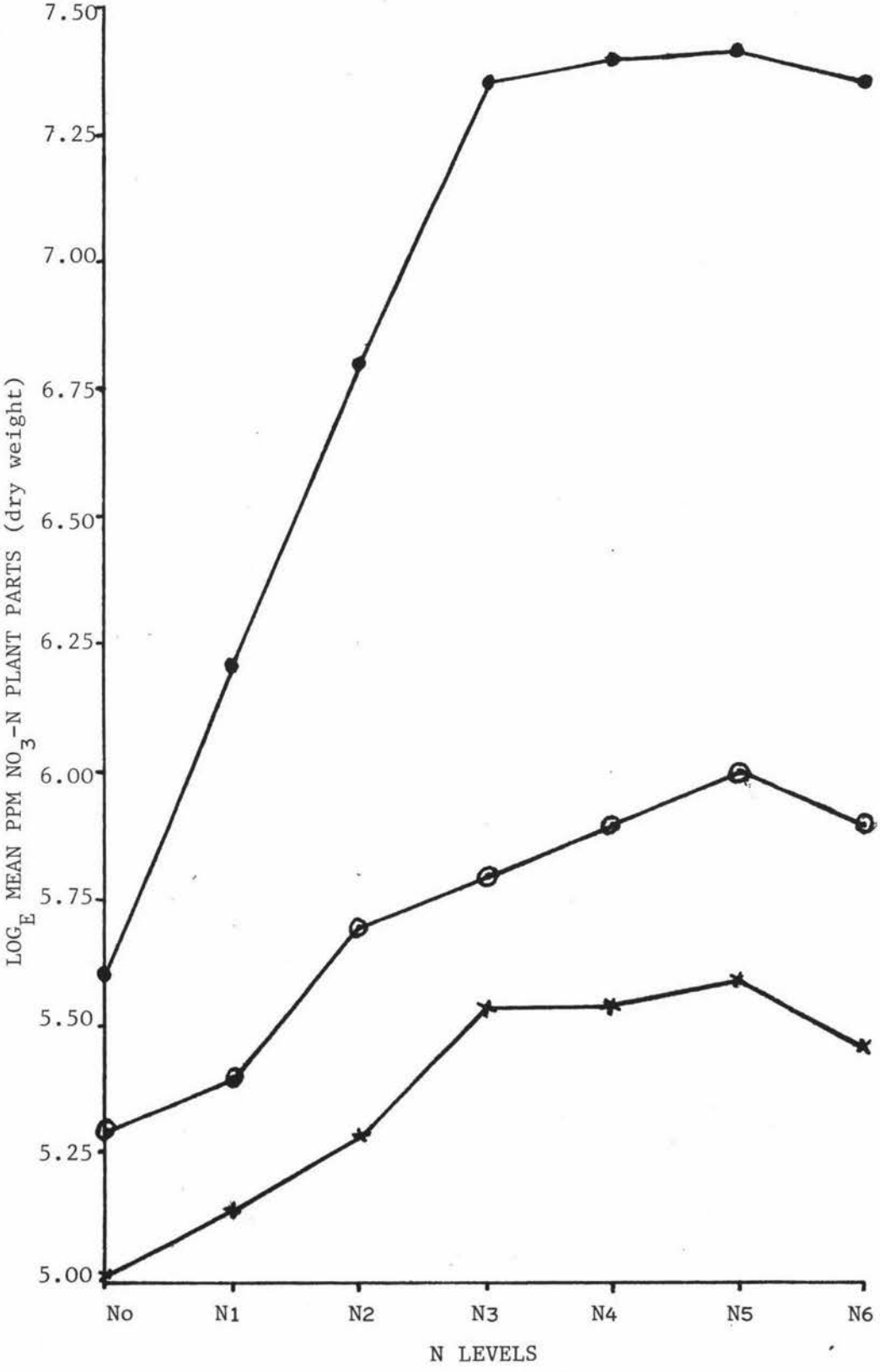


FIG. 33. The influence of N levels on NO_3-N concentration in root (●——●), bulb (⊖——○) and leaf (×——×) of PLK onions.

TABLE 8

EFFECTS OF N TREATMENTS ON NO_3-N CONCENTRATION OF FRESH PLK ONION BULBS MEASURED WITH 'MERCKOQUANT' STRIPS 60 DAYS AFTER EMERGENCE.

	No	N1	N2	N3	N4	N5	N6
FRESH BULB (ppm NO_3-N)	0	0.8	2.3	5.3	17.4	17.4	17.4

8.2.3 TOTAL N

Figures 34, 35 and 36 show the relationship between relative growth of onion plants and total N in the leaves, bulbs and roots at different harvest dates. From the curves obtained, the critical N concentration in the leaves, bulbs and roots were established. The critical concentration in the leaf blades ranged from 4.45% N early in the season to 3.20% N later in the season. When the bulb was sampled, the critical concentration was established at 1.92% N from 60 days after emergence to final harvest. Minor changes occurred in total N concentration in the bulbs with harvest date, hence only one critical concentration figure. The critical concentration in roots ranged from 3.65% N early in the season to 1.95% N late in the growth season. This is a very big range and is due to the relatively high N content in the roots early in the season which dropped markedly later in the season as maturity approached. In general, total N in the leaves, bulb and roots declined with plant age for all N treatments.

The leaves appear to have the highest total N concentration followed by the roots, then bulbs, throughout the growth period (Fig. 37). In general, total N in the onion plant parts increased

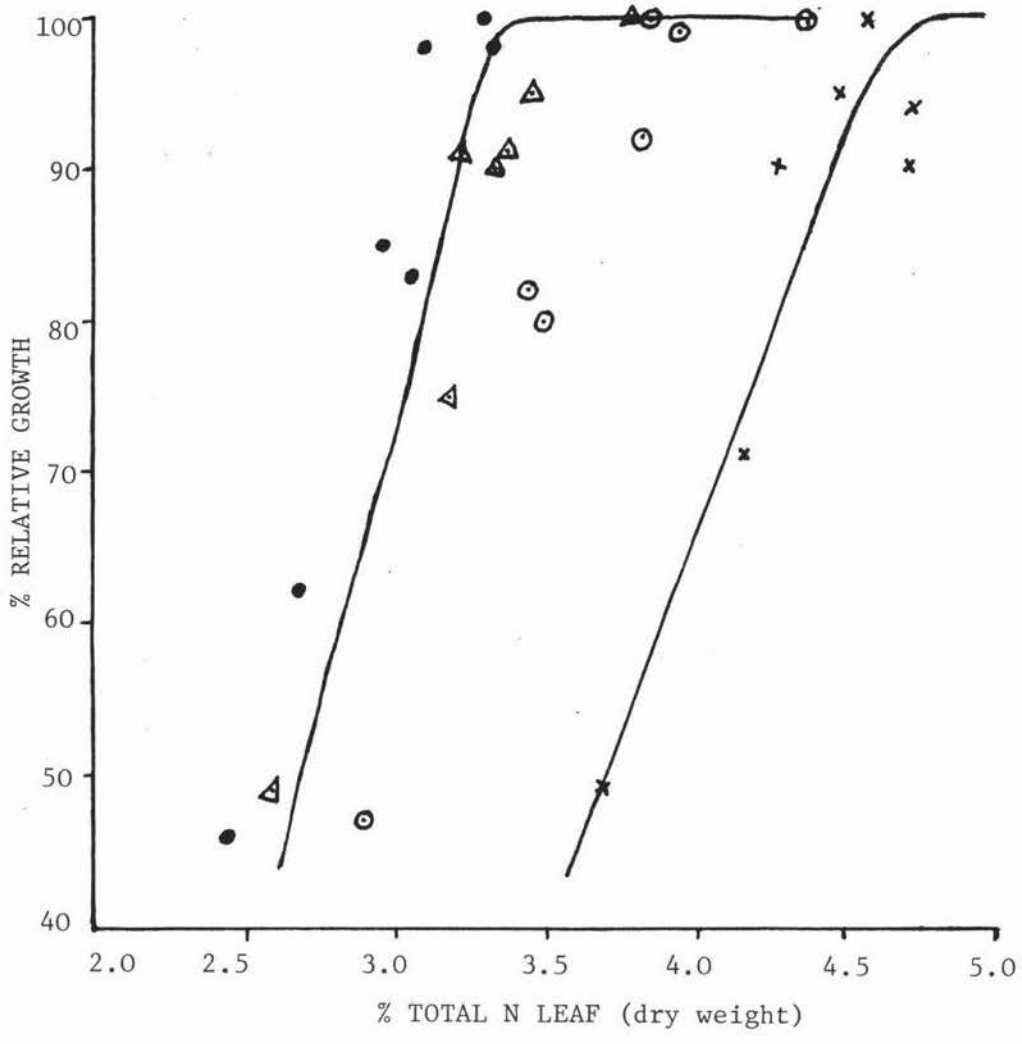


FIG. 34. Relative growth of PLK onions as related to total N concentration in the leaf.

H1, H2, H3, H4.

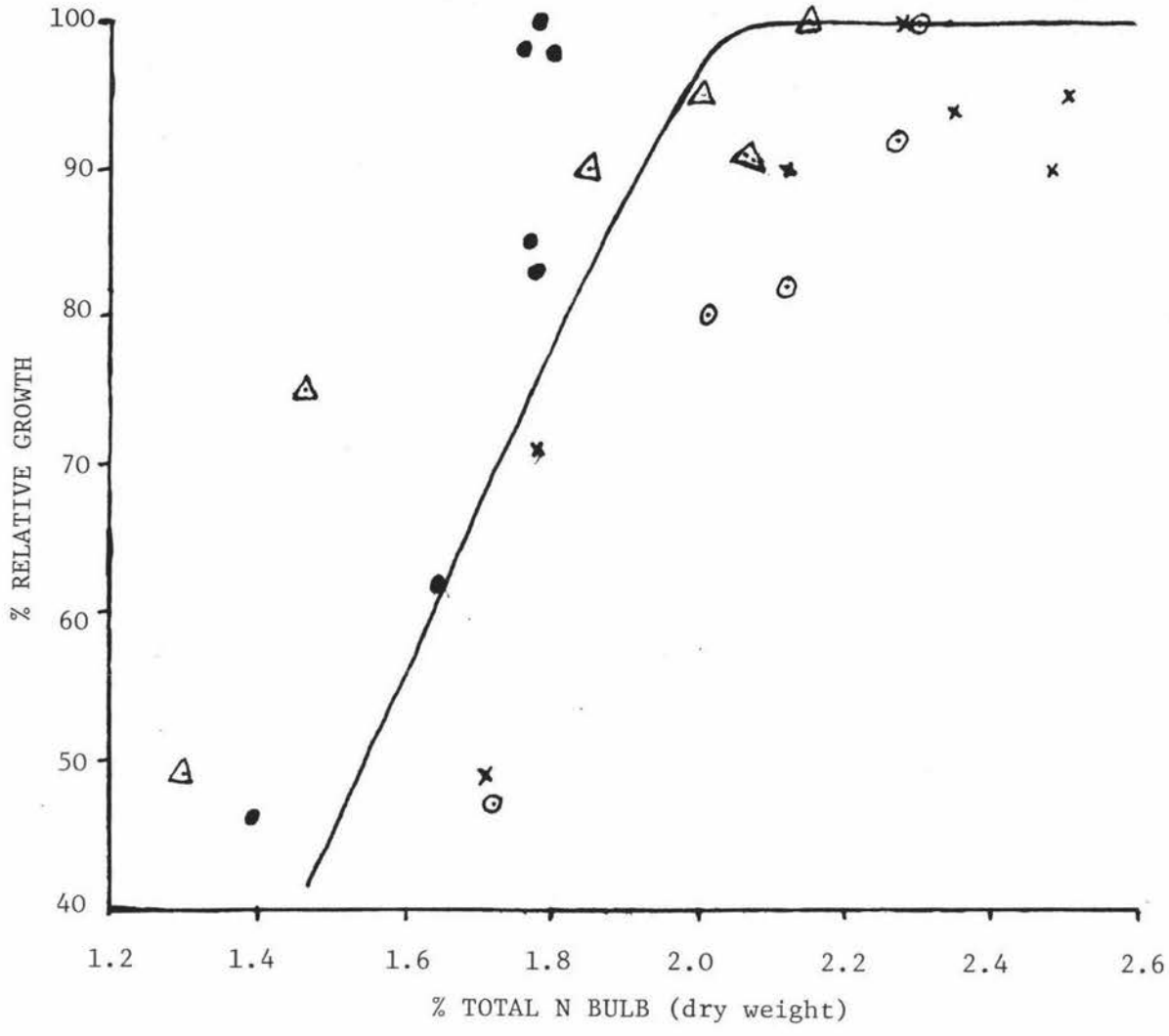


FIG. 35. Relative growth of PLK onions as related to total N concentration in the bulb.

H1, H2, H3, H4.

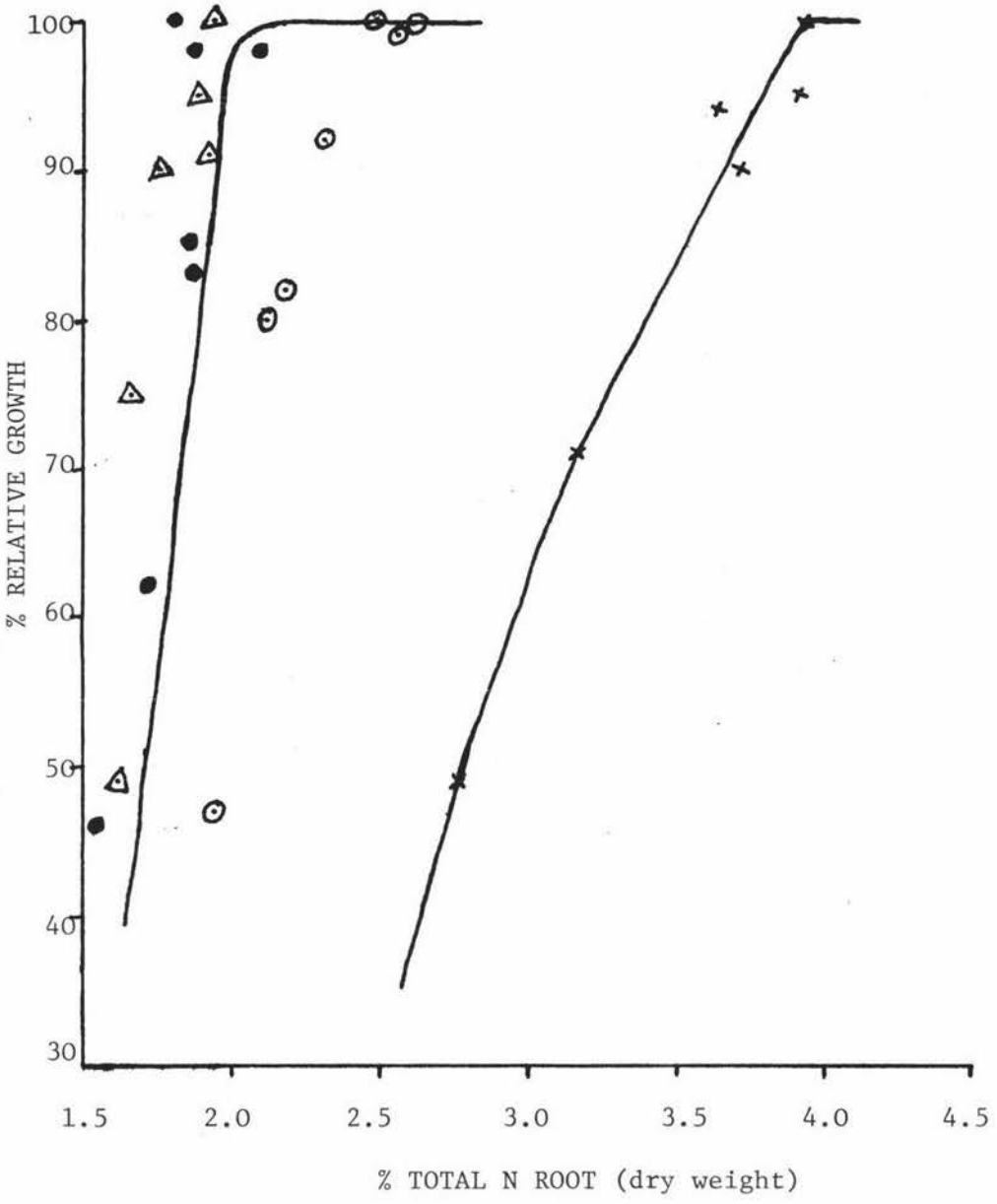


FIG. 36. Relative growth of PLK onions as related to total N concentration in the root.

H1, H2, H3, H4.

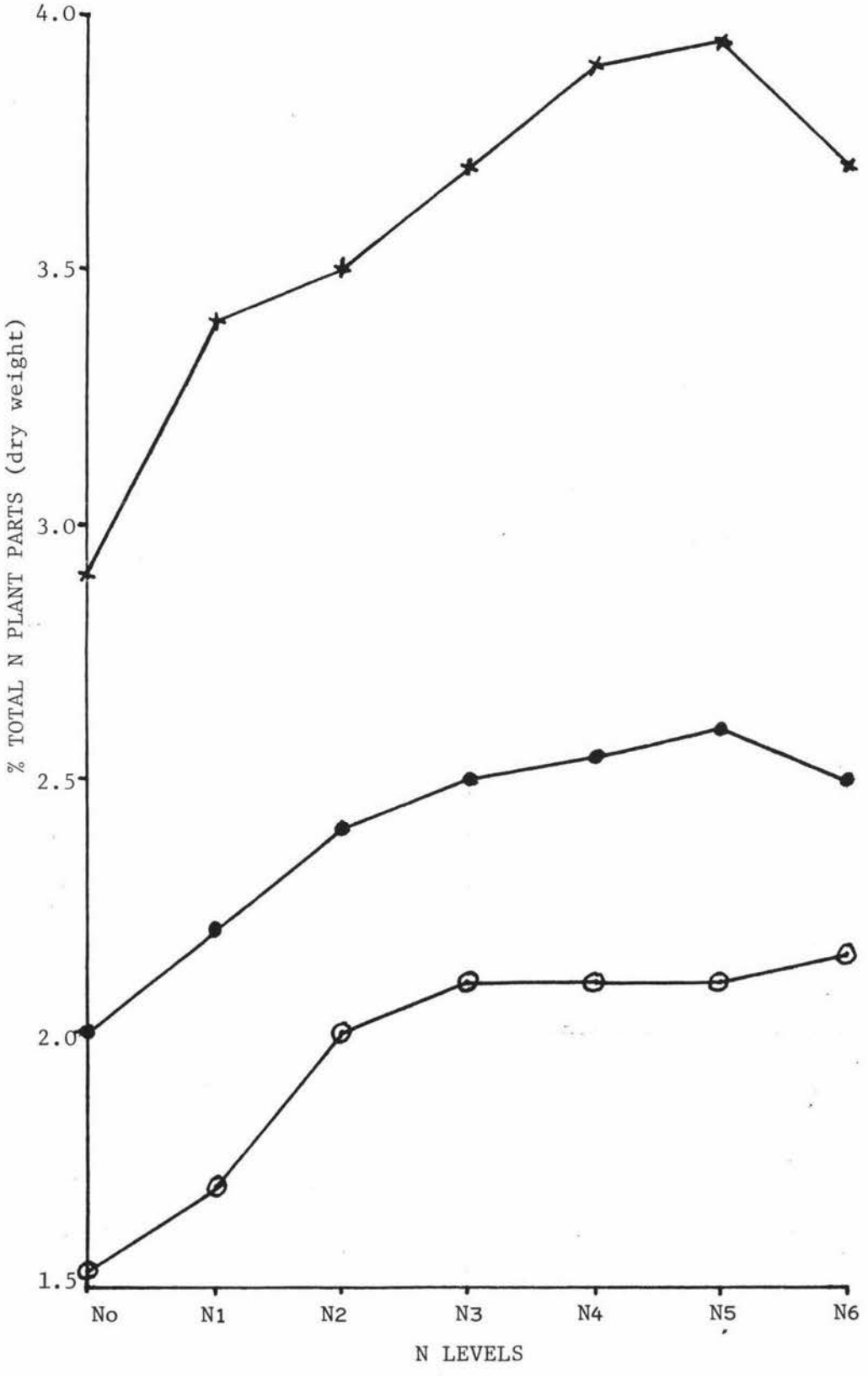


FIG. 37. The influence of N levels on total N concentration in leaf (✕——✕), bulb (○——○) and root (●——●) of PLK onions.

with increasing N fertilizer. Total N declined in the leaves and roots but increased in the bulbs as maturity approached. The explanation is that the senescing leaves and roots passed their N to the growing bulb as the plants advanced in age.

A significant positive correlation was found between the NO_3-N concentration and total N in the leaf (R = 0.73), bulb (R = 0.44) and root (R = 0.84). The NO_3-N and the total N were better correlated in the roots than in the leaves or bulbs.

8.2.4 Nitrogen Uptake

Figure 38 shows the effect of N treatments on the amount of N removed by whole onion plants at different harvest dates. The N removed was calculated from the percent N concentration of the total crop times the total dry matter weight for each harvest date. The high N treatments removed more N than the low N treatments in most of the harvest dates. This was mainly due to the result of bigger plants and higher N concentration in the high N treatments than in the low N treatments.

In the early growth stages the rate of N removal was very slow. The amount of N removed 60 days after emergence ranged from 8-10% (depending on N rate) of the entire N removed by the crop. The highest amount of N removed was recorded 90 days after emergence, when the tops had their maximum leaf area and leaf number and the bulbs rapidly expanding. The total N absorption, in kg/ha, for each treatment is shown in the final harvest in Figure 38. The very high N rates, N5 and N6, removed N at a slower rate than the other high N treatments as maturity approached, probably because of earlier bulb maturity resulting in smaller plants at the final harvest date compared to the other high N treatments (N3 and N4).

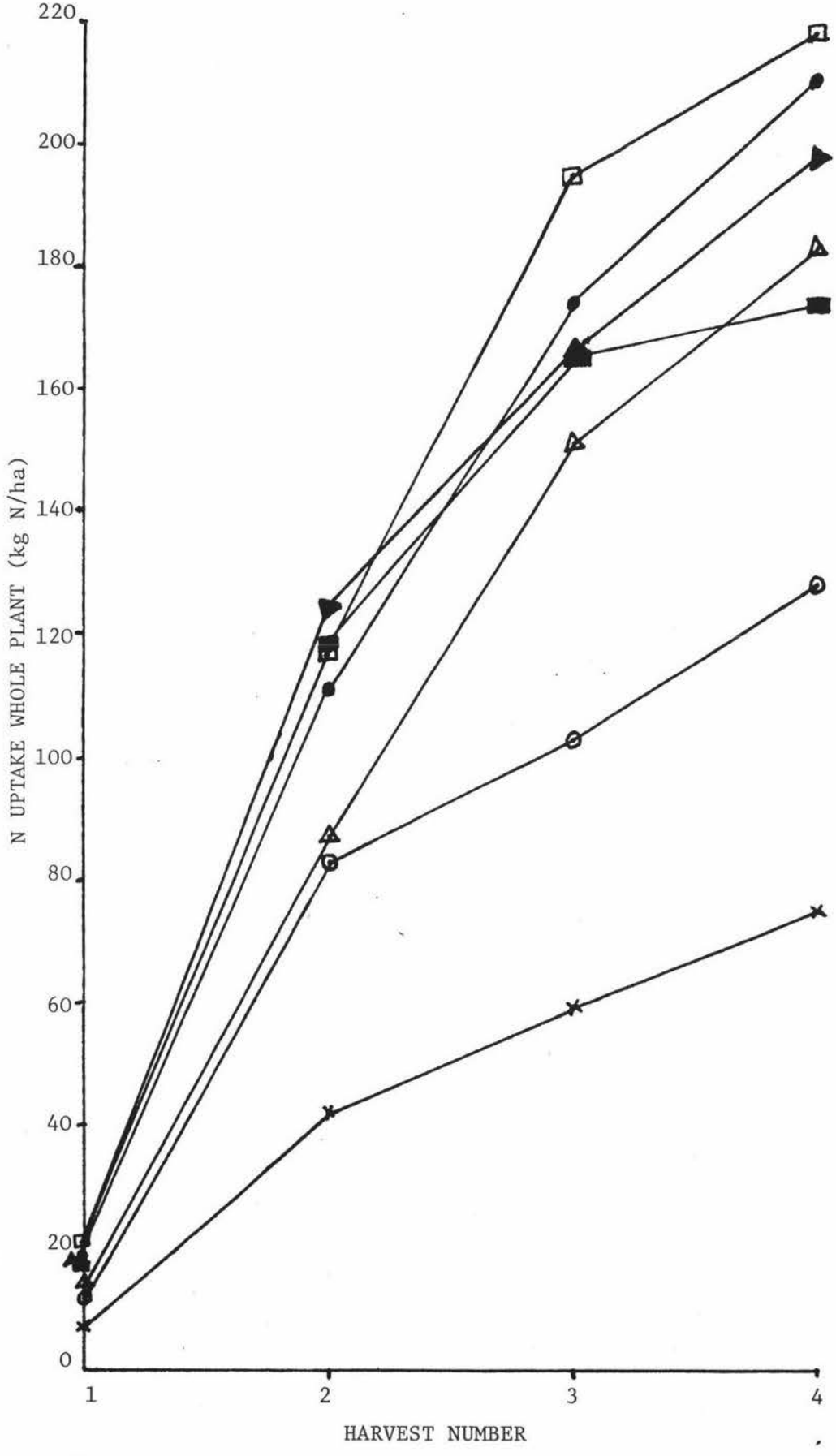


FIG. 38. Nitrogen absorption by PLK onions during crop growth.
No, N1, N2, N3, N4, N5, N6.

In most cases the amount of N removed was more than the amount of N applied, particularly for the low N treatments due to the fertile nature of the soil. However, in soils with very low N levels, the minimum amount of N that should be applied for maximum growth is 218 kg N/ha. In most soil conditions, the predicted optimum N rate is approximately 200 kg N/ha.

Figure 39 shows a linear relationship between bulb yield and N absorption by bulbs. Over 90% of the total N removed by the whole plant was by the bulb part.

Figure 40 shows the relationship between the amount of N applied and the amount of N absorbed. The amount of N removed by whole plants increased linearly with increasing N fertilizer up to 200 kg N/ha, then decreased with further increases in N.

8.3 Bulb Storage

Table 9 shows the effect of N fertilizer on weight loss of onion bulbs stored under high or low temperature conditions. It is apparent that bulbs stored under high temperature lost more weight during the 4 months storage period than bulbs stored under low temperature condition. Weight loss did not follow a consistent trend with increased N fertilizer. Analysis of variance on the data for both high and low temperature storage showed no significant difference ($P = 0.05$) in percent weight loss between N levels.

Bulb decay during the storage period was very insignificant under both storage conditions although bulbs under high temperature condition were slightly higher than bulbs under low temperature condition. No significant difference between N treatments was observed under both storage conditions.

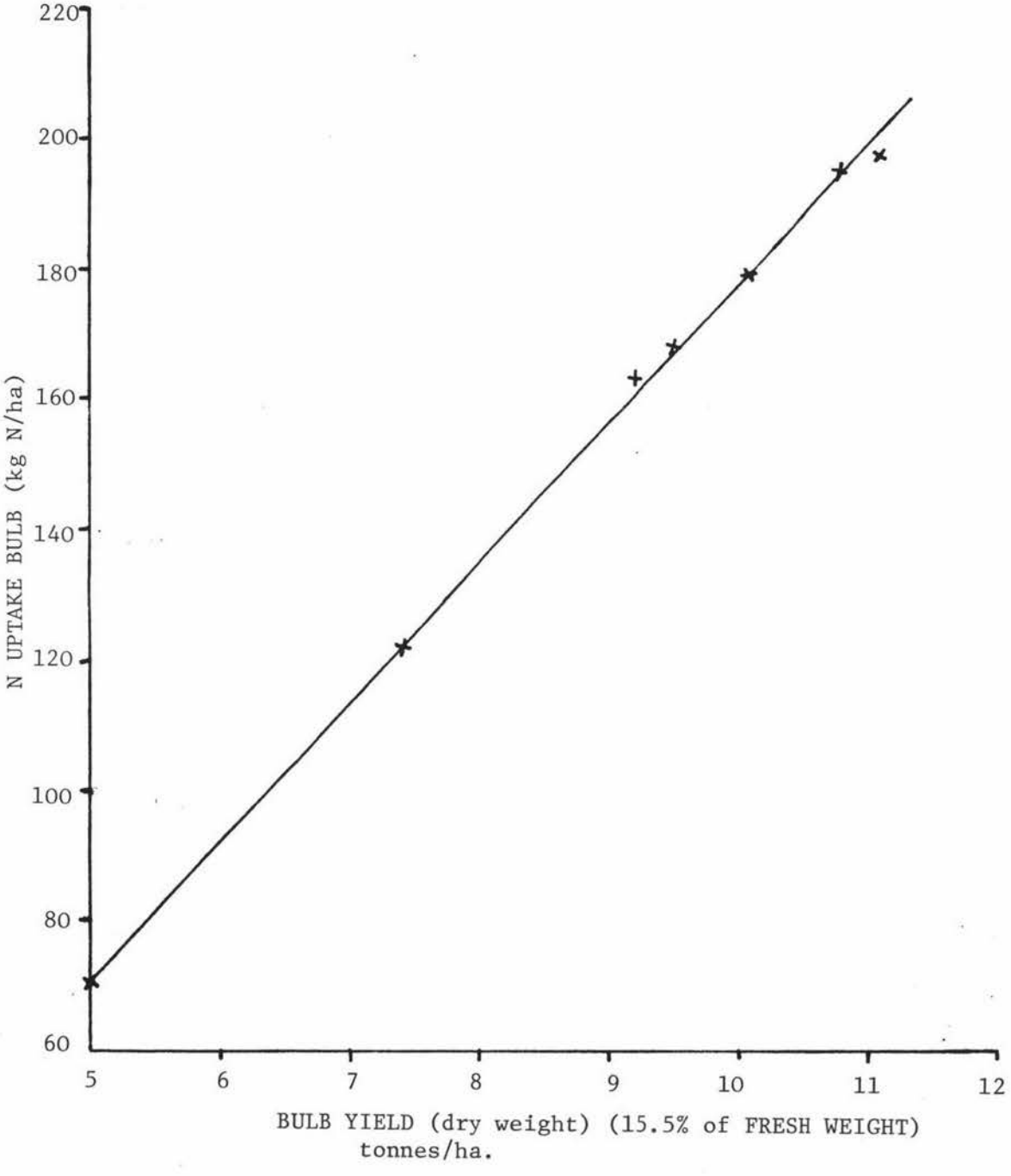


FIG. 39. Relationship between amount of N absorbed by bulb and bulb yield.

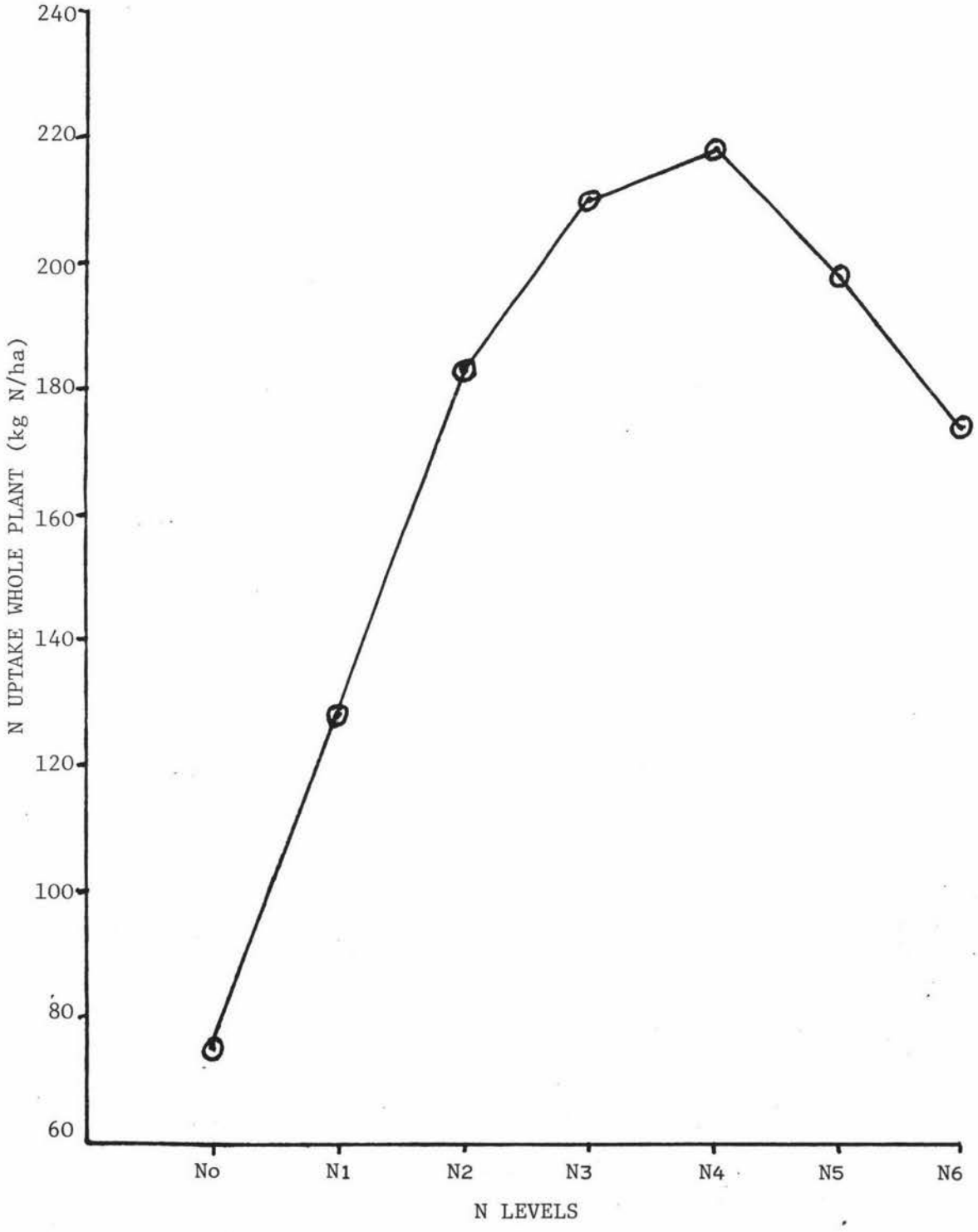


FIG. 40. The influence of N levels on the amount of N absorbed by whole plant PLK onions.

Very few bulbs sprouted under both conditions during the storage period. There was also no significant difference between N treatments under both storage conditions.

Root growth of bulbs was absent under high temperature condition during the storage period. It was, however, very high under low temperature storage. In general, the high N treatments had higher percent root growth of bulbs than the low N treatments. The probable reason for the high percentage root growth under cool storage lies in the fact that the bulbs were stored in perforated plastic bags in a room with very high, uncontrolled relative humidity.

TABLE 9

EFFECTS OF N TREATMENTS ON PERCENT WEIGHT LOSS OF PLK ONIONS STORED UNDER HIGH OR LOW TEMPERATURE CONDITIONS.

	No	N1	N2	N3	N4	N5	N6
HIGH TEMPERATURE	7.25a	6.14a	6.39a	6.41a	6.93a	6.00a	6.99a
LOW TEMPERATURE	1.63a	1.33a	1.48a	1.33a	1.62a	1.88a	1.78a

Mean separation is by Duncan's New Multiple Range Test. Means in rows having the same letters are not significantly different at P = 0.05.

CHAPTER 9

GENERAL DISCUSSION

9.1 Growth and Development Characteristics

It was established from both the greenhouse and field experiments that the fresh weight and dry weight of a PLK onion plant increased with time, reaching maximum at the end of the growing period. Entire plant fresh and dry weight increased slowly early in the season but from bulbing to final harvest increased sharply. Zink (1966) found a similar result with Southport White Globe onions. As maturity approached, the rate of increase of plant fresh weight was found slower than the rate of increase of plant dry weight. This was due to the fact that during this period the plant consisted mainly of bulb which is very high in dry matter compared to leaves which formed a larger proportion of the plant in the earlier stages of growth.

In the field experiment plant fresh and dry weight increased with increasing N fertilizer up to 200 kg N/ha, then decreased with further increases in N. A similar response pattern was also observed in the Greenhouse trial. In general, plots with no N or lower N treatments had a significantly lower fresh and dry weight per plant than plots with high N treatments for most harvest dates.

Onion root growth appeared to be favoured more by low N treatments than by very high N treatments. This supports Hamner and Bartz (1963) contention that lower nutrient status of the soil tended to give deeper rooting systems for onions. However, where N was very deficient, root growth was severely restricted. This was clearly shown in the greenhouse experiment where plots with no added N had plants with very small root systems, much smaller than the highest N treatment. Thus, as pointed out by Russell (1961), if soil is very poor in a nutrient, all growth, including root growth, may be severely restricted. It is there-

fore apparent that sufficient N is necessary for optimum root growth in onion production.

Leaf growth measured in terms of green leaf number, green leaf area and leaf dry weight per plant increased rapidly in the early stages of growth until a peak was reached, then declined as maturity approached. The decline was attributed to the inhibitory effect of bulbing on new leaf initiation and emergence and the dying of older leaves as maturity approached. Leaf growth generally increased with increased N fertilizer.

Leaf area was found to be highly correlated to leaf number. This is not surprising since leaf area is the result of leaf number and leaf size (leaf length x leaf diameter) (Butt 1968), and changes in leaf area depended on how far N levels affected these components. The high N treatments attained maximum green leaf area and green leaf number earlier than the low N treatments. This was probably due to a faster leaf growth induced by high N treatment.

Leaf growth was also faster in the greenhouse experiment than in the field experiment. Maximum leaf area and leaf number was reached approximately 70 days after emergence in the greenhouse and approximately 90 days after emergence in the field experiment. The higher temperature in the greenhouse explains the faster growth rate. Also, N deficiency symptoms in the leaves were more pronounced in the greenhouse than in the field. The media, the restricted root growth and the higher temperature condition in the greenhouse accounts for the difference. Prasad (1980) showed that the retention and release of N by NZ peats is very low. Milthorpe (1963) suggested that at high temperatures the rate of leaf production is higher, and the plant is unable to maintain the supply of nutrients required by them, consequently each leaf does not grow as large.

The growth of the bulb is of paramount importance to the grower because it ultimately determines the final yield of an onion crop. Thus the influence of N on the growth and development of the bulb must be of great interest to the grower. Bulb dry weight increased with increasing N fertilizer up to 200 kg N/ha then decreased with further increases in N in the field experiment. A similar response pattern was also found in the greenhouse experiment. The plots with no N or low N levels had significantly lower bulb dry weight per plant than the high N levels.

Bulb weight increased with time reaching maximum at the end of the season. In the early growth stages bulb growth was very slow. Approximately 90 days after emergence only 2 to 3% of the ultimate bulb dry weight was produced in the field experiment. It should be noted, however, that in the early stages of growth (up to 56 days after emergence in the greenhouse experiment) there was no bulb development in the real sense but merely a slight swelling of the false stem which can occur even under short daylengths (Butt 1968). Most of the final bulb weight was produced during the period when the leaves were drying and bulbs maturing. Zink (1966) found a similar result. Thus, bulb growth should not be limited during this period by lack of N otherwise final yield will be reduced.

Low N levels tended to stimulate earlier bulb formation than high N levels. However, as development progressed, the continued lack of sufficient N drastically limited bulb growth and yield in the low N treatments. Scully *et al* (1945) also established that high N fertilizer reduced relative bulb formation and a low level promoted bulbing near the critical daylength for bulb formation. Similar results were also reported by Bremer (1936). Also, Wilson (1934) showed that large quantities of soil nitrates tended to delay bulb formation and reduce yields. In this study, however, no yield advantage was gained from earlier bulbing by the low N treatments. Thus it is not advisable to

lower the N level in the early growth stages of onions to obtain earlier bulbing since this may limit maximum leaf growth later.

The onion bulb is a storage organ, it cannot make its stored material but depends on the other plant organs, roots and leaves, for supply. Thus the bulb serves as an intense sink for the accumulation of photosynthates and nutrients. It is therefore apparent that when leaf and root growth are limited by lack of N, especially in the early growth stages, the ultimate bulb yield will also be limited.

Bulb maturity, measured in terms of percentage fallen tops was hastened by very high N rates. This primarily caused the decrease in bulb dry weight in the very high N rates in the field experiment. In the greenhouse experiment bulb dry weight was reduced in the highest N rates because of N toxicity and the earlier maturity. It was also found that severe N deficiency, exemplified by the No N plots in the greenhouse experiment, prevented normal bulbing and maturity. Wilson (1934) found similar results. Rickels (1977) reported that maturity was delayed when N was limited with high moisture conditions but noted that it was controlled more by the moisture supply than by N.

Extending the duration of leaf cover at the end of the season has been found useful in onion production. Hewson (1971) showed that four weeks' growth of onions at full leaf cover and maximum crop growth rates represented about 476 g m^{-2} of dry matter. Lorenz and Hoyle (1946) noted that the senescing leaves increased bulb dry matter concentration by both translocating dry matter into the bulb and withdrawing water from it. Brewster *et al* (1977) showed that delaying harvesting by one week increased yield. Also Romanowski (1962) reported 15 to 20% increases in yield as a result of delaying harvest from 80 to 90% die down until only two or three leaves remained green. It is therefore important that onion plants are left until bulbs are fully mature before harvesting since a very high proportion of the total yield of onions is diverted into bulbs if the

plants are left to mature fully. Thus by avoiding application of excess N and controlling moisture supply (Riekels 1977), bulb maturation can be regulated to attain maximum possible leaf cover and yet ensure full bulb maturity.

The high N treatments were found to have heavier bulb weight and larger bulb diameter than the low N treatments. Similar results have been reported by Sypien *et al* (1973) and Hassan (1977). Bulb size was highly correlated with bulb yield. Both bulb size and bulb yield increased with increasing N rates up to 200 kg N/ha then decreased with further increases in N in the field experiment. A similar N response was obtained in the greenhouse experiment. Bulb weight of the very high N rates declined in the field trial because of earlier maturity resulting in less time for the bulbs to develop fully - shorter bulbing period.

Yield was reduced in the very high N levels in the greenhouse experiments presumably because of N toxicity and the effect of earlier maturity discussed above. However, in the field experiment N toxicity was of less importance in yield reduction in the very high N treatments because of the use of a slow release fertilizer, Gold N. With the use of this sulphur coated urea it was possible to perform only one basal application of N which was sufficient for growth of a long term crop like onions, yet avoided an excessive concentration of N in the soil solution. The slow release fertilizer was placed 5 to 8 cm beneath the row at sowing to ensure that the shallow roots of the onion plant got to it. There was therefore increased efficiency of N use by the crop through control of luxury uptake resulting in higher yields. Thus the high cost of the slow release fertilizer was offset by savings from the otherwise expensive split applications and the high yield obtained.

Apart from bulb size, other bulb quality parameters such as splits, doubles, neck thickness, etc. were not influenced by different N levels.

Onion growth and development expressed in terms of Growth Analysis showed the mean of the Relative Growth Rate, the Net Assimilation Rate and the Leaf Area Ratio of the plots with no N added significantly lower than the plots with N added. A good relationship was found between total RGR and bulb RGR. Both increased with increasing N fertilizer levels up to 200 ppm N in the greenhouse experiment then decreased slightly with further increases in N.

Total RGR (change in total plant dry weight per unit total plant dry weight per unit time) measures the efficiency of the plant as a producer of new material (Blackman 1919). It is the product of NAR (change in total plant dry weight per unit of leaf area per unit of time) and LAR (the ratio of the leaf area to the total plant dry weight) (Briggs *et al* 1920). Thus increases in RGR brought about by changes in N fertilizer will be dependent on changes induced on NAR and LAR. In this study, RGR was found to be mainly determined by LAR. Watson (1952) also showed that in general fertilizer responses (mainly of cereals) were due to increases in LAR. In contrast, Austin (1963) working with carrots reported that the increase in RGR is due to increasing NAR. Similarly, Nichols (1971a and b) working with radish and lettuce showed that the response to P fertilizer was due to a higher NAR. Austin (1963) argued that small percentage variation in NAR missed by Watson because of delayed sampling, has as much effect on yields as a considerably greater percentage variation in LAR. However, Eagles (1971) showed that the relative contributions of LAR and NAR to RGR varied with physiological stage of plant development.

The mean RGR and LAR of onions decreased with time but mean NAR showed a rather inconsistent trend with time. NAR was, however, constant in the early stages of growth. Briggs *et al* (1920) showed for certain annual plants that the LAR exhibited an ontogenetic drift essentially similar to that of the RGR and that consequently the NAR change relatively little during a large part of the life cycle of the plants.

LAR is the product of SLA (mean area of leaf displayed per unit of leaf weight) and LWR (leaf dry weight per unit of total plant dry weight) (Evans and Hughes 1961). In a broad sense, LAR represents the ratio of photosynthesizing to respiring material within the plant (Hunt 1978). This concept enables differences in LAR to be attributed to either (i) the differences in leaf thickness, or (ii) the differential distribution of photosynthetic products between leaf growth and other plant growth (Radford 1967). In this study the increase in LAR caused by increases in N fertilizer levels was due mainly to an increase in LWR. Under low light intensity, Blackman (1956) noted that the increase in LAR was largely dependent on changes in SLA, and that LWR remains relatively constant. At low light intensities the plants had much longer but narrower leaves. However, Butt (1968) found that in onions, LWR contributes to changes in LAR besides SLA.

9.2 Plant Tissue Analysis and N Uptake

The critical concentration of a nutrient or nutrient fraction within the plant or some plant part is the concept used in interpreting plant analysis results. It is the critical level at which 90% of the maximum growth and yield is produced (Ulrich and Hills 1967). A number of factors affect the critical nutrient concentration and these have been reviewed by Bates (1971). However, Scaife and Barnes (1977) noted that the critical concentration if defined in terms of percent growth rate depression, would possibly be found to be much less variable than it now seems.

Thus the critical concentrations for onions were established in this study from the relationship between Relative Growth and the NO_3-N and total N concentrations in the leaf, bulb and root of the greenhouse and field experiments. The critical NO_3-N concentration in the leaf blade ranged from 850 ppm NO_3-N dry weight early in the season (up to 6 weeks after emergence) to

190 ppm NO_3-N dry weight late in the season from bulbing to final harvest. Similarly, the critical NO_3-N concentrations for bulbs were established from 800 ppm NO_3-N dry weight early in the season to 240 ppm NO_3-N dry weight late in the season. For roots, the critical NO_3-N concentrations ranged from 600 to 800 ppm NO_3-N dry weight throughout the growth period.

In general, NO_3-N concentrations in the onion leaf, bulb and root declined with plant age. The NO_3-N concentrations in the roots varied much less than the leaves or bulbs between the early and late growth stages.

In practice the leaf blades or bulbs are commonly sampled at mid-growth for establishing the nutritional status of the crop. As such, the lower critical NO_3-N concentrations found for leaves and bulbs in the late season should be used. However, these critical NO_3-N concentrations are very low and can only be regarded as traces of NO_3-N. Very sensitive methods of plant analysis are necessary to determine these critical NO_3-N concentrations. The critical NO_3-N concentrations found for leaves and bulbs early in the season appeared to be alright but in most cropping situations, sufficient nutrients are applied in the early growth stages and so monitoring N status during this period is generally unnecessary. Thus, sampling leaf blades or bulbs for NO_3-N analysis is not a very good reliable method for guiding a nitrogen fertilizer programme for onions. Similarly, Zink (1966) found NO_3-N content of onion plants was 0.18% shortly after emergence but declined to 0.015% dry weight (trace) later in the growth of the crop.

Onion roots appeared to be a better part to sample for NO_3-N analysis for determining the N status of the crop. The accumulation of nitrate in onions was found to be very much higher in the roots than in the leaves or bulbs throughout the growth period. The NO_3-N concentrations in the leaves and bulbs were more or less similar. The higher nitrate-nitrogen

concentration in the roots indicates that nitrate is reduced in the roots in onions. However, the difficulty of sampling roots in the field for NO_3-N analysis makes it less attractive for monitoring the N status of the crop.

Nitrate accumulation in plants is dependent on and related to the genetic make-up of the plant, the nitrate supplying power of the soil and the environmental conditions under which the plant is grown (Maynard *et al* 1976). With onions, it appears that the genetic effect plays a more predominant part in nitrate accumulation. Irrespective of the N level, NO_3-N in the leaves and bulbs was very low. The NO_3-N concentrations in the plant parts were slightly higher with plants in the greenhouse experiment than in the field experiment. This was probably due to differences in environmental conditions and source of N fertilizer used in these trials. As slow release N fertilizer was used in the field trial, there were less chances of unnecessary nitrate accumulation in the plant parts at any particular growth stage. Critical concentrations determined in the greenhouse may on occasions be satisfactory for the field (Bates 1971) but there is sufficient evidence and opinion to the contrary. Thus, it is important that greenhouse determinations are supported with field determinations.

Plants absorb most of their nitrogen from soil as nitrate and in most species is moved in this form to the leaves where it is reduced to ammonia and then combined with carbohydrate to form amino acids, amides and then proteins. Nitrate is therefore a raw material of new leaf growth and its concentration is a very sensitive indicator of the ability of the plant to find enough N to meet immediate demands (Scaife and Stevens 1977). If N supply exceeds demand, nitrate accumulates in the plant and when the reverse is true, nitrate rapidly disappears. However, some crops reduce most of their N to amino acids and amides in the roots so very little nitrate is to be found in the shoots. Onions, in this study appear to fall in this latter

category as the accumulation of nitrate was found to be very much lower in the leaves and bulbs but higher in the roots during most of the growth period.

Nitrate-nitrogen in the sap of the fresh onion bulb was measured in the field with 'Merckoquant' test strips. This is a rapid, simple, inexpensive method for nitrate testing adapted for monitoring nitrate concentration in plant sap (Scaife and Stevens 1977). In this study the fresh bulbs were sampled rather than the leaves because of easier sap extraction and to avoid the problem of chlorophyll masking the colour change. Furthermore, preliminary investigations showed that the bulbs accumulated slightly more nitrate than the leaves.

The NO_3-N concentration in the fresh bulb also declined with age of the plant. In fact, it was only in the early growth stages (up to 70 days after emergence) that any recordings were obtained with the 'Merckoquant' test strips. The later growth stages that really matter in minitoring the N status of the crop showed zero NO_3-N readings with the 'Merckoquant' test strips, irrespective of the N treatment. This was probably due to the very low NO_3-N concentration in the onion bulb and that the 'Merckoquant' test strips were not sensitive enough to pick up the differences between the N treatments. Probably, the roots with higher NO_3-N concentration would have given a better result but the practical problems posed by the sampling of roots in the field will limit its use. It appears therefore, that the laboratory method is a much more sensitive method for monitoring NO_3-N in low nitrate accumulators like onions. Nevertheless, the results obtained with the 'Merckoquant' test strips in the early growth stages when NO_3-N concentration in the fresh bulb was relatively high showed a very good indication of the N nutritional status of the crop. This suggests that the use of 'Merckoquant' strips for quick, easy, cheap nitrate testing in plants, should be a suitable method for monitoring N status in high nitrate accumulating crops. It will be a useful method for

growers and even research workers in developing countries who are mostly handicapped by lack of facilities.

Total N in the leaf, bulb and root to a large extent follows a similar trend to the NO_3-N concentrations in these organs. There was a general decline in total N with time in all the plant parts for the various N levels. Zink (1966) also noted that total N tended to decrease during onion growth and ranged from 4.16 to 1.52%. Geraldson *et al* (1973) found total N in young mature leaf onion at mid-growth ranged from 1.5 to 2.5%. Also total N generally increased with increasing N fertilizer in all the plant parts. In contrast to NO_3-N, total N was found higher in the leaves than in the roots with the bulbs even lower in total N.

The critical total N concentration of onions when the leaf blades, bulbs or roots were sampled was established from both the greenhouse and field trials for the different N levels and harvest dates. The critical N concentration in the leaf ranged from 4.5% N dry weight early in the season (up to 42 days after emergence) to 2.7% N dry weight late in the season. The critical N concentration for bulbs was established from 1.9% N dry weight to 1.6% N dry weight from bulbing to final harvest. That for roots ranged from 3.7% N dry weight early in the season to 2% N dry weight late in the season. The leaves appear to give a better indication of the N status of the onion crop than the bulbs or roots.

A significant, positive correlation was found between the NO_3-N concentrations and total N concentrations in the leaf, bulb or root. However, it appears in this study that monitoring total N rather than NO_3-N in onion plants, in particular, the leaf blades is a much better method for determining the N status of the crop. Nicholas (1956) compared various soluble fractions of a number of nutrients with the total concentrations and in general found that they were closely correlated except in the

range of luxury consumption. Jungk and Wehrmann (1978) showed that in the sub-optimal range of N nutrition an increase in N supply is registered much more sensitively by an increase in NO_3-N concentration in the plant than by an increase in total N. Burhan and Babiker (1968) found NO_3-N in cotton petioles superior to total N. However, Lorenz and Tyler (1978) noted that when N is very low, total N is a better estimate of the nutrient status than is the soluble or nitrate fraction. This supports the result obtained with onions which are very low in nitrate.

The low nitrate accumulation in onions is nevertheless desirable in relation to human health. It means that there is less risk of nitrate poisoning when the bulb or leaves are eaten, even if the crop was grown under very high N levels.

Nitrogen uptake in the field experiment increased with increasing N fertilizer up to 200 kg N/ha then decreased with further increases in N. The removal of N was very slow in the early growth stages. Approximately 60 days after emergence only 8-10% of the total N removed by the crop was absorbed in all N treatments. The largest amount of N removed for all N levels was recorded when the plants had their maximum leaf number and leaf area and the bulbs expanding rapidly. Zink (1966) obtained a similar result. Geraldson *et al* (1973) also noted that during the vegetative stage of plant development, nutrient uptake closely paralleled the plant growth rate. Following bulb enlargement, the rate of nutrient absorption often decreases on a dry weight basis and there is usually a transport of certain elements from the vegetative portions of the plant to the developing bulb. Nitrogen was translocated to the bulb from the leaf and root as maturity approached.

A linear relationship was found between bulb yield (dry weight) and amount of nitrogen absorbed by bulbs. Zink (1966) also obtained a similar result with fresh onion bulbs. However,

Terman and Engelstad (1976) noted that nutrient uptake of mostly mobile elements like N, K and S, by crops is usually linear over wider ranges of application rates than is crop yield. Greenwood *et al* (1974) found that on average, when high levels of fertilizer were applied removal of N was increased by 50% but yields by only 3% over those obtained with the 'optimum' levels. In this study the uptake of N was only linear with low application rates.

The maximum amount of N absorbed by the whole onion plants in this trial was approximately 200 kg N/ha for the various N treatments. Thus this N level should be enough for onion production under most soil conditions. The high N treatments generally removed more N than the low N treatments. This was mainly due to the fact that the high N treatments had bigger plants and higher N concentration than the low N treatments. The use and efficient application of the slow release fertilizer plus the initial presence of N in the soil partly explains the high N uptake and resulting high yield. The use of small plots, easing management, also contributed to the high yield and N uptake.

Direct comparisons of nutrient uptake results are difficult because of the influence that climatic and edaphic variables, cultural practices, variety and plant analysis techniques have on it (Geraldson *et al* 1973). Nevertheless, crop removal figures give a good guide to the amount of nutrient to apply for optimum crop yield.

9.3 Bulb Storage

Onion bulbs stored under high temperature conditions were found to lose more weight than bulbs stored under cool temperature conditions. However, no significant difference in weight loss occurred between N treatments under both storage conditions.

The loss of weight is mainly due to water loss by evaporation, water loss being faster at high temperature than at a low one (Lutz and Hardenburg 1968). The high temperature storage also encouraged respiratory losses of dry matter but this loss was only a minor part of the total since onions have a very low respiration rate (Ward and Tucker 1976). Despite the relatively high weight loss of bulbs under high temperature storage, the quality was still excellent. Thus reasonable weight loss is not a very serious factor on onion storage life; nevertheless it represents a slight loss in salable weight.

Bulb decay and also sprouting of bulbs was insignificant between the N rates under both high and low storage conditions. In the United Kingdom, Tucker *et al* (1977) however found bulb sprouting lower but rotting higher at 30 and 35°C compared with 20 and 25°C. Riekels (1977) found higher doses of N caused more sprouting of onion bulbs than with no N or low N rates. This was not the case in this study, probably because of the use of a different cultivar. However, Kepka and Sypien (1970) did not show any regularity in the effect of N fertilization on the storage of onions.

Root growth was absent from bulbs under high temperature storage but was very high under low temperature storage. The high relative humidity in the cool storage room and the fact that the bulbs were stored in perforated plastic bags caused the high root growth. Lutz and Hardenburg (1968) and Kaufman *et al* (1953) noted that at high relative humidities, above 85%, in which many other vegetables keep best in storage, onions are disposed to root growth and decay. Root growth was found greatest in the high N treatments. Bulbs with root growth are undesirable because they are unsightly and may become a focus for decay.

The storage life of onions depends on many factors, but probably the most important is cultivar. In this trial the use

of the cultivar PLK probably accounted for the excellent quality and long storage life of the bulbs under both high and low temperature conditions. High temperature storage of onions appears to be an extension of the curing process and must be economically worthwhile in the tropics.

* * * * * * * * * * *

CONCLUSIONS

The effects of N fertilizer on the growth of onion plants from seedling through bulbing to maturation and storage life were studied under field and greenhouse conditions.

Fresh and dry weight of the entire plant generally increased with increasing N fertilizer. Thus there was a good response to N fertilizer by the onion plants. The high N treatments had better bulb and leaf growth than the low N treatments. However, increased root growth was favoured more by low N levels than by high N levels but when N was too low root growth was severely limited.

The pattern of growth of the onion plant showed an increase in whole plant fresh and dry weight up to a maximum at the end of the growing period. Bulb dry weight also increased with time reaching maximum at the final harvest but green leaf number, green leaf area, leaf dry weight and root dry weight increased with time up to a maximum then decreased as maturity approached.

Low N rates tended to stimulate earlier bulb formation but this did not not result in earlier maturity or higher yield. Bulb maturity was hastened by very high N rates, consequently, there was not sufficient time for the bulbs to develop fully and so some yield was lost. However, bulb weight and bulb diameter in the final harvest generally increased with increasing N fertilizer up to an optimum N level.

Total RGR, bulb RGR, LAR, LWR and SLA all decreased as the plants advanced in age. NAR was however, rather inconsistent with time but was constant in the early stages of growth. Total RGR and bulb RGR were highly correlated. All the growth analysis parameters generally increased with increasing N rates up to an optimum N level. RGR was mainly determined by LAR. The increase in LAR caused by N fertilizer was due mainly to an increase in LWR.

The NO_3-N concentration in the leaf, bulb and root of the onion plant generally declined with time. The critical NO_3-N concentration for onions from bulbing to final harvest was established at 190 ppm NO_3-N dry weight for leaves, 240 ppm NO_3-N dry weight for bulbs and 600 ppm NO_3-N dry weight for roots. The NO_3-N concentration in the leaves and bulbs was very low and may not be very reliable for determining the N status for onions. The NO_3-N concentration in the roots was much higher and presumably the roots are the site for nitrate reduction in onions. Thus analysing the roots for NO_3-N content should give a better guide to the N status of an onion crop than would the leaves or bulbs. However, practical problems with sampling roots in the field makes it a less attractive choice.

Concentration of NO_3-N in the sap of the fresh onion bulb measured with 'Merckoquant' strips also declined with age of the plant. It was also less sensitive than NO_3-N concentration in the bulb determined in the laboratory on dry weight basis. This rapid field test method using 'Merckoquant' strips was not very useful in showing the N status of the onion crop from mid-growth because of the low nitrate content in the fresh bulb in later growth stages. However, it appears to have a good potential as a rapid, easy and inexpensive method for monitoring the N status of high nitrate accumulating crops. Some work on this area is highly recommended.

Total N in the leaf, bulb and root is positively correlated to NO_3-N concentration in the same plant parts. A general decline in total N with time was also found. However, the leaves had a higher total N than the roots or bulbs in that order. The critical N concentration for onions was established at 4.5% N early in the season to 2.7% N dry weight later in the season for leaf, 1.6% N dry weight for bulbs and 3.7 to 2% N dry weight for roots. The leaves with their higher total N are a better part to sample for use as a guide to N fertilization. Also, analysing for total N in the plant parts, rather than NO_3-N, is a better method for monitoring the N status of an onion crop.

Nitrogen removal by whole onion plants was very slow early in the season but as bulbing progressed the rate of N removal was much faster. The largest amount of N removed was recorded at maximum leaf growth when the bulbs were rapidly enlarging. A linear relationship was found between bulb yield (dry weight) and amount of N absorbed by bulbs. In most soil conditions 200 kg N/ha should be an optimum level for maximum onion production.

"Pukekohe Long Keeper" (PLK) onion bulbs stored under high or low temperature conditions were generally of excellent quality after 4 months storage period. There were no problems with decay or sprouting under both storage conditions. No significant difference in storage life was found between the various N treatments under both storage conditions.

Finally, from the results obtained in these studies it is apparent that sufficient N is required by onion plants throughout their growing period. When N is deficient or in excess early in the season, it can cause reduced leaf and root growth which may ultimately limit bulb yield. When N is deficient or in excess late in the season, rapid bulb growth is restricted, resulting in loss of yield and poor quality bulbs. Thus it is essential that optimum levels of N are supplied to the crop for maximum yield and improved bulb quality. The predicted optimum N level for efficient onion production in this study is 200 kg N/ha for most soil conditions. Furthermore, it seems that high temperature storage of onion bulbs have a very good potential in the tropics.

* * * * * * * * * * *

FUTURE WORK

Within the limits of available research resources and time, answers to some of the N nutritional questions on onion growth, development, maturation and storage life have been achieved in this thesis. However, further research work is necessary to clarify some of the answers and to solve other questions posed by this study. These are summarized as follows:

(a) The use of slow release sulphur coated urea for onion production should be further investigated and compared with conventional N fertilizer sources. This should include economic aspects.

(b) The effects of other major elements and their interaction with N on onion physiology should also be studied in detail.

(c) The use of critical concentrations to predict nutritional status of crops require a simple mathematical model to produce the line of best fit in the relationship between Relative Growth and the nutrient concentration in the plant or plant part.

(d) 'Merckoquant' strips for quick, simple and cheap nitrate testing of plants appear to have a good potential for monitoring N status of high nitrate accumulating crops in the field and should be further investigated. This potential should be brought to the attention of the manufacturers so that the sensitivity and calibration could be improved and made purposely for testing nutritional (N, P, K) status of plants.

(e) Further research work is needed in finding out the interaction nutrient x irrigation x spacing and environmental conditions that are required to extend the maximum leaf canopy and bulbing period for obtaining maximum yield.

(f) The effects of N on bulb storage life should be studied further with a longer storage period and under various high and low temperature conditions.

* * * * * * * * * * *

APPENDIX I

REAGENTS FOR NITRATE-NITROGEN DETERMINATION

1. Copper sulphate ..... $CuSO_4 \cdot 5H_2O$, 0.5% solution

2. Silver sulphate ..... Ag_2SO_4, 0.35% solution

3. Sodium phosphate ..... NaH_2PO_4

   Dissolve 138 g in 500 ml water, add strong NaOH solution to bring pH to 6.5 and make to 1 litre.

4. Calcium hydroxide-magnesium carbonate mixture ... $Ca(OH)_2$, $MgCO_3$

   Triturate 1 part of $Ca(OH)_2$ and 2 parts of $MgCO_3$ in a mortar.

5. Phenol-p-sulphonic acid

   Leave H_2SO_4 in contact with 1 drop of mercury overnight to free it from nitric acid. Add 25 g phenol, C_6H_5OH, to 225 ml H_2SO_4. Heat on steam bath for 2 hours.

6. Ammonium hydroxide — NH_4OH, 50% (V/V)

7. Potassium nitrate — KNO_3, 0.0505% solution.

   1 ml = 0.07 mg N.

APPENDIX II

WHOLE PLANT RELATIVE GROWTH RATE ($g\ g^{-1}\ week^{-1}$)

NITROGEN LEVELS	HARVESTS							
	H1-2	H2-3	H3-4	H4-5	H5-6	H6-7	H7-8	H8-9
No	0.5387	0.2429	0.1309	0.0572	0.0676	0.1461	0.0748	0.0538
N1	0.7993	0.5770	0.4362	0.3917	0.3594	0.1733	0.1896	0.0513
N2	0.8826	0.5623	0.6003	0.3319	0.4157	0.2172	0.2032	0.0496
N3	0.8747	0.5822	0.5630	0.4011	0.4397	0.2287	0.2190	0.0475
N4	0.8699	0.5434	0.5862	0.3871	0.4216	0.2012	0.2281	0.0392
N5	0.7678	0.5304	0.5518	0.4038	0.3566	0.1481	0.2088	0.0058

CV(a) = 19.38%

CV(b) = 18.76%

APPENDIX III

BULB RELATIVE GROWTH RATE ($g\ g^{-1}\ week^{-1}$)

NITROGEN LEVELS	HARVESTS							
	H1-2	H2-3	H3-4	H4-5	H5-6	H6-7	H7-8	H8-9
No	0.9585	0.3232	0.3258	0.1324	0.1386	0.0316	-0.0476	0.4521
N1	0.8834	0.9221	0.6604	0.6395	0.5465	0.3139	0.2273	-0.0031
N2	0.8082	0.8056	0.9448	0.5975	0.5530	0.2924	0.2441	0.1498
N3	0.7933	0.9131	1.0266	0.6264	0.6085	0.3081	0.2607	0.1193
N4	0.8523	0.8202	1.0022	0.7104	0.5729	0.2520	0.2643	0.0990
N5	0.8133	0.7729	0.8761	0.6782	0.4800	0.2416	0.2498	0.0453

CV(a) = 12.36%

CV(b) = 19.29%

APPENDIX IV

NET ASSIMILATION RATE (g m^{-2} $week^{-1}$)

NITROGEN LEVELS	HARVESTS							
	H1-2	H2-3	H3-4	H4-5	H5-6	H6-7	H7-8	H8-9
No	40.52	25.83	32.31	18.60	12.66	42.28	16.39	22.28
N1	38.89	42.03	48.20	61.50	83.70	65.50	104.35	26.63
N2	37.54	31.78	47.68	40.18	88.90	67.20	108.35	47.33
N3	36.15	31.93	44.87	51.16	95.00	72.61	107.61	35.99
N4	35.16	29.64	45.92	47.26	85.76	65.99	120.68	29.22
N5	36.23	30.87	48.55	55.16	81.43	45.49	110.98	4.29

CV(a) = 31.57%

CV(b) = 39.29%

APPENDIX V

LEAF AREA RATIO ($m^2\ g^{-1}$)

NITROGEN LEVELS	HARVESTS							
	H1-2	H2-3	H3-4	H4-5	H5-6	H6-7	H7-8	H8-9
No	0.01356	0.00903	0.00406	0.00355	0.00434	0.00365	0.00477	0.00315
N1	0.02061	0.01373	0.00906	0.00638	0.00434	0.00271	0.00183	0.00187
N2	0.02360	0.01773	0.01260	0.00829	0.00474	0.00328	0.00183	0.00153
N3	0.02442	0.01822	0.01255	0.00786	0.00466	0.00314	0.00206	0.00131
N4	0.02498	0.01832	0.01277	0.00825	0.00492	0.00305	0.00187	0.00135
N5	0.02368	0.01722	0.01139	0.00752	0.00445	0.00315	0.00191	0.00110

CV(a) = 11.56%

CV(b) = 11.13%

APPENDIX VI

LEAF WEIGHT RATIO

NITROGEN LEVELS	HARVESTS							
	H1-2	H2-3	H3-4	H4-5	H5-6	H6-7	H7-8	H8-9
No	0.4994	0.4323	0.3190	0.3421	0.3369	0.2507	0.3242	0.2018
N1	0.6589	0.6209	0.5217	0.4370	0.3341	0.2148	0.1405	0.1123
N2	0.7365	0.7399	0.6845	0.5358	0.3230	0.2329	0.1338	0.1030
N3	0.7464	0.7550	0.6881	0.5329	0.3151	0.2402	0.1541	0.0750
N4	0.7693	0.7697	0.6981	0.5283	0.3331	0.2295	0.1464	0.1076
N5	0.7667	0.7780	0.6515	0.4831	0.3183	0.2176	0.1345	0.0922

CV(a) = 6.29%

CV(b) = 8.19%

APPENDIX VII

SPECIFIC LEAF AREA ($m^2\ g^{-1}$)

NITROGEN LEVELS	HARVESTS							
	H1-2	H2-3	H3-4	H4-5	H5-6	H6-7	H7-8	H8-9
No	0.02716	0.02078	0.01273	0.01035	0.01290	0.01453	0.01562	0.01576
N1	0.03130	0.02218	0.01735	0.01468	0.01294	0.01267	0.01311	0.01688
N2	0.03202	0.02398	0.01842	0.01547	0.01468	0.01408	0.01374	0.01439
N3	0.03270	0.02411	0.01825	0.01476	0.01478	0.01314	0.01340	0.01146
N4	0.03241	0.02379	0.01830	0.01561	0.01485	0.01330	0.01280	0.01252
N5	0.03088	0.02214	0.01750	0.01557	0.01394	0.01445	0.01440	0.01202

CV(a) = 11.30%

CV(b) = 10.56%

BIBLIOGRAPHY

ABDALLA, A.A. (1967)

Effect of temperature and photoperiod on bulbing of the common onion (*Allium cepa* L.) under arid tropical conditions of the Sudan.
Experimental Agriculture, 3, 137-42.

ABDALLA, A.A.; EL HASSAN, G.M. (1977)

Premature bolting of onion in arid tropics of the Sudan.
Acta Hort. No.53, 35-42.

ABDALLA, A.A. and MANN, L.K. (1963)

Bulb development in the onion (*Allium cepa* L.) and the effect of storage temperature on bulb rest.
Hilgardia, 35, 85-112.

ABDEL-RAHMAN, M. and ISENBERG, F.M.R. (1974)

The role of exogenous plant growth regulators in the dormancy of onion bulbs.
Journal of Agricultural Science, U.K. 82, 113-6.

ALDRICH, S.R. (1973)

Plant Analysis : Problems and Opportunities In : *Soil Testing and Plant Analysis*, (Walsh, L.M. and Beaton, J.D. (eds.), 2nd Ed.). Soil Sci. Soc. Amer. Inc., Madison, Wisc.

ALLEN, S.E. and MAYS, D.A. (1971)

Sulphur coated fertilizers for controlled release : Agronomic Evaluation.
J. Agric. Food Chem. 19 : 809-12.

ALLEN, S.E., TERMAN, G.L. and CLEMENTS, L.B. (1976)

Greenhouse Techniques for soil - plant - fertilizer research. National Fertilizer Development Center, Muscle Shoals, Alabama.

AURA, K. (1963)

Studies on the vegetatively propagated onions cultivated in Finland, with special reference to flowering and storage.
Annales Agriculturae Fenniae 2, (suppl. 5) 1-74

AUSTIN, R.B. (1963)

Yield of onions from seed as affected by place and method seed production.
J. Hort. Sci., 38, *277-85.*

AUSTIN, R.B. (1972)

Bulb formation in onions as affected by photoperiod and spectral quality of light.
J. Hort. Sci., 47, *493-504.*

BALDWIN, J.P. (1975)

A quantitative analysis of the factors affecting plant nutrient uptake from some soils.
J. Soil Sci., 26, *195-207.*

BATES, T.E. (1971)

Factors affecting critical nutrient concentrations in plants and their evaluation : A review.
Soil Sci., 112 : *116-30.*

BEDFORD, L.V. and MACKAY, D.B. (1973)

The value of laboratory germination and weight measurements in forecasting emergence of onion and carrot seed in the field.
J. National Instit. Agric. Bot. 13, *50-62.*

BENNETT, E. (1945)

Some aspects of the metabolism of the Ebenezer onion.
Plant Physiology, 20, *37-46.*

BHAT, K.K.S.; NYE, P.H. (1974a)

Diffusion of phosphate to plant roots in soil. II. Uptake along the roots at different times and the effect of different levels of phosphorus.
Plant and Soil, 41, *365-82.*

BHAT, K.K.S.: NYE, P.H. (1974b)

Idem. III. Depletion around onion roots without root hairs.
Ibidem, 41, *383-94.*

BIERHUIZEN, J.F. and WAGENVOORT, W.A. (1974)

Some aspects of seed germination in vegetables. I. The determination and application of heat sums and minimum temperature for germination.
Scientia Hort., 2 : 213-19.

BLACKMAN, V.H. (1919)

The compound interest law and plant growth.
Ann. Bot. 33 : 353-60.

BLACKMAN, G.E. (1956)

Influence of light and temperature on leaf growth. In : *The growth of leaves* (Ed. F.L. Milthorpe). Butterworths, London.

BLACKMAN, G.E. and WILSON, G.L. (1951a).

VI. The constancy for different species of a logarithmic relationship between net assimilation rate and light intensity and its ecological significance.
Ann. Bot. N.S. 15 : 63-94.

BLACKMAN, G.E. and WILSON, G.L. (1951b)

VII. An analysis of differential effects of light intensity on net assimilation rate, leaf area ratio and relative growth rate of different species.
Ann. Bot. N.S. 15 : 373-408.

BLEASDALE, J.K.A. (1966)

The effects of plant spacing on the yield of bulb onions (*Allium sepa* L.) grown from seed.
J. Hort. Sci., 41, 145-53.

BLEASDALE, J.K.A. (1973)

Plant Physiology in relation to Horticulture.
Macmillan Press Ltd, London.

BOOTH, R.H. (1974)

Post harvest deterioration of tropical root crops : losses and their control.
Tropical Sci. Vol.16(2).

BOOTH, R.H. and COURSEY, D.G. (1972)

Storage of tropical horticultural crops.
Span 15, *3.*

BREMER, H. (1936)

Bulb formation and ripening in the onion.
Angewandte Botanik, 18, *204-31.*

BREWSTER, J.L. (1976)

Annual Report of the National Vegetable Research Station for 1975. p.54.

BREWSTER, J.L. (1977)

The physiology of the onion.
Hort. Abstracts Nos 1 & 2, Vol. 47.

BREWSTER, J.L.; BHAT, K.K.S.; NYE, P.H. (1975a)

The possibility of predicting solute uptake and plant growth response from independently measured soil and plant characteristics. II. The growth and uptake of onions in solutions of constant phosphate concentration.
Plant and Soil, 42, *171-95.*

BREWSTER, J.L.; BHAT, K.K.S.; NYE, P.H. (1975b)

Idem. III. The growth and uptake of onions in a soil fertilized to different initial levels of phosphate and a comparison of the results with model predictions.
Ibidem, 42, *197-226.*

BREWSTER, J.L.; BHAT, K.K.S.; NYE, P.H. (1976a)

Idem. IV. The growth and uptake of rape in solutions of different phosphorus concentration.
Ibidem, 44, *279-93.*

BREWSTER, J.L.; BHAT, K.K.S.; NYE, P.H. (1976b)

Idem. V. The growth and phosphorus uptake of rape in soil at a range of phosphorus concentrations and a comparison of results with the predictions of a simulation model.
Ibidem, 44, *295-328.*

BREWSTER, J.L.; HARDWICK, R.C.; HARDAKER, J.M. (1975)

Report of the National Vegetable Research Station for 1974. p.68.

BREWSTER, J.L.; SALTER, P.J. and DARBY, R.J. (1977)

Analysis of the growth and yield of overwintered bulb onions. *J. Hort. Sci., 52, 335-346.*

BRIGGS, G.E., KIDD, F. and WEST, C. (1920)

A quantitative analysis of plant growth. *Ann. Appl. Biol. 7, 202.*

BURHAN, H.O. and BABIKER, I.A. (1968)

Investigations of nitrogen fertilization of cotton by tissue analysis. *Expl. Agric. 4 : 311-23.*

BUTT, A.M. (1968)

Vegetative growth, morphogenesis and carbohydrate content of the onion plant as a function of light and temperature under field and controlled conditions. *Meded. Landbouwhogeschool 68, (10) 1-211.*

CLARK, J.E.; HEATH, O.V.S. (1962)

Studies in the physiology of the onion plant. V. An investigation into the growth substance content of bulbing onions. *J. Expl. Bot., 13, 227-49.*

CLEAVER, T.J.; TURNER, M.K. (1975)

Annual Report of the National Vegetable Research Station for 1974. p.58.

COCKSHULL, K.E. and HEATH, O.V.S. (1962)

A modified bio-assay for growth substances in bulbing onions. *Nature, London. 193 : 495-96.*

COOKE, G.W. (1972)

Fertilizing for maximum yield. Crosby Lockwood & Son Ltd, London.

COOKE, G.W., JACKSON, M.V., WIDDOWSON, F.W. and WILCOX, J.C. (1956)

Fertilizer placement for horticultural crops.
J. Agric. Sci., 47, *249-55.*

CURRAH, I.E. (1975)

Annual Report of the National Vegetable Research Station for 1974. p.81.

CURRAH, L. and OCKENDON, D.J. (1978)

Protandry and the sequence of flower opening in the onion.
New Phytologist. 81 (2) *419-28.*

DAVIS, G.N. (1957)

Onion production in California.
California Agric. Exp. Sta., Ext. Serv. Manual 22 : *1-26.*

DOWNES, J.D. (1959)

Growth and certain aspects of the chemical composition of onion as influenced by nutrition.
Hort. Abstr. 29, *3639.*

DRINKWATER, W.O.; JANES, B.E. (1955)

Effects of irrigation and soil moisture on maturity, yield and storage of two onion hybrids.
Proc. Amer. Soc. Hort. Sci., 66, *267-78.*

EAGLES, C.F. (1971)

Changes in net assimilation rate and leaf area ratio with time in *Dactylis glomerata* L.
Ann. Bot. N.S. 35 : *63-74.*

EMMERT, E.M. (1934)

Tests for phosphate, nitrate, and soluble nitrogen in conducting tissue of tomato and lettuce plants, as indicators of availability and yield.
Ky. Agr. Exp. Sta. Cir., *43.*

EPSTEIN, E. (1965)

Mineral metabolism. In : *Plant biochemistry.* Eds. J. Bonner and J.E. Varner), pp.438-66.
Academic Press, New York.

EVANS, G.C. (1972)

The quantitative analysis of plant growth.
Blackwell Scientific Publications, Oxford.

EVANS, G.C. and HUGHES, A.P. (1961)

Plant growth and aerial environment. I. Effect of artificial shading on *Impatiens parviflora.*
New Phytol. 60 : 150-80.

EVANS, G.C. and HUGHES, A.P. (1962)

Idem. II. On the computation of unit leaf rate.
New Phytol. 61 : 322-67.

FRAPPELL, B.D. (1973)

Plant spacing of onions.
J. Hort. Sci., 48, 19-28.

FRITZ, D. and HABBEN, J. (1973)

Influence of fertilization on the quality of vegetables particularly for processing.
Acta Hort. 29 : 349-60.

GERALDSON, C.M.; KLACAN, G.R. and LORENZ, O.A. (1973)

Plant Analysis as an aid in fertilizing vegetable crops. In : *Soil testing and plant analysis.* (Eds. Walsh, L.M. and Beaton, J.D. 2nd Ed.). Soil Sci. Soc. Amer. Inc., Madison, Wisc.

GOODALL, D.W. and GREGORY, F.G. (1947)

Chemical composition of plants as an index of their nutritional status.
Imp. Bureaux of Hort. and Plantation Crops (East Malling) Tech. Comm. 17.

GREENWOOD, D.J.; CLEAVER, T.J.; TURNER, M.K. (1976)

Fertilizer requirements of vegetable crops.
Proc. Fert. Soc., No.145, 3-30.

GREGORY, F.G. (1917)

Physiological conditions in cucumber houses.
Chesthunt (England) Exp. and Res. Sta. 3rd Annual Rpt. : 19-28

HAMNES, J.K. and BARTZ, J.F. (1963)

Root distribution and development of vegetable crops as measured by radio-active phosphorus injection technique.
Agron. J. 55 : *329-33.*

HASSAN, M.S. (1977)

Effects of source, level and time of nitrogen application on yield of onion in the Sudan Gezira.
Acta Hort. 53, : *59-70.*

HAYMAN, D.S. and MOSSE, B. (1971)

Plant growth responses to vesicular-arbuscular mycorrhiza. I. Growth of Endogone-inoculated plants in phosphate-deficient soils.
New Phytol., 70, *19-27.*

HEATH, O.V.S. and GREGORY, F.G. (1938)

The constancy of the mean net assimilation rate and its ecological importance.
Ann. Bot. N.S. 2 : *811-18.*

HEATH, O.V.S. and HOLDSWORTH, M. (1943)

Bulb formation and flower production in onion plants grown from sets.
Nature. U.K. 152, *334-5.*

HEATH, O.V.S. and HOLDSWORTH, M. (1948)

Morphogenetic factors as exemplified by the onion plant.
Symposia of the Soc. for Exptl. Biol. II : *326-51.*

HEATH, O.V.S. and HOLLIES, M.A. (1965)

Studies in the physiology of the onion plant. VI. A sensitive morphological test for bulbing and its use in detecting bulb development in sterile culture.
J. Exp. Bot. 16 : *128-44.*

HEWITT, E.J. (1966)

Sand and water culture methods used in the study of plant nutrition. 2nd ed. Commonwealth Agric. Bureaux : Farnharm Royal, England. p.547.

HEWITT, E.J. and SMITH, T.A. (1974)

Plant mineral nutrition.
Unibooks. English Universities Press, London.

HEWSON, R.T. (1971)

Studies on weed competition in some vegetable crops.
Ph.D. Thesis, Brunel University, Exbridge.

HEYDECKER, W.; HIGGINS, J.; GULLIVER, R.L. (1973)

Accelerated germination by osmotic seed treatments.
Nature, U.K., 246, *42-4.*

HOFFMAN, C.A. (1933)

Developmental morphology of *Allium cepa* L.
Botanical Gazett, 95, *279-99.*

HOLDSWORTH, M. and HEATH, O.V.S. (1950)

Idem. IV. The influence of daylength and temperature on the flowering of the onion plant.
J. Expl. Bot., 1, *353.*

HOROWITZ, W. (1970)

Official methods of analysis. 11th ed. Association of Official Analytical Chemists, Washington, D.C. pp.17-18.

HOYLE, B.J. (1948)

Onion curing : a comparison of storage losses from artificial, field and non cured onions.
Proc. Am. Soc. Hort. Sci., 52, *407-14.*

HUGHES, A.P. and EVANS, G.C. (1962)

Plant Growth and Aerial Environment. II. Effects of light intensity on *Impatiens parviflora.*
New Phytol., 61, *154-74.*

HUGHES, A.P. and FREEMAN, P.R. (1967)

Growth analysis using frequent small harvests.
J. Appl. Ecol. 4 : *553-60.*

HUNT, R. (1978)

Plant Growth Analysis. Studies in Biology No.96. Instit. of Biol. Edward Arnold (Publishers) Ltd, London.

HUNT, J., NG, W.Y., BARNES, A. and GREENWOOD, D.J. (1979)

A rapid method for estimating nitrate-nitrogen concentrations in field soils.
J. Sci. of Food and Agric., Vol.30, pp.343-53.

ISENBERG, F.M. (1956)

The use of maleic hydrazide on onions.
Proc. Amer. Soc. Hort. Sci., 68, 343-50.

ISENBERG, F.M. (1955)

The effect of height of fall on onion bruising.
Proc. Amer. Soc. Hort. Sci., 66, 331.

JOHNSON, C.M. and ULRICH, A. (1959)

Analytical methods for use in plant analysis.
California Agr. Exp. Sta. Bull.766, pp.26-78.

JONES, J.B. Jr (1978)

Plant analysis : its past, present and future. Proc. 8th International Colloquium on plant analysis and fertilizer problems, Vol.1. 193-207.
Auckland, New Zealand.

JONES, J.B. Jr, LARGE, R.L., PFLEIDERER, D.B. and KLOSKY, H.S. (1971)

How to properly sample for a plant analysis.
Crops Soils 23 (8) : 15-18.

JONES, J.B. Jr and STEYN, W.J.A. (1973)

Sampling, handling and analysing plant tissue samples. In : *Soil testing and plant analysis.* (Eds. Walsh, L.M. and Beaton, J.D.) 2nd Ed. Soil Sci. Soc. Amer. Inc., Madison, Wisc.

JONES, H.A. and EMSWELLER, S.L. (1939)

Effect of storage, bulb size, spacing, and time of planting on production of onion seed.
Bull. Calif. Agric. Exp. Sta. 628 p.14.

JONES, H.A. and MANN, L.K. (1963)

Onions and their allies. Leonard Hill Ltd. Intersciences publishers, Inc., New York.

JONES, H.A. and ROSA, J.T. (1928)

Truck crop plants. McGraw-Hill, New York.

JUNGK, A. and WEHRMANN, J. (1978)

Determination of nitrogen fertilizer requirements by plant and soil analysis. Proc. 8th Inter. Colloquium on Plant Analysis and Fert. Problems, Vol.1. 209-24. Auckland, New Zealand.

KARMARKAR, D.V.; JOSHI, B.M. (1941)

Investigations on the storage of onions. *Indian Journal of Agric. Sci., 11, 82-94.*

KATO, T. (1963)

Physiological studies on bulb formation and dormancy in the onion plant. I. The process of bulb formation and development. *J. Japanese Soc. Hort. Sci., 32, 229-37.*

KATO, T. (1966)

Idem. VII. Effects of some environmental factors and chemicals on the dormant process of bulbs. *Ibidem, 35, 49-56.*

KAUFMAN, J., HRUSCHKA, H.W. and HARDENBURG, R.E. (1953)

Onion pre-packing tests. *Pre-Pack-Age 7, No.1. 9-13.*

KEPKA, A.K. and SYPIEN, M.A. (1970)

The influence of some factors on the keeping quality of onions. *Acta Hort. 20 : 65-71.*

KNOTT, J.E. (1957)

Handbook for vegetable growers. John Wiley and Sons, Inc., Sydney.

LEGGETT, E.K. (1973)

Onion growing. N.S.W. Dept of Agric. Div. of Plant Ind. Bull. P26, p.16.

LEVY, D. and KEDAR, N. (1970)

Effect of Ethrel on growth and bulb initiation in onion. *Hort. Sci., 5,* *80-2.*

LORENZ, O.A. and HOYLE, B.J. (1946)

Effect of curing and time of topping on weight loss and chemical composition of onion bulbs. *Proc. Amer. Soc. Hort. Sci., 47,* *301-8.*

LORENZ, O.A.; BISHOP, J.C. and WRIGHT, D.N. (1955)

Liquid, dry and gaseous fertilizers for onions on sandy loam soils. *Proc. Amer. Soc. Hort. Sci., 65,* *296-306.*

LORENZ, O.A. and TYLER, K.B. (1978)

Plant tissue analysis of vegetable crops. In : *Soil and Plant Tissue Testing in California.* Uni. of Calif. Bull. 1879.

LORENZ, O.A.; TYLER, K.B. and FULLMER, F.S. (1964)

Plant analyses for determining the nutritional status of potatoes. In : C. Bould (ed.) *Plant analysis and fertilizer problems.* Amer. Soc. Hort. Sci. pp.226-40.

LORENZ, O.A. and WEIR, B.L. (1974)

Nitrate accumulation in vegetables. In : *Environmental Quality and Food Supply.* (P.L. White and Robbins, D. eds.), pp.93-105. Futura Publications, Mt Kisco, New York.

LOVATO, A. and AMADUCCI, M.T. (1965)

Examination of the problem of whether dormancy exists in seeds of onion (*Allium cepa* L) and leek (*Allium porrum* L.) II. Effect of temperature, prechilling and light on germination. *Proc. International Seed Testing Assoc., 30,* *803-20.*

LUNT, O.R. (1967)

Sulphur-coated urea. A slow release fertilizer.
Sulphur Inst. J., 3 (2) : 5-8.

LUNT, O.R. (1968)

Modified sulphur coated granular urea for controlled nutrient release. *9th Int. Congr. Soil Sci. Trans. (Adelaide, Aust.), 3 : 377-383.*

LUTZ, J.M. and HARDENBURG, R.E. (1968)

The commercial storage of fruits, vegetables and florist and nursery stocks.
USDA, Agriculture Handbook No.66, p.94.

MAGRUDER, H. and ALLARD, H.A. (1937)

Bulb formation in some American and European varieties of onions as affected by length of day.
J. Agr. Res. 54 : 719-52.

MANN, L.K. (1952)

Anatomy of the garlic bulb and factors affecting bulb development.
Hilgardia 21 : 195-228.

MASUDA, T. and HAYASHI, K. (1956)

Studies on the seed raising of onion.
Sci. Rep. Fac. Agric. Okayama Univ., 8, 45.

MATHUR, M.M. (1971)

Response of *Allium cepa* L. transplants to different plant growth regulators.
Indian Journal of Horticulture, 28, 296-300.

MAYNARD, D.N. and BARKER, A.V. (1972)

Nitrate content of vegetable crops.
Hort. Sci. Vol.7 (3), 224-26.

MAYNARD, D.N.; BARKER, A.V., MINOTTI, P.L. and PECK, N.H. (1976)

Nitrate accumulation in vegetables.
Adv. in Agronomy 28 : 71-118.

McCOLLUM, G.D. (1968)

Heritability and genetic correlation of soluble solids, bulb size and shape in White Sweet Spanish onion.
Can. J. Genetics and Cytology, 10, 508-14.

MELERA, P.W. (1971)

Nuclei acid metabolism in germinating onion. I. Changes in root tip nucleic acid during germination.
Plant Physiology, 48, 73-81.

MILTHORPE, F.L. (1963)

Growth analysis and dormancy. In : *The growth of the potato.* Butterworths Scientific Pulbs, London.

MUNSON, R.D. and NELSON, W.L. (1973)

Principles and practices in plant analysis. In : *Soil testing and plant analysis.* (eds Walsh, L.M. and Beaton, J.D.). Soil Sci. Soc. Amer. Inc., Madison, Wisc.

MUSA, S.K.; HABISH, H.A.; ABDALLA, A.A. and ADLAN, A.B. (1973)

Problems of onion storage in the Sudan.
Trop. Sci. 15 (4) 319-27.

NAGAI, M. (1967)

Growth of onions in a summer crop. II. Fresh weight and dry matter content of the leaves as indicators for measuring growth and maturity.
J. Japanese Soc. Hort. Sci., 36, 299-305.

NICHOLAS, D.J.D. (1948)

The application of rapid chemical tests to the diagnosis of mineral deficiencies in horticultural crops. I. Crops grown on a manurial trial.
J. Hort. Sci., 24, 72-105.

NICHOLAS, D.J.D. (1956)

An appraisal of the use of chemical tissue tests for determining the mineral status of crop plants. In : *Plant Anal. and Fert. Problems* (ed. T. Wallace). pp.119-139. IRHO Paris.

NICHOLS, M.A. (1971a)

Growth responses of radish to nitrogen and phosphorus fertilizers.
Hort. Res. 11 : 156-60.

NICHOLS, M.A. (1971b)

Growth studies with lettuce. Ph.D. Thesis, Massey Univ., New Zealand.

NYE, P.H.; BREWSTER, J.L.; BHAT, K.K.S. (1975)

The possibility of predicting solute uptake and plant growth response from independently measured soil and plant characteristics. I. The theoretical basis of the experiments. *Plant and Soil, 42, 161-70.*

PAGE, E.R. (1973)

Fertilizers may increase yields but they can also decrease emergence. *Grower, 80, 393-95.*

PANTASTICO, ER. B. (1975)

Post harvest physiology, handling and utilization of tropical and sub-tropical fruits and vegetables. AVI, Westport, Connecticut.

PATERSON, D.R.; BLACKHURST, H.T.; SIDDIQUI, S.H. (1960)

Some effects of nitrogen and phosphoric acid on premature seedstalk development, yield and composition of three onion varieties. *Proc. Amer. Soc. Hort. Sci., 76, 460-67.*

PRASAD, M. (1976a)

Gaseous losses from sulphur coated urea, ammonium sulphate and urea applied to calcareous soil (pH 7.3). *J. Soil Sci. Soc. Am., 40 : 130-33.*

PRASAD, M. (1976b)

The release of nitrogen from sulphur-coated urea as affected by soil moisture, coating weight and method of placement. *J. Soil Sci. Soc. Am., 40 : 134-36.*

PRASAD, M. (1980)

Retention of nutrients by peats and wood wastes. *Scientia Hort., 12 : 203-09.*

PURSEGLOVE, J.W. (1972)

Tropical Crops : Monocotyledon I, Longman Group Ltd, London.

PUUSTJARVI, V. and ROBERTSON, R.A. (1975)

Physical and chemical properties of peat : In : *Peat in Horticulture*. (Ed. D.W. Robinson and Lamb, J.G.D). Academic Press, London. 23-38.

RADFORD, P.J. (1967)

Growth analysis formulae - their use and abuse. *Crop. Sci. 7 : 171-75.*

RICHARDS, F.J. (1969)

The quantitative analysis of growth. In : *Plant Physiology - a treatise.* (Ed. F.C. Steward), Vol.5A : 3-76. Academic Press, New York.

RIEKELS, J.W. (1972)

The growth and maturity of onions grown on organic soil. *J. Amer. Soc. Hort. Sci. 97 : 37-41.*

RIEKELS, J.W. (1977)

Nitrogen-water relationships of onions grown on organic soil. *J. Amer. Soc. Hort. Sci. 102 (2) : 139-42.*

ROBINSON, J.C. (1971)

Studies on the performance and growth of various short-day onion varieties (*Allium cepa* L.) in the Rhodesian low veldt in relation to date of sowing. I. Yield and quality analysis. *Rhodesian Journal of Agric. Res. 9, 31-8.*

ROMANOWSKI, R.R. (1962)

Effect of time of harvest on yield, colour development, scale retention, storage losses and firmness of the onion. *Hort. Abstr., 33, 964.*

RUSSELL, E.J. (1961)

Soil conditions and plant growth. Longmans, Green and Co., London.

RYALL, A.L. and LIPTON, W.J. (1978)

Handling, transportation and storage of fruits and vegetables. AVI, Westport, Connecticut.

SANDERS, F.E. and TINKER, P.B. (1971)

Mechanism of absorption of phosphate from soil by Endogone mycorrhizas.
Nature, U.K. 233, *278-79.*

SCAIFE, M.A. (1975)

Field measurements of nitrate and ammonium nitrogen under growing crops. Rept. National Vegetable Res. Sta. for 1974, pp.49-50.

SCAIFE, M.A. and BARNES, A. (1977)

The relationship between crop yield and petiole nitrate concentration at various growth stages.
Plant and Soil 46, *705-12.*

SCAIFE, M.A. and BRAY, B.G. (1977)

Quick sap tests for improved control of crop nutrient status.
ADAS Quarterly Review, Vol.27, pp.137-45.

SCAIFE, M.A. and STEVENS, K. (1977)

Two-minute sap test takes guesswork out of N levels.
Grower, Vol.88, *1223.*

SCULLY, N.J.; PARKER, M.W.; BORTHWICK, H.A. (1945)

Interaction of nitrogen nutrition and photoperiod as expressed in bulbing and flowerstalk development of onion.
Botanical Gazett, 107, *52-61.*

SHARMA, G.C. (1979)

Controlled-release fertilizers and horticultural applications.
Scientia Horticulturae, 11 : 107-29.

STECKEL, J.E. and FLANNERY, R.L. 1971 :

Simultaneous determination of phosphorus, potassium, calcium and magnesium in wet digestion solutions of plant tissue by Auto Analyser. p.83-96.
In : L.M. Walsh ed. *Instrumental methods for analysis of soils and plant tissue.*
Soil Sci. Soc. Amer., Madison, Wisconsin.

STEER, B.T. (1980a)

The bulbing response to day length and temperature of some Australasian cultivars of onion (*Allium cepa* L.).
Aust. J. Agric. Res., 31, *511-18.*

STEER, B.T. (1980b)

The role of night temperature in the bulbing of onion (*Allium cepa* L.).
Aust. J. Agric. Res., 31, 519-23.

STOW, J.R. (1976)

The effect of defoliation on storage potential of bulbs of the onion.
Annals of appl. Biol., 84, 71-9.

STRYDOM, E. (1964)

A root study of onions in an irrigation trial.
South African J. Agric. Sci. 7, 593-601.

STUART, N.W. and GRIFFIN, D.M. (1946)

The influence of nitrogen nutrition on onion seed production in the greenhouse.
Proc. Amer. Soc. Hort. Sci., 48, 398-402.

SYPIEN, M.A.; SMOTER, J.; KEPKOWA, A. and NOWOSIELSKI, O. (1973)

The influence of nitrogen fertilization on onion quality and storage.
Acta Horticulturae, No.29, 341-47.

TERABUN, M. (1965)

Studies on the bulb formation in onion plants. I. Effects of light quality on the bulb formation and growth.
J. Japanese Soc. Hort. Sci. 34, 60-62.

TERABUN, M. (1967)

Idem. III. The effects of plant growth regulators on the swelling of basal sheaths.
Ibidem, 36, 306-14.

TERMAN, G.L. and ENGELSTAD, O.P. (1976)

Agronomic evaluation of fertilizers : Principles and Practices. National Fertilizer Development Center, Muscle Shoal, Alabama, Bull. Y - 21.

THOMAS, T.H. and ISENBERG, F.M. (1972)

Hormone physiology of onion bulbs during dormancy.
Expt. Hort., 23, 48-51.

THOMPSON, H.C. and SMITH, O. (1938)

Seedstalk and bulb development in the onion (*Allium cepa* L.). *Bull. Cornell Agric. Exp. Sta., No.708, p.21.*

TUCKER, W.G.; STOW, J.R. and WARD, C.M. (1977)

The high temperature storage of onions in the U.K. *Acta Hort. 62, 181-87.*

ULRICH, A. (1942)

The relationship of nitrogen to the formation of sugar in sugar beets. *Amer. Soc. Sugar Beet Tech. Proc. 3 : 66-80.*

ULRICH, A. (1952)

Physiological basis for assessing the nutrient requirements of plants. *Ann. Rev. Plant Physiol. 3 : 207-28.*

ULRICH, A. (1978)

Plant analysis as a guide in fertilizing crops. In : *Soil and plant tissue testing in California* (ed. H.M. Reisenauer). Uni. of California. Bull. 1879.

ULRICH, A. and HILLS, F.J. (1967)

Principles and practices of plant analysis. In : *Soil test and plant analysis, Part II* (eds G.W. Hardy *et al.*) pp.11-24. Soil Sci. Soc. Amer. Special Pub. No.2.

VAISH, C.P. (1965)

Effects of NAA and IBA on the germination of onion seeds. *Hort. Abstr. Vol.36, 4819.*

VINCE-PRUE, D. (1975)

Photoperiodism in plants. McGraw-Hill, London.

VITTUM, M.T. (1963)

Effects of fertilizers on the quality of vegetables. *Agronomy Journal, 55 : 425-29.*

WAGENVOORT, W.A. and BIERHUIZEN, J.F. (1977)

Some aspects of seed germination in vegetables. II. The effect of temperature fluctuation, depth of sowing, seed size and cultivar, on heat sum and minimum temperature for germination.
Scientia Hort., 6 : *259-70*

WARD, C.M. (1976)

The influence of temperature on weight loss from stored onion bulbs due to dessication, respiration and sprouting.
Ann. appl. Biol., 83 : *149-55.*

WARD, C.M. and TUCKER, W.G. (1976)

Respiration of maleic-hydrazide-treated and untreated onion bulbs during storage.
Ann. appl. Biol., 82 : *135-42.*

WARD, G.M. and JOHNSTON, F.B. (1960)

Chemical methods of plant analysis. Plant Research Institute. Canada Dept. of Agric., Ottawa, Ontario, Publ. 1064.

WATSON, D.J. (1947a)

Comparative physiological studies on the growth of field crops. I. Variation in net assimilation rate and leaf area between species and varieties, and within and between years.
Ann. Bot. N.S. 11 : *41-76.*

WATSON, D.J. (1947b)

Idem. II. The effect of varying nutrient supply on net assimilation rate and leaf area.
Ann. Bot. N.S. 11 : *375-407.*

WATSON, D.J. (1952)

The physiological basis of variation in yield.
Adv. Agron. 4 : *101-44.*

WATSON, D.J. (1956)

Leaf growth in relation to crop yield. In : *The growth of leaves.* (Ed. F.L. Milthorpe), pp.178-91. Butterworths, London.

WATSON, D.J. (1958)

The dependence of net assimilation rate on leaf area index.
Ann. Bot. N.S. 22 : 37-54.

WEAVER, J.E. and BRUNER, W.E. (1927)

Root development of vegetable crops. 1st Ed.
McGraw-Hill Book Co., Inc. New York.

WILLIAMS, R.F. (1946)

The physiology of plant growth, with special reference to the concept of net assimilation rate.
Ann. Bot. N.S. 10 : 41-72.

WILLIAMS, R.J.B. (1969)

The rapid determination of nitrate in crops, soils, drainage and rain-water by a simple field method using diphenylamine or diphenylbenzidine with glass fibre paper.
Chem. Ind. 1735-6.

WILSON, A.L. (1934)

Relation of nitrate nitrogen to the carbohydrate and nitrogen content of onions.
Cornell Univ. Agr. Expt. Sta. Memoir 156.

WITTWER, S.H.; SHARMA, R.C.; WELLER, L.E. and SELL, H.M. (1950)

The effect of preharvest foliage sprays of certain growth regulators on sprout inhibition and storage quality of carrots and onions.
Plant Physiology, 25, 539-49.

WOODBURY, G.W. and RIDLEY, J.R. (1969)

The influence of incandescent and fluorescent light on the bulbing response of three onion varieties.
J. Amer. Soc. Hort. Sci. 94, 365-67.

WRIGHT, M.J. and DAVISON, K.L. (1964)

Nitrate accumulation in crops and nitrate poisoning in animals.
Adv. Agron. 16 : 197-247.

YAMAGUCHI, M.; PRATT, H.K. and MORRIS, L.L. (1957)

Effect of storage temperatures on the keeping quality and composition of onion bulbs and on subsequent darkening of dehydrated flakes.
Proc. Amer. Soc. Hort. Sci., 69, 421-26.

ZINK, F.W. (1966)

Studies on the growth rate and nutrient absorption of onion.
Hilgardia, 37, 203-18.

* * * * * * * * *