INFLUENCE OF NITROGEN RATES AND STORAGE CONDITIONS ON QUALITY AND SHELF-LIFE OF FRENCH BEANS (*Phaseolus vulgaris L.*)

BY

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A thesis submitted in partial fulfilment for the degree of Master of Science in Horticulture, University of Nairobi.

1989

DEDICATION

To my father Njeru and mother Ruguru for their love.

To Dr. Mburu for his constant prayers and encouragement.

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

L. W. NJERU — Date 10/7/91

This thesis has been submitted for examination with our approval as University Supervisors

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ACKNOWLEDGEMENTS

I am sincerely grateful to the University of Nairobi for financing my studies and the research work.

I wish to express my sincere gratitude and appreciation to my supervisors, Dr. J.A. Chweya, Department of Crop Science and Dr. J.K. Imungi, Department of Food Technology and Nutrition, for their guidance, advice, constructive criticisms and friendship throughout the study and in writing up of the thesis.

I also acknowledge the help I got from the technicians, especially Messrs S.B.N. Wainaina and J. Thuku, both of the Department of Crop Science, who greatly assisted me in laying out the experiments in the field. Special thanks go to Mr. J.N. M'Thika of the Department of Food Technology and Nutrition for his help in the laboratory.

I am grateful to Miss H.N. Muthui and Mr. J.K. Mbugua, both of the Department of Public Health, Pharmacology and Toxicology, for their efforts in typing this thesis.

Last and not least, I thank Drs. J.N. Mburu, J.M. Nguhiu and S.G. Maina for their prayers and encouragement.

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ABSTRACT

Two experiments were conducted at the field station of the Faculty of Agriculture, University of Nairobi, between July 1988 and April 1989 to show the effects of N application on plant growth, yields, quality and shelf-life of pods of French beans (*Phaseolus vulgaris L.*).

The bean plants of Monel variety were topdressed with N at 0, 26, 52 and 78kg/ha and data on dry matter accumulation in leaves, stems and nodules, days to 50% flowering, total and marketable yield, quality and shelf-life of the pods were collected. Freshly harvested pods were analysed for crude protein, total ash, crude fibre, nitrates, ascorbic acid and chlorophyll.

For storage study, freshly harvested pods were separated into fine and extra fine grades and stored in 1kg lots in fibre board cartons at 4°C and at room temperatures (23 ± 1°C and 25 ± 1°C in the first and second experiments respectively). During storage the pods were analysed for weight loss, withering, percent retention of ascorbic acid, and chlorophyll contents and chilling injury for those stored at 4°C.

Nitrogen application significantly increased the dry matter of the leaves sampled at the bloom and pod stages in the first experiment (first season). Application of 26kgN/ha effected the greatest increase on the dry matter content of the leaves sampled at bloom stage while at pod stage, 52kg/ha effected the greatest increase. The latter rate also had the greatest increase on the accumulation of dry matter

in the stems. The dry matter yield in the nodules was significantly lowered by N top-dressing.

Days to 50% flowering were not significantly affected by N application.

Nitrogen application had no significant effect on the total and marketable pod yields but, in the second season, the topdressed plants yielded significantly more reject grade pods than those that were not.

The effects of N on crude protein, total ash, crude fibre and nitrate contents were not significant although N tended to increase the crude protein and nitrates and to decrease the total ash and fibre contents.

Weight loss, withering and retentions of ascorbic acid and chlorophyll during storage were not significantly affected by nitrogen application. Judged from the extent of withering the extra-fine and fine grade pods had a shelf life of two and three days respectively at room temperatures, while judged by the extent of chilling injury the shelf-life of the two grades was also limited to two and three days respectively at 4°C. Storage conditions had a significant effect on losses of ascorbic acid and chlorophyll. The losses were generally higher from pods stored at room temperatures than from pods stored at 4°C.

CHAPTER 1

INTRODUCTION

The bean (*Phaseolus vulgaris L.*) is the most important food crop in Kenya, second only to maize. The dry seeds supply supplementary protein to the predominantly cereal-based diets especially for the rural Kenyans. A small proportion of the beans also provides green vegetables in form of green leaves or immature pods.

The terms French bean, snap bean, string bean, kidney bean and pole bean are all synonyms for beans that produce pods for vegetables. The pods contribute to human nutrition by providing particularly ascorbic acid, proteins, minerals and fibre.

French beans are among the most important horticultural produce in the Kenyan export market. They constitute slightly over 20% by volume and value of all fresh horticultural exports. In 1986, they ranked first with a volume of 8845 tons. This was equivalent to 8.7% of the total fruits and vegetables exported to the leading European markets (UNCTAD/GATT, 1987). There is a large demand for fresh French beans in Western Europe especially in the winter months. Major importers of Kenyan French beans include the United Kingdom, France, Germany, Belgium, Switzerland and Italy. Of late, however, there has developed a stiff competition for the export market due to the increasing number of exporters, who include other African countries like the Cameroon, Burundi, Cote

d'Ivoire and Zimbabwe. However, due to Kenya's geographical position, favourable climate and soil, high quality French beans can be produced throughout the year, making the country the major exporter of both the fine and extra-fine grades. Quality, therefore, remains the major criterion for maintaining Kenya's superiority in the export market.

Production of French beans in Kenya is in the hands of both large scale and smallholder farmers. The production is concentrated in Central, Eastern and Western provinces, and limited cultivation in the Coast province, especially in the Taita/Taveta district. By 1986, a total of 3310 ha were under French bean cultivation, mostly along riverbeds and in irrigated areas. Most popular variety is the Monel which is mainly grown for export. Of lesser importance are the varieties Primour, Royanel, Vernadon and Garonel.

One main problem facing Kenyan French bean farmers, especially small holders, is lack of sufficient capital to purchase fertilizers. The farmers usually are supposed to plant the crop with Diammonium Phosphate (DAP: 18%N, 20%P) and topdress twice with Calcium Ammonium Nitrate (CAN:26%N). Varying rates of the fertilizers are therefore used, depending not only on soil types, but also on the financial capability of the farmer. However, to-date, there is no information on the effect of CAN fertilizer rates on the economic yield and quality of French beans under Kenyan conditions.

Another problem facing the French bean producers is the rapid deterioration of the produce after harvest. During the peak production periods (November - May), there is usually a shortage of

cargo space in the planes and most exporters are forced to either temporarily hold their produce in cold rooms for a few days awaiting airlifting, or only purchase quantities that they are able to airlift each day. Several farmers may, therefore, be unable to export their produce which is then eventually channelled through the local markets. Due to the low local demand, the beans are held at ambient temperatures for several days before they are sold out. This may result in a lot of wastage.

To-date, there is no information on what effect cold storage could have on the shelf-life and quality of the beans, or for how long the beans can maintain their saleable quality at ambient temperatures under Kenyan conditions.

The objectives of this study were therefore:-

1) To establish the effects of nitrogen rates on growth, yields, nutritive quality and shelf-life of French beans.
2) To establish the effect of storage conditions on the quality of French beans.

CHAPTER 2

LITERATURE REVIEW

2.1 The French Bean

Beans (*Phaseolus vulgaris* L.) belong to the Leguminosae family, which consists of about 600 genera and a corresponding large number of species. Only about 40 of these species, however, are of economic importance for human consumption (Hawthorn, 1981).

The bean is of new world origin, principally South America (Kaplan, 1981). *Phaseolus vulgaris* L. is the best known and most widely cultivated species of Phaseolus in the world (Tripath and Singh, 1986). In the wild state, beans or near relatives are found from the lowlands of warm humid tropics, to the cold high altitude mountains and hot deserts. However, most familiar varieties grown in the tropics perform well within a relatively narrow ecological zone ranging from 0-1000m above sea level. (Tindall, 1983). Many hundreds of cultivars are cultivated for immature pods and green or dry seeds. There is, however, no clear distinction between cultivars for pods and those for seeds, and the same cultivar may be used for both pods and seeds (Grubben, 1977).

French beans are principally grown for immature pods which are consumed fresh or processed. The two major types grown are:-

a) Dwarf or, bush cultivars which are day length neutral, early maturing, 20-60 cm in height, with lateral terminal inflorescence and determinate growth. They do not require any support.

b) Climbing or pole cultivars with indeterminate growth, grow up to 3m in height and are normally supported. Both daylength neutral and short daylength types are available.

French bean pods are thin and narrow, mostly glabrous, straight or curved with colours from yellow to dark green. The seeds also vary in colour but from white to black (Tindall, 1983).

In Kenya, French beans can be grown in areas with average annual rainfall ranging between 500 and 1500 mm, as long as the rainfall is well distributed during the growing season. However, supplementary irrigation may still be necessary. For an off-season crop and in drier areas, irrigation is an absolute necessity. The optimum altitude for growth of French beans is between 900 and 1500 m above sea level. Satisfactory growth can however, be obtained upto 2000m, although growth period will be slightly longer and disease may be a problem. French beans are susceptible to damage by frost or excessive heat. The optimum temperature range for good growth is between 16-24^{o}C. Below 10^{o}C bean plants are destroyed by frost while above 30^{o}C blossom drop is very serious and seed set may be hampered. (Anon, 1989).

French beans can be grown on a wide range of soil types from light sand to heavy clays. However, best growth is obtained in friable well drained medium loam soils with high organic matter (Tindall, 1983). The beans are very sensitive to water logged conditions and are easily injured. The soils should have a pH in the range between 6.5 and 7.5, although pH between 4.5 and 5.5 can also be tolerated. However, below this pH range, the beans suffer from aluminium and/or manganese toxicity, as well as phosphorus deficiency. In

Kenya French beans are mainly grown in soils with pH range below 6.5 (Anon, 1989).

2.2 *Nutritional Value of French Beans*

Although French beans are mainly grown for their young pods as vegetables,sometimes mature seeds and young leaves are also consumed (Tindall, 1983). The young pods are very similar to leafy vegetables in their supply of nutrients. They particularly supply better quality proteins than even the mature seeds. The proportion of seeds in the pod, however, affects the protein quality, such that the young fruits with a high proportion of pods are better balanced in the essential amino acids than the more mature fruits. The pods are also rich in minerals like calcium and phosphorus, and in vitamins, especially the ascorbic acid. (Mengel (1979).

The average nutritional value of French beans (per 100g edible portion) as recorded by Tindall (1983) are :- 88g water, 36kcalories, 2.5g proteins, 0.2g fat, 7g carbohydrates, 1.8g fibre, 43 mg Ca, 48mg P, 1.4mg Fe, 750 equivalent (µg) β–carotene, 0.8mg Thiamine, 0.12mg Riboflavin, 0.5mg Niacin and 27mg Ascorbic acid.

2.3 *French Bean Production in Kenya*

French bean is relatively new in Kenya and therefore only limited information on the crop is available. It is, however, among the most important horticultural produce in the Kenyan export

market, especially during the winter periods in Europe (November - May).

Although the bulk of the produce is exported in fresh form, a bit of processing is also carried out. The Njoro canners company in Nakuru produces canned beans while Panveg, Naivasha dehydrates the beans. A small quantity of fresh beans is also consumed locally especially in the urban areas, mainly in hotels and restaurants.

Production of French beans is carried out by both smallholders and large scale farmers. However, the bulk of the produce is from the smallholders. Cultivation is mainly along riverbeds and in irrigated areas such as Mwea, Karen and Athi River in Central Province; Naivasha in Rift Valley Province and Machakos, Embu and Meru in Eastern Province. Presently, Monel is the most popularly grown variety. In 1987, trials on Finbel variety were carried out in various locations in the country but the variety proved to be less prefered than Monel, especially due to its poor establishment and greater pod length which posed problems in grading and packaging by the standardized methods for Monel (Nyamiaka, 1989).

The major constraints in the French bean production in Kenya include: high costs of production, lack of proper post-harvest handling and packaging, especially for export, and lack of adequate cargo space for air freighting (Mulandi, 1988). However, the Horticultural Crops Development Authority (HCDA) is looking for ways of overcoming these bottle-necks. The French bean is also not a popular vegetable to Kenyans, which therefore tends to limit the

local market. Production of French beans in Kenya is, however, on the increase each year (Mulandi, 1988).

2.4 *Response of French Beans to Nitrogen*

Plants require nitrogen for growth and reproduction. Nitrogen is an essential constituent of amino acids, amides, nucleotides and nucleoproteins, and is therefore essential for cell division, expansion and growth (Garderner et al. 1985). The largest proportion of soil nitrogen in normal arable soil is in the organic matter and humus fractions. This nitrogen is, therefore, only available to plants with well developed mycorrhiza (Russel, 1973). Small amounts of soil nitrogen are also found in nitrate form dissolved in the soil water, as ammonium in exchangeable form and as chemical complexes within the clay particles. The available form of nitrogen rarely constitutes more than 1-2% of the total nitrogen in the soil (Russel, 1973).

Worldwide, crops are more deficient in nitrogen than in any other element, even in developed nations that depend on chemically fixed nitrogen (Frank and Vients, 1965). On land not receiving nitrogen fertilizer, the principal source of nitrogen for crops is decomposition of organic matter. Other sources like the rain only add a few kg/ha annually (Erikson, 1952).

Plants take up nitrogen through various paths. The majority of plants do so through roots, while aquatic plants use their leaves. Some plants like legumes have symbiotic associations with nitrogen fixing organisms, while a few obtain ammonia from the atmosphere

(Frank and vients, 1965). Plants generally take up nitrogen either as ammonium ions (NH_4^+) or as nitrate ions (NO_3^-) (Russel, 1973). According to Mengel and Kirkby (1982) there is, however, genetic variation as to which ion is absorbed at higher rates than the other. The ion taken up by the plant also depends partly on rainfall and partly on the acidity of the soil. Generally, NO_3^- is the predominant ion absorbed by crop plants other than rice. However, acid soils have been found to enhance NO_3^- uptake while depressing NH_4^+ uptake (Mengel and Kirkby, 1982).

The rate of nitrogen uptake is dependent on plant type, developmental stage of the plant, the nitrogen supplying power of the soil, and the availability of the form of nitrogen existent in the soil (Russel, 1973).

Legumes have the ability to establish root nodule symbiosis with Rhizobium species and to convert atmospheric nitrogen to a utilizable form (Russel, 1973). Several workers have reported varietal differences in the nitrogen demand and rate of nitrogen fixation by legumes. McElhannon and Mills (1978) reported that lima beans (*Phaseolus lunatus* L) required adequate amounts of nitrogen during pod development while requirements by soybeans (*Glycine max* L.) were highest during flowering and pod set (Israel, 1981; Brevedan et al., 1978). However, it has been reported that although beans are legumes, a low rate of fertilizer nitrogen may be needed for early growth and during the entire growing season when symbiotic nitrogen fixation by rhizobium is inhibited (Israel, 1981; Brevedan et al., 1983; Eaglesham et al., 1983). Gibson (1976) also reported that a relatively low amount of available nitrogen during

the initial plant development stage generally enhances nodulation and plant growth. According to Russel (1973), the amount of fixed nitrogen per hectare by a leguminous crop depends on the number of nodules/ha, nodule size and longevity and the bacterial strain in the nodules. The same author further suggests that a good supply of each of Ca, Mg, K, P, SO_4^{2-} Bo, Mo and Co is essential, although different leguminous crops have different requirements. Nitrogen supply by the soil also affects the rate of fixation. The symbiotic nitrogen capacity by beans is reported to be 40kgN/ha (Diebert, 1979; Hardy et al., 1968). Nitrogen fertilizer has been reported to reduce the maximum rate of nitrogenase activity, relative seasonal nitrogenase activity and timing of maximum nitrogenase activity (Westermann et al., 1981).

Sprent and Bradford (1977) observed that nitrogen fixation in legumes decreases during fruiting. The probable explanation is that fruits compete for supplies of available photosynthates with the nodules. The developing seeds could also be heavily drawing nitrogenous compounds from the nodules. The genetic constitution of the nodulating strain of *Rhizobium leguminosarum* and its interaction with the host cultivar have also been found to affect the nitrogen nutrition of the crop (Mytton and Sorwli, 1985).

Nitrogen affects the vegetative growth of plants more than any other nutrient. High rates of nitrogen allow plant leaves to grow larger and become succulent. The leaves also attain a greener colour and remain so for a longer time. Low rates of nitrogen on the other hand result in yellowish/reddish leaves which are tough and fibrous (Russel, 1973). However, these effects depend on the

responsiveness of the crop as well as the time of nitrogen application relative to crop development (Russel, 1973).

In French beans, nitrogen has been reported to affect nodule growth, vegetative growth, yields and quality of the crop (Peck and Macdonald., 1984). Westermann et al. (1981) reported that nitrogen application decreases the proportion of nitrogen contributed by symbiotic fixation, but has only minor effects on the proportion obtained from the available nitrogen sources. High nitrogen levels have been reported to inhibit nitrogen fixation in French beans through nodule growth inhibition rather than through nodule initiation (Robinson et al., 1965; Fontes, 1972; Miller et al., 1982; Eaglesham et al., 1983 ; Peck and Macdonald 1984),

Peck and Macdonald (1984) reported that fertilizer nitrogen decreases growth of French bean plants in the seedling stage but not at the pod stage. Doss et al. (1977) reported increase in growth and final height of French bean plants treated with nitrogen fertilizer. MCewen (1970) observed that French bean plants treated with nitrogen fertilizer retained their leaves longer and matured a week later than the controls. No effect on flowering date was observed. Robinson et al. (1965) noted a decrease in dry weight of French bean seedlings after nitrogen application. Very high nitrogen rates have been reported to increase lodging in French bean plants (Mullins, 1987).

Nitrogen has also been found to affect pod set and development in French beans (Paterson et al., 1966). Reports on the effect of nitrogen fertilizer rates on the yields of French beans are, however, inconsistent. Mullins (1987) observed no effects of high

nitrogen rates on yields of eight French bean cultivars. Only one cultivar recorded high yields at high nitrogen rates. The most favourable yield response was recorded at a nitrogen rate of 17kg per hectare. Smith (1977) also recorded no increase in yields of Bush Blue Lake cultivar when high nitrogen rates were applied. On the contrary, Asif and Greig (1972), Doss et al (1977), Paterson et al. (1966), and Worley and Harman (1967) reported high yields at higher nitrogen rates but with different cultivars. The same workers recorded maximum yields of French beans at nitrogen rates of 17-56kg per hectare. Response to higher rates have been reported only on very fine sandy soils (Busanda et al., 1984; Paterson et al., 1966; Worley and Harmon, 1967).

Nitrogen together with other factors like planting date (Moss and Muirhead, 1983), cultivar (Sistrunk, 1969), and maturity at harvest (Robinson et al., 1965), have been reported to affect the quality of French beans. As pods approach optimum harvest maturity, the yields increase but quality decreases (Robinson et al., 1965). Doss et al. (1977) noted that application of nitrogen reduced the percentage marketable pods of half-runner French beans, but the effect was counteracted by increase in yields. Robinson et al. (1965) reported that nitrogen application reduced yields of large pods and percentage of seeds in the the pods. Both factors indicate increase in quality. Doss et al. (1977) observed no consistent effect of nitrogen application on French bean grade or size distribution, but reported that the number of seeds per pod was lower. Mullins (1987) reported that high nitrogen rates depressed pod quality and mechanical harvester suitability. The same

author, also reported that due to higher rates of plant lodging, there was increased pod decay due to easy mechanical injury of the pods.

2.5 *Influence of Nitrogen Fertilizer on the Chemical Composition of French Beans*

The mineral composition of various vegetables has been found to depend on factors such as soil characteristics, climate and season (Sims and Volk, 1947). According to the same authors, the organic matter content of the soil and its pH are of primary importance, while other factors, though having significant effects, are of secondary importance.

Sims and Volk (1947) recorded the highest calcium content in French beans growing on calcareous soils, while iron content was lowest on the same soils. Highest manganese levels were recorded in beans growing on soils with a low pH and high organic matter contents.

Janes (1951) reported that there was no difference in the mineral contents of the French beans grown on moderately different N fertilizer levels. Although the total amount of various minerals was proportional to the growth of the plant, the percentage mineral content was constant in both large and small plants. Asif and Greig (1972) reported that application of high nitrogen rates on French beans resulted in higher levels of N, K, Ca, Mg and Zn in leaves.

Fertilizer nitrogen has been found to affect the total nitrogen levels in French beans. Peck and Macdonald (1984) reported that fertilizer nitrogen generally increases the total nitrogen in all plant parts at all stages of growth, development and maturation. The partitioning of nitrogen in the plant parts was found to depend on

the stage of physiological growth. Nitrogen fertilizer increased the concentration of total nitrogen in the bean plant at pod stage, but there was a decrease in all plant parts during the later stages of growth. The fertilizer was reported to have a greater effect on the increase in nitrate concentration than on the increase in total nitrogen in plant parts.

Nitrate accumulation in plants is a natural phenomenon resulting from uptake of the nitrate ions in excess of its reduction and subsequent assimmilation. Other factors affecting nitrate accumulation include genetic make up of the plant, nitrate supplying power of the soil, soil temperature and moisture content, plant part and plant age. (Maynard et al., 1976)

Nitrates can be reduced to nitrites which have been found to cause health hazards in man especially in infants. The lethal dose of nitrates is relatively low ranging between 15-70mg per kg of body weight, while that of nitrites is 20mg per kg body weight (Burden, 1961; Lee, 1970). The nitrite ion oxidizes the ferrous ion of blood haemoglobin to the ferric form producing methemoglobin which cannot transport oxygen. This is termed methaemoglobinaemia. Methemoglobin levels higher than 70% are lethal to humans (Maynard et al, 1976). Most vegetables have relatively low nitrate contents except vegetables of the mustard family *(Cruciferae)* and the *Chenopodiaceae* family which have been reported to accumulate high levels of nitrates (Maynard, 1978). The nitrate content of pulses varies between 30 and 600ppm, with beans having the upper limit (Taisser et al., 1986). Fertilizer nitrogen has been found to increase the concentration of nitrates in all plant parts at all stages of growth,

development and maturation of French beans (Peck and Macdonald, 1984). The same authors reported that nitrate-N also decreased during the later stages of plant growth. Asif and Greig (1972) reported that application of N-carrying fertilizers increased nitrate-N in French bean pods.

Very little information is available on the effect of nitrogen fertilizer on the ascorbic acid contents of French beans. However, it has been reported that nitrogen generally reduces levels of the vitamin in various plant parts. Nygaard (1984) reported that nitrogen fertilizer reduced the amount of ascorbic acid in white cabbage. Similar results were reported by Scharrer and Werner (1957) with several species of vegetables. However, Nilsson (1979) reported that nitrogen fertilizer level and source had no effects on the ascorbic acid contents of cabbage and leeks. Generally, sub-optimal nitrogen has been found to favour ascorbic acid accumulation in plant parts, whereas generous application of nitrogen decreases the ascorbic acid accumulation (Hehl and Mengel, 1972). Ammonium nitrogen source has been reported to have a more pronounced reduction in ascorbic acid accumulation than the nitrate (NO_3^-) source (Nygaard, 1984). Other factors that lower ascorbic acid accumulation include low levels of zinc, boron, copper, magnesium and manganese (Scharrer and werner, 1957) and also low light intensity (Hulme, 1970).

Nitrogen fertilizer has been reported to affect the dietary fiber content in plant tissues. Nygaard (1984) reported that increased nitrogen supply decreased the fiber accumulation in white cabbage. Chweya (1984) reported that side-dressing of kales with N tended to

increase dietary fiber. The same author also observed that close spacing had similar effects on the vegetable. Phosphorus fertilizer has also been found to slightly increase dietary fibre in some vegetables (Nygaard, 1984). Information on the effects of N fertilizer on the dietary fbre in French beans is lacking.

2.6 *Postharvest Losses in French Beans*

French beans are highly perishable (Ryall and Lipton, 1978). They rapidly deteriorate at high temperatures and therefore refrigerated storage has been recommended. Watada and Morris (1966) reported rapid senescence of the bean pods at 10°C and above. Similar observations were made by Gorini et al. (1973). Littman (1967) noted a rapid toughening and an increased seed content in the bean pods when stored at temperatures above 10°C

The optimum storage temperature range is narrow as is indicated by the recommendations of Watada and Morris (1966) of 3° - 6°C; Smith et al. (1966) of 4.5° - 7°C; Lutz and Hardenburg (1968) of 4°-7°C. However, the specific temperature differs with cultivars. Gorini et al. (1973) reported a shelf-life range between 2 and 7 days at 7°C, while Watada and Morris (1966) reported a range of 18.3 to 29 days at 15°C. Even within this narrow temperature range, the shelf-life depends on the actual storage temperature. Also cultivar differences in sensitivity to storage temperatures are highly significant (Watada and Morris, 1966; Gorini et al., 1973). To extend the shelf-life of French beans precooling and a high relative

humidity (90-95%) in the store are essential (Lutz and Hardenburg, 1968).

French beans do not benefit greatly from controlled atmosphere (CA) storage (Ryall and Lipton, 1978). However, Buescher and Hendersen (1977) reported a reduction in discoloration of the beans held in a carbon dioxide enriched atmosphere.

The principal factors involved in French bean deterioration in order of importance are transpiration, bruising and mechanical injuries, chilling injury and decay (Kader, 1983).

The rate of transpiration depends on temperature, relative humidity, air movement, nature and size of produce (Lutz and Hardenburg, 1968), and also the genetic make up of the commodity (Hoffman, 1967; Gorini et al., 1973). Transpiration adversely affects the appearance, texture, flavour and weight of the commodity by inducing wilting, shrinkage and loss of firmness, crispness and succulence (Ben-yehoshua, 1987). Senescence of tissues is also accelerated by water loss through faster rates of membrane disintegration and leakage of cellular contents (Ben-yehoshua, 1987). Watada and Morris (1966) reported a rapid senescence of French beans stored at 10°C. This was characterized by a leathery appearance, small depressions on the surface, dull colour, collapsed endocarp, and darkened tips and calyx. Rapid withering and toughening were also observed with beans held at 7°C (Gorini et al., 1973).

Desiccation of French bean pods was reported as the principal cause of loss in retail stores (Ceponis and Butterfield, 1984). Robinson et al. (1975) reported that saleability of broad beans and

runner beans is affected after loss of 6% and 5% moisture respectively.

Although stomata per unit surface area, thickness of cutin, hair length and cell size are reported to determine the extent of moisture loss in most commodities (Ben-Yehoshua, 1987), these factors are not related to the rate of wilting in French beans (Hoffman, 1967). Rather the number of epidermal hairs, and especially the broken ones is the major factor determining water loss in French beans. The more fibrous cultivars delay appearance of flaccidity of the pods despite their water loss (Hoffman, 1967).

Precooling has been reported to minimise water loss in French beans. Lewis (1958) reported that sprinkling the beans with a fine mist aids in maintaining turgidity but leads to russetting of some cultivars. Hydrocooling was also reported to reduce weight loss in French beans stored at 4°C (Gorini et al., 1973). However, all the methods of precooling do not effectively minimise water loss in French beans to the same extent. Gorini et al. (1973) noted higher weight loss in air precooled beans than in the hydrocooled ones. It was also noticed that hydrocooling controlled toughness and disease better than air-cooling.

Packaging of the beans in plastic bags has also been found to minimise water loss (Ceponis and Butterfield, 1984).

Chilling injury is the permanent and irreversible physiological damage to plant tissues, cells or organs, resulting from exposure to temperatures below some critical threshold. French beans are susceptible to chilling injury when exposed to temperatures below 10°C, but above freezing (Watada and Morris

1966). Susceptibility has been reported at 4°C (Gorini et al., 1973), 0.5°C and 5°C (Watada and Morris, 1966). Watada and Morris (1966) also observed senescence at 5°C. Gorini et al. (1973) reported that cultivar differences in susceptibility to chilling injury is highly significant. Astro, Orbit and Tendercrop cultivars were unaffected at 4°C while Topcrop and Contender were highly susceptible at the same temperature.

Chilling injury increases in severity as the temperature of storage decreases and duration of exposure increases (Lewis, 1958; Watada and Morris, 1966; Gorini et al., 1973). The stage of physiological development (Lipton, 1978) and growing conditions (Abdel-maksoud et al., 1974) also affect susceptibility to chilling injury. The less mature tissues are more susceptible than the more mature ones.

Chilling symptoms are not readily apparent at the injurious chilling temperatures but develop rapidly when the material is removed to warmer temperatures (Lyons and Breidenback, 1987). Watada and Morris (1966) noted an accelerated development of symptoms after beans chilled at 4°C were removed to 15°C. The rate of respiration was also found to accelerate once chilling symptoms were visible.

Although susceptibility to chilling injury in French beans is dependent on cultivar, the symptoms are fairly common to all cultivars. The major symptoms so far reported include surface pitting, diagonal brown streaks, dullness of colour and russetting (Watada and Morris, 1966; Gorini et al., 1973).

Depending on cultivar, chilling injury also predisposes beans to development of rots due to microbial breakdown (Watada and Morris, 1966). Minimum chilling injury and therefore maximum shelf-life for French beans has been found to be at 5°C (Watada and Morris, 1966).

Bruising and mechanical injury can be caused by pods rubbing against each other, windrub, rough containers and rough transportation (Ryall and Lipton, 1978). Mechanical injury can occur at all stages from pre-harvest operations to the time the produce reaches the consumer. This can result in substantial losses of certain commodities (Proctor et al., 1981). Gonzalez et al. (1983) reported that increased bruising during mechanical harvesting of the pods accelerated quality deterioration.

Other than lowering the appearance quality of the produce, bruises are principal avenues of entry for decay organisms. The bruised product also has accelerated respiration and moisture loss (Lutz and Hardenburg, 1968).

Attack by micro-organisms (fungi, bacteria and to a lesser extent viruses) may lead to serious losses in perishable produce (Proctor and Coursey, 1981). The most common postharvest diseases affecting French beans as described by Ryall and Lipton (1978) are:

a) Gray mold: This is caused by *Botrytis Cinerea*.. Infection takes place in the field and is carried to the store. It is the most destructive on pods shipped to fresh vegetable markets. It is characterized by water soaked lesions with dark greenish - grey concentric rings on tissues which become flaccid and slimy. It is favoured mostly by conditions of high relative humidity.

b) Anthracnose: The causal agent is *Colletotrichum lindenuthianum*. It is characterized by deep black spots with reddish borders. Its development is also favoured by high relative humidity.

c) Watery soft rot: This is caused by soil fungi belonging to the *Sclerotinia spp*. Incipient infection develops into active decay at favourable temperatures (above 20°C) in the store. It is characterized by water-soaked lesions. Precooling to 7°-10°C will slow down disease development. The disease can cause serious losses in French beans in seasons when a cool, moist weather precedes harvest.

d) Soil rot: This is caused by a soil-borne fungus *Rhizoctonia solani*. It is characterized by small rusty-brown lesions. The tissues become soft and eventually dry out to a chocolate brown colour. Market decay develops from incipient infection during harvest. Disease development can be controlled by precooling beans to 7°C.

e) Cottony leak: This is caused by *Pythium butleri* in bean growing areas receiving heavy rainfall. Infection starts when the pod cuticle gets damaged, especially during harvest. Precooling of the beans to 10°C and storage at 7°C helps reduce the decay.

Ascorbic acid is one of the major nutrients supplied by fresh vegetables and fruits. It exists in two readily inter-convertible forms: reduced ascorbic acid and oxidized dehydro-ascorbic acid. The reduced form is the predominant form in most crops (Watada, 1987).

Plant tissues contain oxidase enzymes that are capable of oxidizing ascorbic acid. Under unfavourable conditions of storage (stress) like high or low (chilling) temperatures, physical damage and wilting, oxidation of reduced ascorbic acid to dehydro-ascorbic acid is highly accelerated (Heinze, 1974). The conversion of reduced ascorbic acid to the Dehydro-ascorbic acid is reversible and is not considered to be a serious loss of the vitamin, because dehydroascorbic acid has a vitamin activity of about 80%. However, the dehydro-ascorbic acid is unstable and under stress conditions, it is irreversibly converted to 2, 3-diketogulonic acid (DGA), which does not possess antiscorbutic properties, and its formation therefore represents complete loss of ascorbic acid from the produce (Harkette, 1977).

Ascorbic acid is highly sensitive to storage conditions especially temperature. Its retention is usually used as an index for the general quality of a commodity (Kramer, 1977). Loss of ascorbic acid during storage of fresh produce varies considerably with commodities (Harkette, 1977). Cabbage held at 20°C lost very little ascorbic acid while Cauliflower and Brussels sprouts lost considerable amounts at the same temperature.

Shewfelt et al. (1985) reported high rates of desiccation in French beans held at 21°C and 70% RH for 4 days. Loss of ascorbic acid followed a similar trend. Shewfelt et al. (1986) also reported high losses of ascorbic acid throughout postharvest handling of French beans, especially during transportation for 6 hrs at 6°C and in storage at 21°C for 6 days.

Colour is an important attribute to the appearance of most horticultural products. It is either an element of attraction or an indication of a healthy plant organ (Phan, 1987). Factors that influence the colour of products vary widely and the major ones include cultivar and stage of maturity. Others are climate and enviroment, season, soil type, plant nutrition, plant density and habit, and post-harvest treatments (Arthey, 1975).

In green vegetables, chlorophylls are the main contributors to the green colour. The two main types of chlorophyll are chlorophyll a, which is bluish-green and chlorophyll b, which is yellow-green (Arthey, 1975). As a general rule, mature organs have quite a stable colour, and unless they undergo drastic wilting, they are capable of retaining it for sometime after harvest. Immature organs like French beans and peapods undergo very drastic chlorophyll degradation after harvest (Phan, 1987). Chlorophyll b is more susceptible to harvest shock and its degradation is therefore faster than that of chlorophyll a. Phan (1987) reported that placing peapods in a cold place immediately after harvest reduced degradation of chlorophyll a to 4-6%, while that of chlorophyll b was still high at 35-55%. The degradation of chlorophyll is through the action of the enzyme chlorophyllase and proceeds as follows:

Chlorophyll (porphyrin ring + phytol)	Chlorophyllase an esterase	Chlorophyllide (porphyrin ring)+phytol

The hue (green colour) in French beans has been found to be closely related to their overall acceptability (Shewfelt et al., 1985). The colour is dependent on cultivar, maturity, growing conditions

and climate (Bedford, 1983). Shewfelt at al. (1986) reported that the hue of beans is also affected by storage conditions. No significant change in the hue was observed during post-harvest handling except in storage, where the beans held at 21°C for 6 days showed more yellowing (lower hue angle) than the beans at 5°C for the same period of storage. Yellowing was most extensive in the low-price beans which were most mature. Beans belonging to intermediate and high-price groups lost chlorophyll during the initial days of storage and later the chlorophyll content remained constant (Shewfelt, 1986). Similar observations were made by Phan (1977) during storage of peapods, where the chlorophyll degradation was faster in pods stored at room temperature, although cold storage immediately after harvest resulted in some degradation which stabilized later. However, cold storage was reported to minimise chlorophyll degradation.

Increasing the availability of food becomes a pressing problem with the expansion of the world's population. A major but often neglected measure towards offering more food is prevention of postharvest losses (Proctor et al., 1981). Although detailed studies have been carried out on the postharvest losses of the more durable foodstuffs like cereals and grain legumes, the more perishable horticultural commodities have been relatively ignored (Coursey and Proctor, 1975).

Fresh horticultural commodities are subject to an active metabolism at the time of harvest. After harvest, numerous biochemical processes continue to change the original composition of the produce till marketability is lost (Schwertfeger, 1979). Due to

the diversity in morphological structure, composition and general physiology, the requirements and recommendations for maximum postharvest life vary among various groups (Kader, 1983).

The rate of deterioration depends on the type of commodity and the environmental factors such as temperatures, relative humidity, atmospheric composition and pressure (FAO, 1981; Tindall and Proctor, 1980; Harvey, 1978).

The relative importance of the deteriorative factors depends on the commodity (Kader, 1983). The principal loss areas have been grouped into the following three categories (NAS, 1979):

a) Quantitative loss, which includes reduction in weight due to water loss, and loss of dry matter by respiration.
b) Qualitative loss, frequently described by comparison with locally accepted quality standards.
c) Nutritional loss, such as decline in vitamin contents. All these losses can occur throughout the postharvest handling systems and are cummulative (Kader, 1983)

CHAPTER 3

MATERIALS AND METHODS

The study was carried out during two seasons, one season in 1988 (July-October) and the other in 1989 (January - April). During each season, field and storage experiments were conducted. The French bean seeds of Monel variety used in this study were obtained from Kenya seed company ltd., Nairobi.

3.1 *Field Experiments*

3.1 1: Experimental site:

These experiments were carried out at the field station of the Faculty of Agriculture, university of Nairobi, Kabete Campus which lies at an altitude of 1940m above sea level, and at latitude 1° 15s' and longitude 36° 44' E. The mean monthly maximum temperature is 23°C, while the mean minimum temperature is 12°C. The annual rainfall is slightly above 1000mm. It is bimodal with Peaks in April and November.

The soils in the area have been described as humic nitisols according to FAO/UNESCO (1988) classification with oxic peleustult as the soils taxonomy. They are deep friable kaolinitic clay type, formed in situ from the tertiary trachytic lava (Siderius, 1976).

The mean monthly weather records and soil composition during the seasons of the trials were as shown in Appendices 1 and 2.

3.1.2 Treatments and design of the experiment

The treatments consisted of top dressing with four levels of N viz 0, 26, 52 and 78kg/ha using CAN as the source of N. The treatments were laid out in a randomized complete block design. Since the field was fairly uniform each treatment was replicated three times only Each block measured 14.5m x 6m and was subdivided into 4 plots each measuring 3m x 4m. The beans were planted at the rate of 50kg/ha in rows, with spacing of 30cm between and 10cm within the rows respectively. At planting, Diammonium Phosphate Fertilizer (DAP 18%N and 20%P) was applied along the rows at the rate of 200kg/ha. To prevent seed injury by the fertilizer, the fertilizer was thoroughly mixed with the soil before the seeds were planted. Immediately after planting, the whole plot was watered using overhead sprinklers. During top dressing split topdressing method was used where half the fertilizer was applied at the two leaf stage, and the other half at the start of blooming

3.1.3 Crop husbandry

The crop was periodically supplemented with water using overhead sprinklers during the two seasons. During the dry spell, watering frequency was twice a week but this was reduced to once or none during the wet periods, depending on the rain intensity.

In order to control disease and insect pests, starting at three days after emergence, the seedlings were sprayed with Rogor E (70 ml/100 litres of water) at weekly intervals to control aphids (*Aphis fabae*), flower thrips (*Taeniothrips sjostedti*), and beanflies (*Ophiomyia phaseoli*). During flowering and podding stages ,

ambush replaced Rogor E due to its shorter safe period of 1-2 days as compared to the safe period of rogor E which is about one week. The recommended rate for ambush was used (100ml/20 litres of water). Fungal diseases like rust and angular leaf spot were controlled by spraying with Benlate and Baycor at two-week intervals at the recommended rates of 1kg/1000 litres of water and 1/2 teaspoonful per 4 litres of water respectively.

The field was maintained free of weeds by hand weeding. Weeding was carried out twice after which plants developed weed suppressing canopy. The first weeding was done at the two-leaf stage and the second just before the beginning of flowering. Weeds were not a problem in the later stages of growth.

3.1.4: Field data collection

Data on the following were collected during each season:

a) Dry matter of leaves, stems and nodules.

b) Total and economic yields

c) Number of days to 50% flowering.

3.1.4.1: Determination of dry matter of leaves, stems and nodules were started one week after the first topdressing and were repeated at weekly intervals through blooming to podding stages. Five plants were carefully uprooted at random from each plot, after watering, making sure the nodules were intact. The plants were separated into leaves, stems and roots. The roots were carefully washed in tap water contained in a tray and rinsed several times to remove the soil. The nodules were then carefully separated from the

roots and dried with tissue paper. The dry matter of the leaves and stems were obtained by drying in an air oven at 105 ± 1°C for 12 hours, and that for the nodules in the same oven at 80°C for 24 hours.

3.1.4.2: Determination of total and economic yields: The harvest maturity was determined by visual judgement combined with pod size measurement . According to Kenya Bureau of Standards (KBS, 1983) specifications, harvestable pods should have a diameter between 6-9mm, and a minimum length of 10cm. Ten plants were selected at random in each plot and the total number of pods on them counted. The length and diameter of each pod were also measured using a vernier calliper. All the pods conforming to the above standards were said to be mature for harvest. The proportion of mature pods was expressed as a percentage of the total pods counted. Harvest was initiated when this proportion was about 12% because , the most mature pods were then not yet overgrown.

The centrally located $4m^2$ of each plot was demarcated for evaluation of total and economic yields. This area comprised of four rows with a plant population of 64. All the mature pods were hand picked at two day intervals for a period of one month, after which pod production ceased. The pods from each plot were weighed on a pan balance and all weights added together to obtain the total weight for each harvest. These were summed up over the whole harvest period to give the total yield. The economic yield was obtained by grading the harvested pods according to size. Pods with a diameter of 6mm or less and a minimum length of 10cm were graded as extra-

fine while those with diameter ranging between 6 to 9mm with a minimum length of 10cm constituted the fine grade. Pods larger than the fines were categorized as overmature and were rejected. The lots from each grade were weighed separately on a pan balance and the sum of these weights for all harvests gave the total economic yield for each grade.

3.1.4.3: Determination of days to 50% flowering: The middle three rows of each plot were used for this determination. The total number of plants in these rows was about 90. Daily counts of plants in the rows with open flowers was carried out. Flowering at 50% was attained when 45 plants had flowered.

3..2: *Storage Study and Chemical Analyses*

These were carried out in the Department of Food Technology and Nutrition, Faculty of Agriculture, University of Nairobi.

3.2.1: Storage study

Pods harvested from each replicate were graded into fine and extra-fine grades. Each grade from each replicate was divided into two batches and each batch packed into paper board cartons for storage. One batch was stored at room temperatures (23-26^{o}C) and the other in a cold store (4 ± 1^{o}C). The cold room was at a relative humidity of 94%, while the relative humidity of ambient air averaged 64.5% during the first season and 69.8% during the second season, (See Appendix 1)

During storage, the samples at room temperature were analysed for weight loss, percent retention of ascorbic acid and chlorophyll and degree of wilting after every two days of storage in the first experiment and every day in the second due to the very short shelf-life recorded in experiment one. The samples stored in the cold room on the other hand were analysed for weight loss, percent retention of ascorbic acid and chlorophyll, withering and symptoms of chilling injury after four, and eight days of storage. The beans were stored until they were determined to be no longer attractive for sale under either of the storage conditions.

3.2.1 1: Determination of weight loss: The weight of each batch of beans was determined accurately using a pan balance, initially and for each subsequent day of storage. Each day of storage, the cummulative weight loss for each batch was expressed as a percentage of the initial weight.

3.2.1 2: Determination of percent withering: This was determined by carrying out a snapping test on a sample of 30 pods. Each pod at a time was held so as to leave about 8cm between fingers for the fine and 5cm for the extra fine pods, then bent to form a closed loop. If the pod looped without snapping it was considered withered, while if the pod snapped before making the loop, it was considered still turgid and sound. The number of pods that looped without snapping was expressed as a percentage of the total pods sampled.

3.2.1.3: Determination of percent chilling: This was determined on beans held in the cold store after four and eight days. Thirty pods were randomly picked from each carton and visually checked for symptoms of chilling injury. The symptoms included surface pitting and browning of pods. The number of pods showing the symptoms was expressed as a percentage of the total pods sampled. After each of the four and eight days of storage in the cold store, a sample from each grade and replicate was brought out to the room temperatures and evaluated for shelf stability by monitoring withering and chilling injury as already described.

3.2.2: Chemical analyses

This involved determination of dry matter, ascorbic acid, chlorophyll, protein, total ash, crude fibre and nitrates. Ascorbic acid and chlorophyll were determined on fresh samples. For determination of the rest, 500g of beans from each replicate were dried at 105±1°C in an air-oven to constant weight, then ground to pass through a 500 micron sieve, using a laboratory hammer mill. All the chemical analyses were performed on duplicate samples.

3.2.2.1: Determination of dry matter: This was carried out by drying 5g of finely chopped samples at 105 ± 1°C in an air oven to constant weight. The weight of the dry residue was expressed as a percentage of the original sample weight.

3.2.2.2: Determination of ascorbic acid (vitamin C): Ascorbic acid contents were determined by titration with N-Bromosuccinimide

(Barakat et al., 1955) with slight modifications. Thirty grams of pods, chopped with a kitchen knife, were placed in a blendor together with 60ml of 10% aqueous solution of trichloroacetic acid. The mixture was blended at high speed for three minutes. It was then filtered through Whatman No. 41 filter paper. Ten millilitres of the filtrate were pippeted into a 200ml conical flask, and 5ml of a 4% aqueous solution of potassium iodide added, followed by 2 ml of a starch solution. The mixture was then titrated with a solution of N-Bromosuccinimide containing 100mg in 1000ml of distilled water. The end point was indicated by a faint violet/blue colour that persisted for at least 15sec. The ascorbic acid content was calculated from the following formula:

Ascorbic acid = V x C x 176/178

Where V = volume (ml) of N-Bromosuccinimide used.

C = concentration of N-Bromosuccinimide as mg per ml.

176/178 = ratio of the molecular weight of ascorbic acid to that of N-Bromosuccinimide

The ascorbic acid content were expressed as mg/100g (DMB).

3.2.2.3: Determination of chlorophyll: Chlorophyll was determined as optical density by modified AOAC methods (AOAC, 1984), as follows:

Half gramme of the sample was weighed into a mortar. This was thoroughly crushed using a pestle, then the pigment extracted completely with 5ml portions of diethylether. The combined extracts were made to volume in a 25ml volumetric flask and dried with anhydrous sodium sulphate. The absorbance was determined on a

Beckman model 25 spectrophotometer at 428nm, using a 1cm cuvette. The absorbance was finally converted to that corresponding to 0.05g dry matter.

3.2.2.4: Determination of crude protein: Crude protein was determined as total nitrogen by the micro-Kjeldahl method (AOAC, 1984). Percentage of total nitrogen was multiplied by the factor 6.25 to convert it to percentage of proteins. 0.5g of sample was weighed on a nitrogen-free filter paper and placed into a Kjeldahl flask. One Kjeldahl tablet was added together with two antibumping pumice, followed by 20ml of concentrated sulphuric acid. The flask was placed on a Kjeldahl heating plate and heated at low setting till all frothing stopped and a clear solution remained. Heating was changed to high setting and the mixture digested for another two hours. After cooling to room temperature, the white residue was dissolved in a minimum amount of distilled water then transfered to a distillation flask. The solution was mixed with 100ml distilled water and sufficient 40% sodium hydroxide solution added to make the mixture alkaline to phenolphthalene indicator. The mixture was then heated on an electric mantle to distill off the ammonia, which was received in a 250ml conical flask containing 50ml of 0.1N hydrochloric acid and two drops of methyl orange indicator. Distillation was considered complete when 150ml had been collected The quantity of nitrogen in the distillate was determined by back-titration with 0.1N sodium hydroxide.

3.2.2.5: Determination of total ash: Total ash was determined by AOAC methods (AOAC, 1984). Two grammes of sample were weighed in a porcelain ashing crucible, previously dried in an oven at 105°C, cooled and tared. The dish was then held in a muffle furnace at 550°C overnight. It was cooled to room temperature in a desiccator and weighed. The weight of the residue was converted to percent total ash.

3.2.2.6: Determination of crude fibre: Crude fibre was determined by AOAC methods (AOAC 1984). Two grams of sample were weighed into a 600ml beaker and 25ml of 2.04N sulphuric acid added. The volume was increased to 200ml with boiling water, and the sample boiled for exactly 30 minutes with occasional stirring, while maintaining the volume at 200ml with the hot distilled water. The sample-acid mixture was filtered through glass wool and the residue washed three times with hot distilled water. The residue and glasswool were quantitatively transfered back to the 600ml beaker and boiled for exactly 30 minutes with 25ml of 1.78N potassium hydroxide, always in a total volume of 200ml hot distilled water. The sample-base-glasswool mixture was filtered quantitatively through more glass wool and washed thrice with hot water, then with 15ml of 95% ethyl alcohol. The residue and glasswool were quantitatively transfered into a porcelain dish and dried at 105°C in an air-oven to constant weight. The dish was cooled in a desiccator and weighed. The dish, glass wool and residue were ignited in a muffle furnace at 550°C for 4 hours, then cooled in a desiccator and weighed. The percent of fibre was calculated from the equation:

$$\% \text{ Fibre} = \frac{\text{Weight of dish after drying} - \text{Weight of dish after igniting} \times 100}{\text{Weight of sample}}$$

3.2.2.7: Determination of nitrates: Nitrate contents of the pods were determined by the method of Cataldo et al. (1975) with slight modification. A hundred milligrams of sample were suspended in 10ml distilled water and incubated at 45°C for one hour. After filtration through Whatman No. 41 filter paper, 0.2ml of the filtrate was pipetted into a 50ml test tube and 0.8ml of a 5% (w/v) solution of salicylic acid in concentrated sulphuric acid was added and mixed thoroughly. The mixture was left to stand for 20 minutes at room temperature before adding 19ml of 2N sodium hydroxide. After cooling for 30 minutes the absorbance was read on a Beckman model 25 spectrophotometer at 410nm against a common blank (0.2ml distilled water + 0.8ml of salicylic acid in concentrated suphuric acid + 19ml 2N sodium hydroxide). The nitrate content was calculated from a standard curve prepared from absorbance values of pure potassium nitrate solutions in distilled water.

3.3: *Statistical Analysis of Data*

The data obtained were subjected to analysis of variance (ANOVA) using methods illustrated by Steel and Torrie (1981). Separation of means was by least significant difference test, at 5% probability level, as illustrated by the same authors.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 *Dry Matter Accumulation*

Nitrogen application had a significant effect ($p \geq 0.05$) on dry matter accumulation in the leaves sampled at the bloom and pod stages (7 and 8 weeks from planting, respectively) in the first season (Figure 1a). At blooming stage, plants that were supplied with N produced leaves with significantly higher dry matter than those that were not. However, application of more than 26kgN/ha did not significantly increase the leaf dry matter. During podding, plants that had been topdressed with more than 26kgN/ha produced leaves with significantly higher dry matter than those that were not topdressed. Application of more than 52kgN/ha, did not significantly increase the dry matter content of the leaves. In the second season (Figure 1b), application of N to plants had no significant effect on the dry matter contents of the leaves. However, the plants that were supplied with N tended to produce leaves that had higher dry matter than those that were not.

The results obtained in the first season indicated that a higher N rate was needed to increase the leaf dry matter during podding than at the seedling or blooming stages. The probable explanation could be the high competition for photosynthates between the

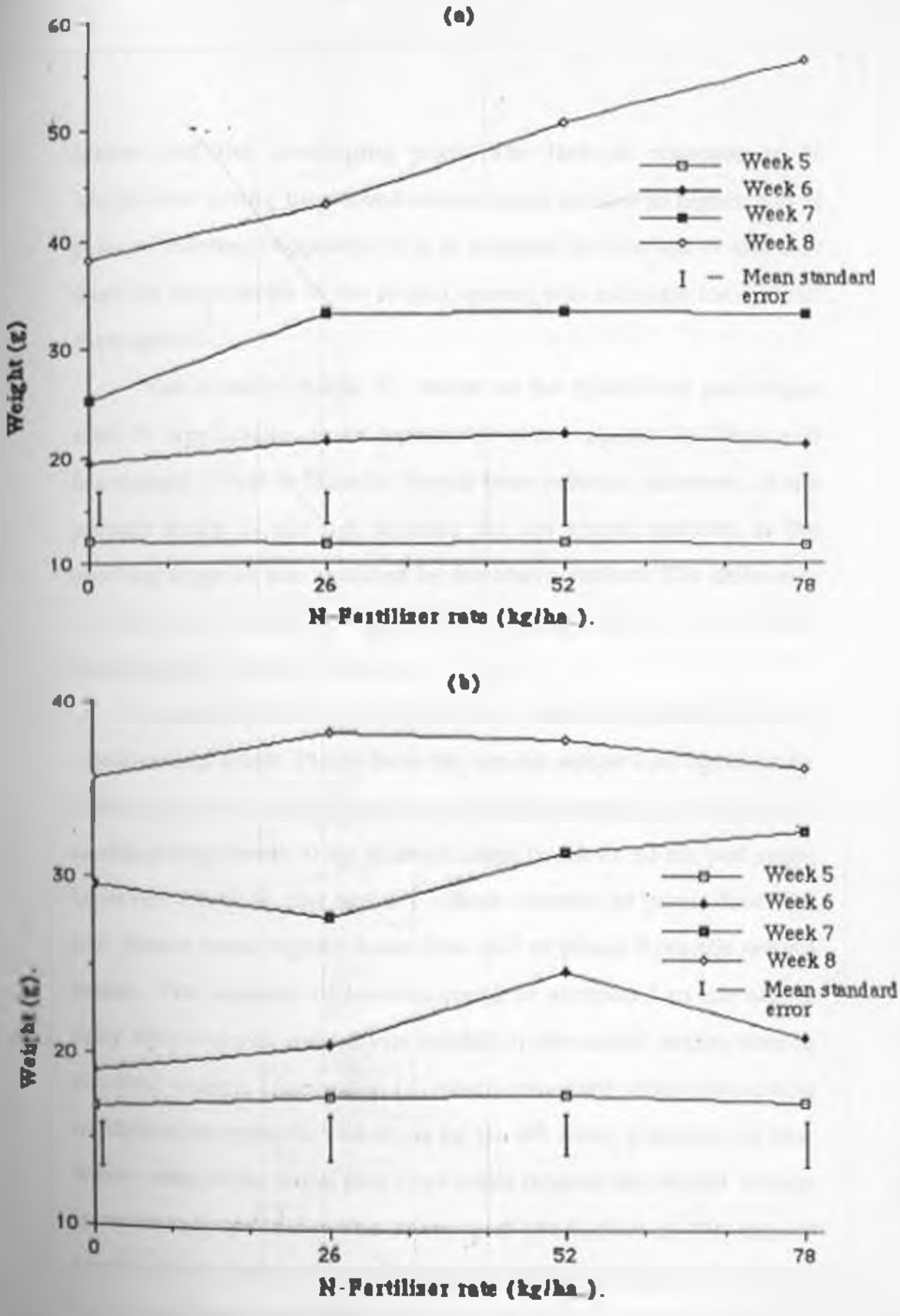

Figure 1: Effects of N-Fertilizer rates on accumulation of dry matter in French Bean (*P. vulgaris (L.)*) leaves.
(a) Season one (b) Season two.

leaves and the developing pods. The lack of response to N application during the second season could be due to higher soil N prior to planting (Appendix 2). It is probable that the soil N and that fixed by the nodules in the second season, was adequate for optimal plant growth.

The increase in leaf dry matter at the bloom and pod stages with N application is in agreement with reports by Peck and Macdonald (1984) in Humilis French bean cultivar. However, in the present study, N did not decrease the dry matter contents at the seedling stage as was reported by the above authors. The difference in response could be attributed to differences in the soil characteristics and the cultivars.

Seasonal effect on the leaf dry matter accumulation was significant.($p \leq 0.05$). Plants from the second season had significantly more dry matter than those from the first season, right from the seedling stage (week 5) up to bloom stage (week 7). At the pod stage, however, (week 8), the leaf dry matter contents of plants from the first season were slightly more than that of plants from the second season. The seasonal differences could be attributed to the higher daily temperatures and heavier rainfall in the second season than in the first season (Appendix 1), which provided more favourable conditions for growth. Therefore, by the 8th week, plants in the first season were at the initial pod stage while those in the second season were already podding. The heavy pod production in the second season could have reduced the photosynthates supply to the leaves due to increased competition between the leaves and the pods thus reducing the dry matter accumulation in the leaves.

Application of N had significant effects on the dry matter accumulation in the stems during the podding stage in the first season (Figure 2a). Plants that were topdressed with more than 26kgN/ha produced stems with significantly higher dry matter than those that were not. Application of more than 52kgN/ha, however, did not increase the dry matter contents significantly. N had no significant effect on the dry matter of stems in the second season (Figure 2b). Generally, the plants that received N produced stems with higher dry matter than those from the control plots.

Plants grown in the second season accumulated more dry matter than those from the first season (Figures 2a and 2b). This was probably due to the more favourable climatic conditions in the second season which resulted in more vigorous vegetative plant growth compared to that of the first season (Appendix 1). The higher soil nitrogen in season two could also be responsible for more dry matter accumulation in the stems. High nitrogen fertilizer rates have been reported to decrease dry weight of french beans at the seedling stage of development only. (Peck and Macdonald., 1984, Robinson et al., 1965).

Nitrogen application had a significant effect on dry matter accumulation in the nodules. In the first season (Figure 3a), only topdressing with more than 52kgN/ha significantly reduced the nodule dry matter at the early seedling stage (week 5). The differences between the effects of the other N rates and the control were not significant. Samples taken at bloom stage (week 7) showed that plants that were supplied with nitrogen produced nodules with significantly lower dry matter than those that were not. The dry

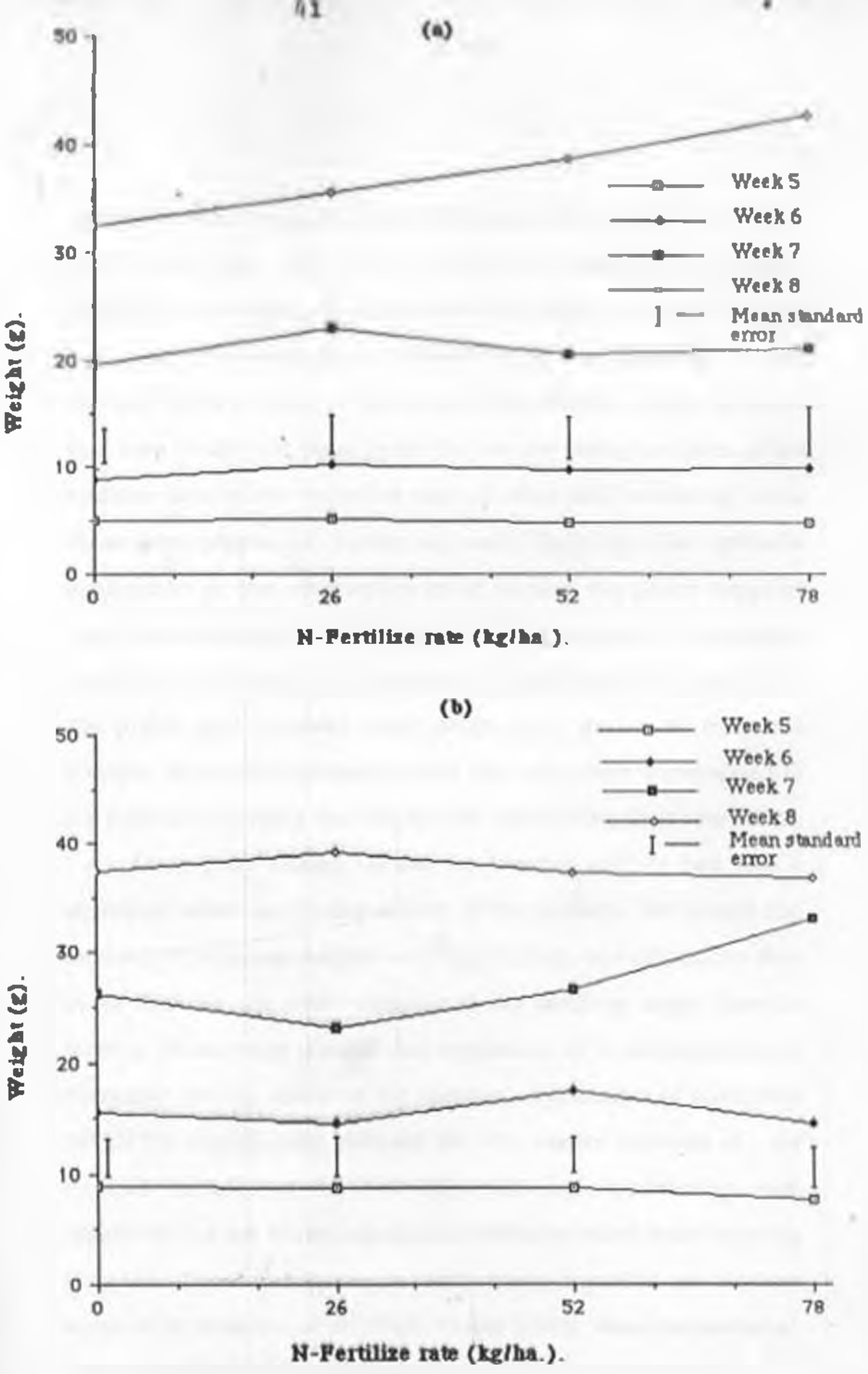

Figure 2: Effects of N-Fertilizer rates on accumulation of dry matter in French Bean (*P. vulgaris (L)*) stems.
(a) Season one (b) Season two.

matter contents of nodules from the topdressed plants did not differ significantly from each other. Plants that were topdressed had nodules with significantly lower dry matter contents than those that were not. Application of more than 26kgN/ha, however, did not decrease the dry matter of the nodules significantly. Figure 3a shows that even at the pod stage (week 8), the dry matter contents of the nodules from plants supplied with N were still increasing while those from plants not topdressed were declining. The probable explanation to this observation could be that the plants supplied with N had enough N even at the pod stage such that the pods did not draw the N stored in the nodules. On the other hand, pods from the plants that received none could have drawn N from the nodules. More photosynthates could also have been translocated to the pods thus starving the nodules and accelerating their senescence.

During the second season, topdressing with N had also a significant effect on the dry matter of the nodules. The plants that received N produced nodules with significantly less dry matter than those that did not when sampled at the seedling stage. Samples taken at bloom stage showed that application of N also significantly decreased the dry matter of the nodules. Application of more than 26kgN/ha significantly reduced the dry matter contents of the nodules sampled at the pod stage although topdressing with 78kgN/ha did not have a significantly different effect from applying 52kg/ha. These results agree with those reported on various legumes by Robinson et al. (1965), Fontes (1972), Westermmann et al. (1982), Eaglesham et al. (1983), and Peck and Macdonald (1984).

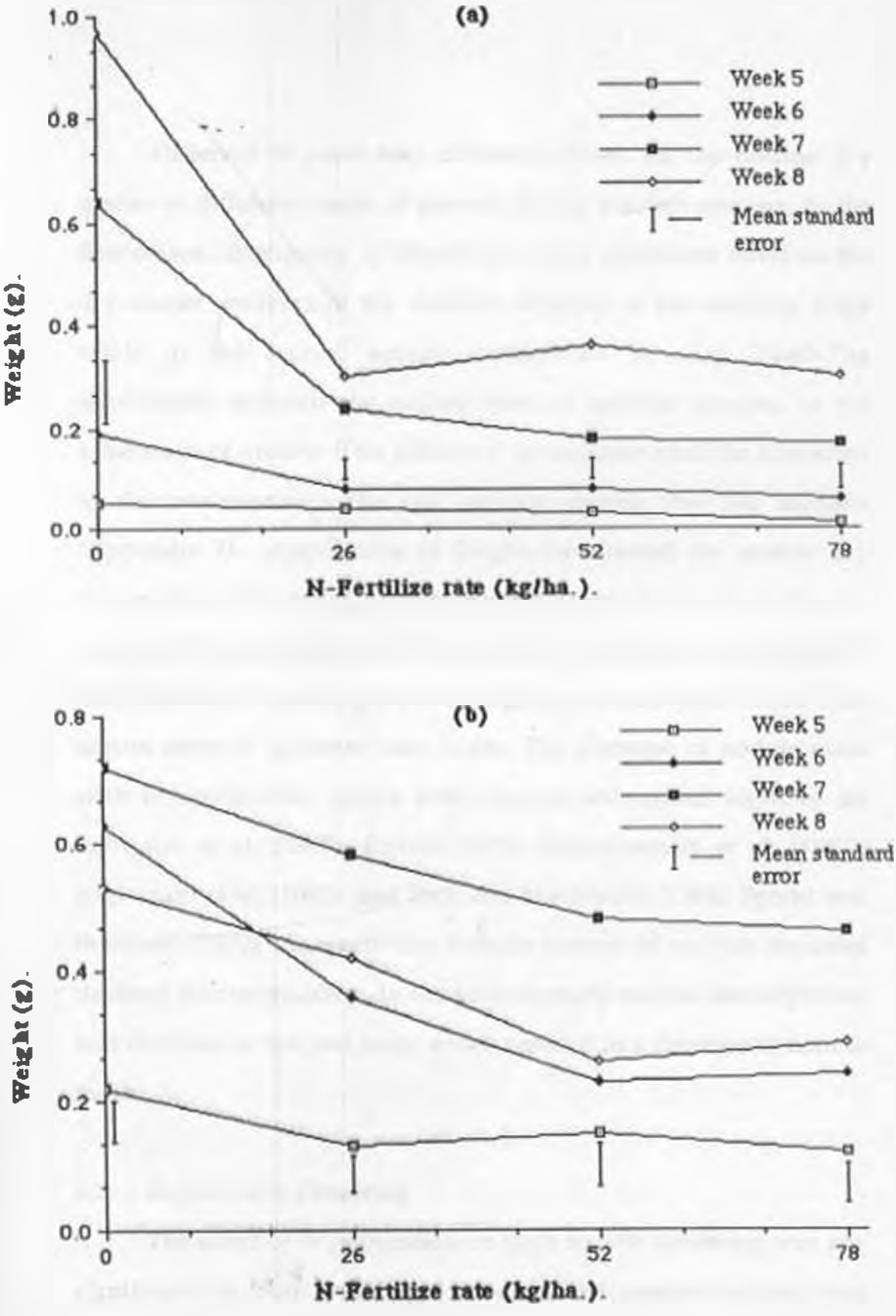

Figure 3: **Effects of N-Fertilizer rates on accumulation of dry matter in French Bean (*P. vulgaris (L)*) nodules.**
(a) Season one (b) Season two.

Different N rates had different effects on the nodule dry matter at different stages of growth during the two seasons. In the first season, application of 78kgN/ha had a significant effect on the dry matter contents of the nodules sampled at the seedling stage while in the second season, application of only 26kgN/ha significantly reduced the nodule mass of nodules sampled at the same stage of growth. This difference in response could be attributed to the variations in the soil fertility during the two seasons (Appendix 2). Application of 26kgN/ha affected the nodule dry matter at the bloom stage in the second season but not during the first season. The higher soil N contents in the second season could have inhibited nodule growth to a greater extent than in the first season when N contents were lower. The decrease of nodule mass with N application agrees with reports on various legumes by Robinson et al. (1965), Fontes (1972), Westernmann et al. (1982), Eaglesham et al. (1983), and Peck and Macdonald (1984). Sprent and Bradford (1977) observed that nodule masses of various legumes declined during podding. In the present study nodule disintegration was observed at the pod stage which resulted in a decrease in nodule mass.

4.2: Days to 50% Flowering

The effect of N application on days to 50% flowering was not significant in both seasons. However, the seasonal effect was significant. In the first season, 50% flowering was attained after 47 days from planting while in the second season, it was attained at 40 days from planting. This seasonal variation could be attributed to

the higher daily temperatures and heavier rainfall in the second season (Appendix 1), both of which accelerated plant growth. Mcewan (1970) also reported no effect of N on days to 50% flowering in other bean cultivars.

4.3: Total and Marketable Pod Yields

Table 1 shows the effect of N application on total and marketable pod yields. The effect was not significant on both yields. Nitrogen application, however, tended to increase the reject grade pods. This was observed to be due to attack by rot organisms. During the experiment, it was observed that N application increased plant lodging which resulted in many pods touching the soil, thereby increasing pod rot especially during the rainy period. Most of the rotten pods were of the fine grade pod size particularly those on the lower plant nodes. The rot problem was mainly noticed during the second season during which rains were very heavy.

There were seasonal variations in the yields of the total, and marketable pods. In the first season, the average yields of the total, fine and the extra-fine grade pods were 15.4, 12.53 and 2.88 ton/ha respectively. In the second season, the total yields were on the average 16.33 ton/ha while the extra-fine pod yields were 3.19 ton/ha. The yields of the fine grade pods decreased to 9.69 ton/ha in the second season due to the rot problem. The more favourable climatic conditions could have been responsible for the higher yields in the second season than in the first season.

Table 1 Effect of nitrogen rates on total and marketable pod yields of French Beans (*Phaseolus Vulgaris* L.) var monel

Nitrogen rates (kg /ha)	Yields (tons/ha)							
	First experiement			Second experiment				
	Fine	Extra Fine	Total marketable	Fine	Extra Fine	Total marketable	Rejects	Total
0	13.30 (0.64)	2.90 (0.89)	16.20 (1.36)	9.72 (1.54)	3.61 (0.81)	13.33 (1.55)	2.68 (0.66)	16.01 (2.38)
26	11.20 (2.08)	2.90 (0.06)	14.10 (2.04)	9.57 (1.85)	2.86 (0.42)	12.43 (3.48)	3.66 (0.34)	16.09 (2.69)
52	12.60 (0.49)	2.90 (0.50)	15.50 (0.67)	9.70 (1.50)	3.05 (0.54)	12.76 (1.18)	3.12 (0.61)	15.87 (2.35)
78	13.00 (1.27)	2.80 (0.44)	15.80 (0.93)	9.78 (1.70)	3.25 (0.57)	13.03 (1.12)	4.31 (0.97)	17.34 (2.73)

( ) standard deviations (N=3)

The findings that N had no significant effects on pod yields is in agreement with results of other workers on different French bean cultivars. Smith (1977) found no effect of N application on the yields of Bush Blue Lake cultivar, while Mullins (1987) reported a similar response by eight French bean cultivars. The finding that N application had no effect on marketable pod yields agree with report by Doss et al. (1977), who found that N had no consistent effect on grade distribution among French bean plants. However, N significantly increased the reject grade pod yields. Similar findings were made by Mullins (1987) in other French bean cultivars.

Generally, leguminous crops do not respond by yield increases to soil or applied N to the same degree as other crops. Maximization of fixation of atmospheric N has been suggested as a better way of increasing yields (Miller et al., 1982). Response to high N rates have been reported only on very sandy soils (Busanda et al., 1982). Maximum yields of snap beans have been obtained with N at 17 to 56kg/ha (Paterson et al. 1966, Worley and Harman, 1967.,Asif and Greig, 1972., Doss et al., 1977., and Smith, 1977).

In the present study, it is probable that the N supply from the soils and that from the nodule fixation was adequate for optimal pod production. From the results prior to planting, the soils were found to contain 2635.38ug/g and 2962.10ug/g in the first and second seasons, respectively. Therefore, dry matter was accumulated in the vegetative tissues at the expense of pod production with additional fertilizer nitrogen. However, it would be important to establish the correlation between dry matter and yields. It is probable that plants

with a higher dry matter accumulation would have a longer harvest period than those with less thus resulting in higher yields.

4.4: Protein Content

Table 2 shows the effect of N application on the protein contents of the fine and extra-fine grade pods. The effect was not significant during the two seasons. Differences in protein content between the grades were however, significant during the second season only. The extra-fine grade pods had a higher average protein content of 20.22% than the fine grade pods which had an average of 16.33% protein. This difference could be attributed to the age of the pods. Brown and Broadbent (1950) reported that protein synthesis is fastest in young cells that are actively growing. Since the extra-fine grade pods are younger than the fine grade pods, more amino acids are translocated to them so as to sustain the high growth rate. It is also likely that the extra-fine pods have a higher concentration of the cytokinin hormones which have been reported to affect the rate of protein synthesis by Skoog and Armstrong (1970).

The results from the present study do not agree with those obtained by Peck and Macdonald (1984) in Humilis French bean cultivar, that N application increased the protein content in the bean pods. The variation could be due to differences in cultivar efficiency in amino acid assimilation and in the differences in the growing conditions.

Table 2 Effect of nitrogen rates on percent crude protein in French Beans

	% Proteins									
	First experiment				Second experiment					
	1st harvest (9 weeks after planting)		2nd harvest (12 weeks after planting)		1st harvest (9 weeks after planting)		2nd harvest (10 weeks after planting)		3rd harvest (12 weeks after planting)	
Nitrogen rates (Kg/ha)	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine
0	23.10 (4.45)	28.10 (7.07)	20.60 (0.92)	24.40 (0.00)	15.17 (2.53)	17.79 (0.62)	19.72 (0.79)	21.00 (3.85)	12.43 (1.78)	20.59 (1.24)
26	24.40 (6.22)	28.50 (6.58)	21.90 (0.00)	25.00 (0.00)	14.70 (1.39)	16.51 (0.20)	19.94 ((0.76)	23.51 (0.37)	13.36 (1.07)	20.42 (1.85)
52	25.70 (6.15)	28.50 (8.41)	21.90 (1.77)	23.80 (0.00)	14.58 (1.80)	16.57 (1.94)	20.83 (0.63)	22.99 (0.27)	13.42 (0.82)	21.47 (0.86)
78	27.80 (3.11)	28.80 (6.15)	21.90 (0.00)	23.80 (0.00)	16.63 (2.63)	18.55 (1.67)	20.42 (0.10)	22.29 (0.10)	14.70 (3.38)	21.00 (1.72)

( ) standard deviation (N=3)

4.5: Total Ash

Effect of N application on total ash was significant only in the fine grade pods harvested after 9 weeks from planting during the first season Table 3 shows that the ash contents did not show a consistent trend with increasing rates of N. Pods harvested from plants that were not top-dressed with N, however, had significantly higher ash content than those from the top-dressed plants.

Although the effect of nitrogen application on the ash content was not significant at all the harvests, there was a decreasing trend in ash contents in both grades.

The grades differed significantly in their ash contents. Except in the pods harvested after 9 weeks from planting during the first season, the extra-fine grade pods had significantly higher ash contents than the fine grade pods. Nitrogen application generally tended to decrease total ash content.

Janes (1951) reported that N rates had no effect on percent minerals in the Tendergreen and the Bountiful French bean cultivars grown in Florida. However, the same author reported that climate and location significantly affected the mineral composition of the crops. Therefore the decreasing trend observed in the present study could be attributed to the climatic variations and soil characteristics of the experimental sites. There could also have been a dilution effect on the minerals as N increased plant growth. The higher mineral contents in the extra-fine grade pods could have been due to faster translocation of the ions to the more actively growing younger extra-fine pods.

Table 3 Effect of nitrogen rates on percent total ash in French Beans

	% Ash									
	First experiment				Second experiment					
	1st harvest (9 weeks after planting)		2nd harvest (12 weeks after planting)		1st harvest (9 weeks after planting)		2nd harvest (10 weeks after planting)		3rd harvest (12 weeks after planting)	
Nitrogen rates (Kg /ha	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Exatra fine	Fine	Extra fine
0	9.76[a] (0.04)	8.14 (0.03)	7.16 (0.03)	7.42 (0.33)	7.57 (1.35)	12.37 (1.74)	9.00 (0.00)	9.60 (0.10)	6.23 (5.43)	6.87 (0.49)
26	10.04[b] (0.37)	8.14 (0.03)	7.14 (0.28)	7.27 (0.37)	6.90 (0.10)	10.87 (0.23)	9.00 (0.00)	9.40 (0.26)	5.43 (1.27)	7.07 (0.40)
52	8.87[c] (0.40)	8.19 (0.04)	6.85 (0.31)	7.22 (0.00)	6.50 (0.82)	11.97 (1.42)	9.00 (0.00)	9.23 (0.57)	5.93 (0.64)	7.47 (0.45)
78	9.24[d] (0.00)	8.16 (0.72)	6.70 (0.09)	7.27 (0.37)	7.83 (2.14)	11.10 (0.75)	9.00 (0.00)	8.57 (0.76)	5.50 (0.40)	6.67 (0.76)

( )standard deviation (N=3)

Means in the same column followed by the same letter(s) are not significantly different (P≤ 0.05) according to Least Significant Difference test.

According to Salisbury and Ross (1978), ion uptake by growing cells is faster than by non-growing cells due to the dilution effect by absorbed water upon the ion concentration gradient across the membranes of growing cells. The lower ash contents of the extra-fine grade pods harvested after 9 weeks in the first season could have been due to reduced translocation of minerals from the older pods and vegetative tissues to the younger pods due to reduced daily temperatures. Asif and Greig (1977) reported that low temperature in the fall, lowered the translocation of minerals like Potassium, Copper and Calcium from the vegetative tissues to the pods in French bean plants.

4.6 Crude Fibre Content

Table 4 shows the effect of N application on the fibre content of bean pods. A significant N application effect was observed only in the fine grade pods harvested after 12 weeks from planting in the first season. The plants topdressed with more than 26kgN/ha produced pods with significantly lower fibre contents than those topdressed with less or none. The fibre contents of the pods decreased with increase of N applied. Generally, topdressing with N tended to reduce the fibre contents of the pods.

The present results that N decreased the fibre contents are in agreement with the report by Nygaard (1984) on white cabbage.

Table 4 Effect of nitrogen rates on percent fibre in French Beans

	% Fibre									
	First experiment				Second experiment					
	1st harvest (9 weeks after planting)		2nd harvest (12 weeks after planting)		1st harvest (9 weeks after planting)		2nd harvest (10 weeks after planting)		3rd harvest (12 weeks after planting)	
Nitrogen rates (Kg /ha)	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine
0	14.00 (1.41)	14.00 (1.41)	14.00[a] (0)	13.50 (0.71)	19.33 (1.53)	17.66 (0.58)	16.33 (1.15)	17.33 (0.58)	14.67 (0.58)	15.00 (1.0)
26	14.00 (1.41)	13.50 (0.71)	14.00[a] (0)	12.50 (0.71)	17.00 (0)	17.33 (1.15)	16.00 (1.0)	17.33 (0.58)	14.33 (0.58)	14.67 (1.15)
52	13.50 (0.71)	13.00 (0)	13.00[b] (0)	12.00 (0.71)	17.00 (0.82)	17.33 (1.15)	16.00 (1.0)	17.33 (0.58)	14.33 (0.58)	14.33 (0.58)
78	12.50 (0.71)	12.00 (0)	12.00[c] (0)	12.00 (0)	16.33 (0.58)	17.33 (0.58)	16.00 (1.0)	17.33 (0.58)	14.33 (0.58)	13.67 (0.58)

( ) standard deviation (N=3)

Means in the same column followed by the same letter(s) are not significantly different ($P \leq 0.05$) according to Least Significant Difference Test.

Krauss and Marschner (1971) observed that N fertilizer promoted the activity of sucrose synthetase, which converts sucrose into uridine diphosphate glucose (UDP) in storage tissues. Uridine diphosphate is a precusor of polyuronic acid and cellulose. High N supply during the filling period of vegetative storage tissues favours the growth of the storage organs but reduces filling of the cells with carbohydrates. Such tissues remain in a juvenile condition. This may explain why pods harvested from plants that were supplied with N differed significantly in their fibre contents from those harvested from plants that were not.

4.7: Nitrates Accumulation

Effect of N application on nitrates accumulation was significant in the extra-fine grade pods harvested after 12 weeks from planting and in the fine grade pods harvested after 10 weeks from planting, in the first and second seasons respectively. Table 5 shows that the nitrate content increased with increasing rates of N. Pods harvested from plants that were not top-dressed with N had significantly lower nitrate content than those from plants that were top-dressed.

Table 5 Effect of nitrogen rates on nitrate-nitrogen accumulation in French Beans

	Nitrate-Nitrogen (mg/g)									
	First experiment				Second experiment					
	1st harvest (9 weeks after planting)		2nd harvest (12 weeks after planting)		1st harvest (9 weeks after planting)		2nd harvest (10 weeks after planting)		3rd harvest (12 weeks after planting)	
Nitrogen rates (Kg/ha)	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine
0	1.8 (0.6)	0.8 (0)	2.6 (0)	2.0[a] (0.07)	1.67 (0.66)	1.91 (0.67)	2.50[a] (0.25)	1.07 (0.30)	4.12 (0.34)	4.26 (0.42)
26	2.7 (0.6)	1.00 (0.2)	3.1 (0.1)	2.1[ab] (0.2)	1.57 (0.37)	1.94 (0.05)	2.85[b] (0.34)	1.07 (0.30)	4.12 (0.38)	4.21 (0.56)
52	2.7 (0.6)	1.50 (0.07)	3.0 (0)	2.3[b] (0.07)	1.82 (0.14)	2.42 (0.55)	3.65[c] (0.47)	1.14 (0.16)	4.51 (0.09)	5.05 (0.01)
78	2.8 (0.6)	1.40 (0.2)	3.2 (0.1)	3.5[c] (0.4)	1.71 (0.21)	1.91 (0.19)	3.78[d] (0.11)	1.32 (0.20)	4.19 (0.32)	4.46 (0.48)

( ) standard deviation (N=3)

Means in the same column followed by the same letter(s) are not significantly different ($P \leq 0.05$) according to Least Significant Difference test.

The nitrate contents of pods from plants that were top-dressed with 26kgN/ha did not differ significantly from the control in the first season whereas applying more N significantly increased the nitrate contents. In the second season N application incresed nitrate contents in the fine grade pods harvested after 10 weeks from planting.

Grades differed significantly in their nitrate contents in the first season only. The fine grade pods harvested after 12 weeks from planting had higher nitrate content than the extra-fine grade pods. Nitrogen application significantly affected the nitrate contents of the fine grade pods harvested after 10 weeks from planting in the second season. Pods from plants that received N contained more nitrates than those from plants that were not topdressed. The effect of N rates on nitrate levels in the second season was similar to that observed in the first season. Increase of nitrates with N application has been reported by Asif and Greig (1977) and by Peck and Macdonald (1984) in Humilis and Topcrop French bean cultivars respectively. Nilsson (1979) reported similar results on carrots, cabbage and leeks. The nitrate concentration obtained in the present experiment ranged between 0.08 and 0.35% in the first season and between 0.11 and 0.50% in the second season. These levels were much lower than the lethal dose of 15-70mg per kg of body weight (Burden, 1961., Lee, 1970). The probable explanation for the high nitrate levels in the extra fine grade during the second season (2nd harvest) could be due to the lower daily temperatures which could have reduced the activity of the nitrate reductase resulting in more unreduced nitrates being translocated to the young growing pods

(Maynard and Barker, 1978). In the second season, N application significantly increased the nitrate levels in the fine grade pods harvested after 10 weeks from planting. This coincided with the peak pod production and it is probable that more nitrates were absorbed and translocated to the pods whereby more were accumulated in the older fine grade pods. Therefore, any excess nitrate was accumulated in the pods. Less accumulation occured in the extra-fine grade pods probably due to faster growth rate which could have had a dilution effect.

The increase of nitrates in the pods as harvest progressed could have been due to a possible high N availability throughout the growing periods and also the age of the plants. Work by Westernmann et al., (1981) showed that N uptake by beans increased linearly from pod development to physiological maturity. McElhannon and Mills (1978) also noted peak nitrates absorption at flower set, pod set and pod filling stages of development in lima beans (*Phaseolus lunatus L*). Maynard et al., (1976) reported a higher nitrate content in older celerly and lettuce petioles grown on soils with a high nitrate content. Similar results were obtained in the present study whereby nitrate concentration increased in both the fine and extra fine grades as harvest progressed but a higher accumulation was noted in the older fine grade pods.

4.8. Weight Loss During Storage

The effects of nitrogen application and storage temperature on weight loss in French beans was not significant ($p \leq 0.05$) in both seasons. The two grades differed significantly ($p \leq 0.05$) in their rates

of weight loss as shown in Tables 6a and 6b. The extra-fine grade pods consistently lost weight faster than the fine grade pods at both temperatures of storage. By the second day of storage at room temperature, the extra-fine grade pods had lost over 10% of their original weight and signs of senescence were very pronounced. By the third day, the pods were severely shrivelled, had developed tiny depressions on their surfaces, were dull in colour and were therefore declared unfit for sale. By the third day at room temperatures, although signs of senescence were not very severe (Plate 2), the fine grade pods were fairly wilted such that the seeds bulged out of the pods forming constrictions on the pod surface. With some sorting out, a small proportion of the pods could still be sold. By the fourth day at room temperatures, symptoms of senescence were very pronounced and the pods had lost about 14% of their original weight. In the second season, the pods maintained their quality for a shorter time at room temperatures than in the first season, probably due to the higher daily temperatures and lower relative humidities in the second season than in the first season (Appendix 1). These conditions also varied during the growing periods and this could have had an effect on the physiological maturity of the pods at harvest.

Table 6a Percent weight Loss During Storage

SEASON 1

Storage temperature	23 ± 1°C								4 ± °C					
Days in storage	1		2		3		4		4		6		8	
Nitrogen rate (kg /ha)	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine
0	3.73 (1 37)	5.77 (0.50)	6.88 (1.88)	11.37 (1.21)	11.6 (3.06)	-	13.60 (2.90)	-	3.27 (0.46)	9.10 (0.26)	7.20 (0.61)	11.10 (1.71)	7.8 (0.49)	12 (1.70)
26	2.80 (0.17)	6.93 (1.55)	5.80 (0.10)	13.53 (3.03)	8.67 (1.29)	-	12.1 (1.50)	-	3.33 (0.21)	9.9 (1.65)	7.70 (1.13)	1.40 (1.37)	8.57 (0.99)	13.97 (1.50)
52	3.03 (0.06)	5.53 (0.21)	6.40 (0.56)	10.40 (3.27)	11.33 (0.76)	-	14.87 (0.72)	-	3.33 (0.15)	10.27 (2.46)	6.53 (0.35)	12.57 (1.72)	7.53 (0.31)	13.13 (1.01)
78	3.40 (0.89)	6.93 (1.95)	5.90 (0.62)	12.33 (2.45)	14.87 (0.46)	-	14.03 (0.21)	-	3.40 (0.26)	10.13 (0.64)	6.90 (0.26)	12.43 (1.99)	7.60 (0.26)	13.10 (0.04)

( ) standard deviation (N=3)

- Produce had already perished.

Table 6b Percent weight Loss During Storage

SEASON 2															
Storage temperature	25 ± 1°C						4 ± 1°C								
Days in store	1		2		3		2		4		6		8		
Nitrogen rate kg/ha.	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	
0	4.90 (0.97)	6.92 (0.69)	10.12 (1.96)	15.1 (2.45)	16.18 (3.07)	-	3.65 (0.41)	5.40 (0.56)	6.02 (0.65)	10.28 (1 01)	9.64 (0.81)	15.8 (1.35)	12.19 (2.33)	19.19 (2.06)	
26	4.23 (0.68)	6.37 (0.49)	8.14 (0.86)	13.92 (1.44)	13.08 (0.78)	-	3.74 (0.16)	4.76 (0.37)	6.17 (0.42)	9.21 (0.50)	8.93 (0.77)	14.24 (0.70)	10.80 (1.09)	15.96 (2.15)	
52	3.77 (0.16)	6.06 (0.34)	7.55 (0.63)	14.52 (1.09)	11.79 (0.51)	-	3.18 (0.33)	5.23 (0.52)	5.74 (0.40)	10.37 (0.92)	8.67 (0.48)	15.5 (1.06)	10.30 (0.55)	17.31 (0.42)	
78	4.15 (0.20)	6.00 (0.49)	8.86 (0.62)	12.86 (1.21)	13.69 (0.01)	-	3.30 (0.12)	4.87 (0.31)	5.78 (0.19)	10.10 (0.85)	9.12 (0.36)	14.90 (1.08)	11.77 (0.53)	18.53 (3.79)	

( ) standard deviation (N=3)

- Produce had already perished.

a b

Plate 1 Freshly harvested fine (a) and extra-fine (b) grade pods
Note the bright green colour, turgidity of the pods and the smooth surfaces.

c d

Plate 2 Pods after three days storage at room temperature (23 ± 1°C).
Note the bulging seeds in the fine grade pods (c) and the severe shrivelling of the extra-fine pods (d).

The results obtained in the experiment indicate that, the fine and the extra-fine grades could be considered as having lost their salable quality after they had lost about 7% and over 10% respectively of their original weights. Then, the fine grade maintained quality for three days while the extra-fine grade maintained quality for only two days at room temperatures. Termination of shelf-life was not based on weight loss alone but other subjective quality factors which have been associated with French bean quality were also considered. These factors included pod turgidity, which was evaluated in a snapping test, colour, presence of depressions on the pod surface and presence of stains.

The percent weight loss of the pods before being declared unsalable was slightly higher than the 5% and 6% reported by Robinson et al. (1975) for Runner beans and Broad bean cultivars respectively. The same authors also used the same subjective quality factors to evaluate shelf life of the beans. However, the present results agree with reports by Shewfelt et al. (1985) who observed significant desiccation in beans held at 21°C, 70% RH after only four days of storage. The same authors found out that appearance quality factors were very important in overall acceptability of fresh beans. The slightly higher percent weight loss before the beans were considered unsalable in the present study could be due to variation in sensitivity to storage temperatures between cultivars. Gorini et al. (1973) reported a weight loss range of between 3.48 to 12.72 percent in various French bean cultivars which were hydrocooled then stored for three days at 4°C. Beans stored for seven days were found to lose between 9.40 and 27.17 percent of their original weights. The faster

loss of weight by the extra-fine grade pods was due to their larger surface area to volume ratio.

Weight loss at 4°C was lower than that at room temperature. Symptoms of senescence were first noticed on the extra-fine grade on the fifth day of storage, and on the sixth day on the fine grade. Although the weight loss from pods of all treatments increased with storage time, the extra fine grade lost weight faster than the fine grade. However, as shown in plate 3, although the pods still looked fairly firm and turgid after four days of storage, symptoms of chilling injury had already started showing, which hastened the termination of shelf-life. Watada and Morris (1966) and Gorini et al. (1973) also reported that lower temperatures of storage extended the shelf-life of various bean cultivars, but depending on their susceptibility to chilling injury.

a b

Plate 3 Extra fine (a) and fine (b) grade pods after storage at 4 ± 1°C for four days. Note the mild pitting of the pod surface

c d

Plate 4 Extra fine (c) and fine (d) grade pods after storage at 4 ± 1°C for eight days. Note the pronounced and extensive pitting.

According to the standard specifications for good quality, French beans for Kenyan fresh market (KBS, 1983), the extra fine grade can at most store for only two days at 4°C and the fine grade for three days, judged on the basis of the onset of chilling injury. However, the beans can keep for as long as seven days at 4°C before browning starts.

At room temperature (23 ± 1°C), both the extra fine and the fine grades intended for the export market should be exported on the day of harvest before wilting sets in. However, material for local consumption can keep for slightly longer. The fine grade can at most keep for three days while the extra fine grade can store for only two days.

4.9 *Withering During Storage*

Table 7 shows the effect of nitrogen fertilizer and storage temperature on percent withering of French bean pods. The fertilizer had no significant effect ($p \leq 0.05$) on withering of both the fine and extra-fine grades at both temperatures of storage. The two grades showed significant differences on the extent of withering, with the extra-fine grade withering faster than the fine grade. By the third day at room temperature, all the extra fine pods had withered to the extent that they could be regarded as unfit for sale. After the same period of storage, about 70% of the fine grade had withered to the extent that they could be considered unsalable. On the basis of withering alone therefore, the fine and extra fine grade pods could maintain their quality for only two days. Percent withering of 50% was considered as the level beyond which salable quality was lost since sorting out the sound pods was no longer practical.

Pods stored at 4°C remained turgid and snappy for a longer period than those stored at room temperatures. At the latter temperature, 50% withering was observed between the fourth and sixth day in the extra-fine grade. By this day only about 20% withering was recorded among the fine grade pods. By the eighth day of storage, 100% withering had occured in the extra fine grade and about 90% in the fines. Therefore, at 4°C, the extra fine grade can at most store for four to five days and the fine grade for six to seven days before being declared unfit for domestic sale, on basis of withering alone. Plate 3 shows the extent of withering after three days at room temperature.

Table 7 Percent withering During Storage

Storage temperature	25± 1°C						4± 1°C					
Days in store	1		2		3		4		6		8	
Nitrogen rates(Kg/ha)	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra Fine
0	6.67 (0.00)	34.45 (10.72)	25.56 (5.09)	46.67 (0.00)	74.44 (1.93)	-	0	0	22.22 (1.92)	77.78 (6.94)	90.00 (3.33)	100 0.00
26	7.78 (1.92)	35.56 (13.88)	24.44 (1.93)	45.56 (1.93)	74.44 (5.09)	-	0	0	21.22 (3.95)	80.00 (6.67)	92.22 (1.92)	100 (10.00)
52	6.67 (0.00)	36.67 (0)	24.44 (1.93)	47.78 (1.92)	74.44 (5.09)	-	0	0	21.11 (1.92)	83.33 (6.67)	86.67 (0.00)	96.67 (3.30)
78	8.89 (3.85)	35.56 (7.70)	22.33 (1.73)	45.56 (5.09)	80.00 (3.33)	-	0	0	22.22 (5.09)	80.00 (8.82)	90.00 (5.77)	96.67 (3.30)

( ) standard deviation (N=3)

- Produce had already perished

Gorini et al. (1973) reported a significant difference in percent withering at 4°C and 7°C, between different French bean cultivars. In some cultivars, withering was noticed on the day of storage, while in others withering was only noticed after seven days of storage. The same authors reported a range between 38 and 95% withering in beans stored at 4°C for 3 days after hydrocooling. The percent withering increased to between 61 and 100% after 7 days of storage. Watada and Morris (1966) also observed similar trends in other French bean cultivars.

The fact that the extra fine grade pods withered at a faster rate than the fine grade may have been due to their larger surface area to volume ratio. Since the extra-fine pods were younger and more delicate, it is probable that more epidermal cells were broken during handling. These have been reported to accelerate moisture loss from the pods of various French bean cultivars by Hoffman (1967).

4.10 Chilling Injury

As shown in Table 8, N-fertilizer had no significant effect on percent chilling ($p \leq 0.05$) at 4°C. However, the pods from the control plots seemed to have slightly severer chilling injury in most cases.

Grades differed significantly in their susceptibility to chilling injury. The extra fine grade pods were more susceptible to the injury than the fine grade pods and symptoms of the injury were first noticed on the third day of storage. The injury appeared as tiny depressions on the surface of pods, but which still remained turgid (Plate 3). By the fourth day, about 48% of the extra fine grade pods

had developed the pits, while about 30% of the fine grade pods showed signs of chilling. The chilling intensity increased with storage and by the eighth day, over 90% and over 70% of the extra-fine and the fine grade pods were severely pitted respectively. The pits were now more pronounced and the pods became discoloured brown (Plate 4). The pods also looked dull and flaccid and sorting out of the turgid and sound pods was no longer practical. At this temperature therefore, the pods could be stored for not more than four days. The extra-fine pods could at most store for two days before chilling injury symptoms could be noticed, while the fine grade pods could keep for three days.

The pods deteriorated much faster once they were transfered from 4°C to the ambient temperatures. After four days at 4°C, the extra-fine grade pods could hold for only one day at room temperature, while the fine grade pods could keep for two days. After eight days at 4°C, the extra-fine grade pods deteriorated after only a few hours at room temperature while the fine grade could keep for one day.

Different cultivars of French beans have been reported to differ significantly in their susceptibility to chilling injury at different temperatures. Gorini et al. (1973) noted that chilling injury occured in some cultivars after only three days of storage at 4°C, while other cultivars could keep for seven days. Still, other cultivars showed no signs of chilling injury at this temperature even after seven days of storage. Rapid deterioration of beans previously held at chilling temperature then transfered to room temperatures has

Table 8 Percent chilling Injury During Storage

Days in store	4		6		8	
Nitrogen rates (Kg/ha)	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine
0	32.22 (6.93)	47.78 (10.18)	48.89 (3.85)	75.56 (9.62)	83.33 (6.67)	96.67 (3.34)
26	27.51 (2.16)	47.78 (3.85)	46.67 (3.34	76.67 (8.82)	76.67 (8.82)	97.78 (1.92)
52	30.00 (11.54)	47.78 5.09)	47.78 (1.92)	70.00 (8.82)	78.89 (3.85)	94.44 (1.93)
78	27.78 (8.39)	47.78 (1.92)	52.22 (12.62)	77.78 (9.62)	73.33 (10)	92.22 (8.39)

( ) standard deviations (N=3)

also been reported (Watada and Morris, 1966; Lutz and Hardenburg, 1968).

The present results indicate that prolonged storage of French beans of the Monel variety at 4 ± 1°C is not possible due to their susceptibility to chilling injury. Material intended for the fresh export market can be stored for a maximum of two and three days for the extra-fine and the fine grades respectively, before development of the chilling injury symptoms. However, material for home consumption can keep at the same temperature for a longer period. The extra-fine grade can store for about 4 days while the fine grade pods can keep for about six days.

4.11: *Retention of Ascorbic Acid (vitamin C) During Storage*

The effects of levels of N-fertilizer and storage temperature on ascorbic acid retention are presented in Tables 9a and 9b. In the first season (Table 9a), although the effect was not significant ($p \leq 0.05$), the results show that the pods from the N applied plots retained more ascorbic acid than those from the control plots during storage at both temperatures.

Table 9a Percent retention of Ascorbic Acid During Storage

	SEASON 1							
Storage temperature	23±1°C				4±1°C			
Days in store	2		4		4		8	
Nitrogen rate kg/ha.	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine
0	54.61 (3.29)	71.21 (11.46)	32.09 (9.62)	-	67.75 (5.62)	67.38 (7.81)	43.94 (4.91)	38.65 (3.18)
26	70.23 (1.95)	69.75 (11.75)	43.37 (3.76)	-	64.64 (12.80)	71.58 (19.69)	55.32 (8.12)	57.27 (16.33)
52	75.42 (7.68)	68.30 (14.72)	49.15 (14.19)	-	62.67 (9.13)	71.70 (19.07)	54.87 (12.02)	52.17 (11.13)
78	71.87 (4.17)	67.49 (13.28)	38.55 (4.38)	-	56.04 (2.52)	68.80 (16.57)	52.29 (2.10)	48.85 (10.14)

- Not performed because the produce had already perished

( ) standard deviation (N=3)

Table 9b Percent retention of Ascorbic Acid During Storage

	SEASON 2									
Storage temperature	25±1°C						4±1°C			
Days in store	1		2		3		4		8	
Nitrogen rate (kg /ha)	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine
0	47.80 (3.75)	69.13 (4.42)	23.10 (5.01)	40.39 (15.52)	14.55 (3.11)	-	68.45 (5.85)	66.65 (5.18)	55.19 (10.58)	36.38 (5.15)
26	46.11 (1.18)	51.40 (2.67)	35.03 (6.00)	35.77 (2.89)	14.16 (3.39)	-	64.66 (10.95)	70.93 (13.54)	56.48 (9.99)	41.05 (5.56)
52	49.63 (7.84)	59.13 (5.74)	33.62 (2.21)	36.35 (1.22)	16.37 (1.83)	-	62.73 (8.13)	71.28 (9.15)	53.00 (10.51)	42.27 (5.32)
78	40.22 (10.87)	50.40 (7.82)	27.76 (4.47)	35.90 (1.15)	14.67 (1.29)	-	56.19 (0.92)	71.31 (2.09)	50.10 (1.67)	43.02 (5.70)

- Not determined because the produce had already perished

( ) standard deviation (N=3)

The extra-fine grade pods generally significantly retained more of the vitamin than the fine grade pods, except after eight days at 4°C when the fine grade had retained more. The percent vitamin retained declined significantly as storage progressed, so that by the time the material held at room temperature (23 ± 1°C) was discarded, the fine grade had an average of 41% of their intial vitamin, while the extra-fine had an average of 69% in the first season. In the second experiment (Table 9b), fertilizer had no consistent effect on the percent retention of the vitamin at both temperatures of storage. The extra-fine grade pods, however, still retained more of the vitamin than the fine grade pods. Loss of the vitamin was much faster at an average of 25°C room temperature in the second season than at an average of 23°C in the first season. By the time the pods were discarded, the fine grade had an average of 15% of their initial vitamin while the extra-fine grade pods had an average of 37% of the initial vitamin. The probable explanation for the seasonal difference in the loss of the vitamin at room temperatures could be the higher average daily temperatures, low relative humidities and higher wind runs during the second season (Appendix 1).

The climatic variations during the growing seasons, may also have had an effect on the physiological maturity of the pods at harvest. In the second season, the pods stored for a shorter period than in the first season. The extra-fine grade stored for only two days while the fine grade maintained quality for three days at room temperature.

Loss of the vitamin at 4°C was much slower than at the room temperatures. By the time chilling injury symptoms started showing (fourth day), the fine grade had retained an average of 63% of the vitamin while the extra-fine grade pods had retained an average of 70% of the vitamin. After eight days of storage, over 50% of the vitamin had been lost from all the treatments.

The present findings that N fertilizer had no significant effect on ascorbic acid retention agrees with reports by Nilsson (1979) from work with cabbage, leeks and carrots.

Degradation of ascorbic acid during storage has also been reported by several workers. Shewfelt et al. (1985) observed significant loss of the vitamin in French beans stored for four days at 21°C and 70% RH. Shewfelt et al. (1986) also noted that levels of ascorbic acid in French beans declined throughout the handling process, with the greatest loss occuring during refrigerated transportation for six hours at 6°C and in storage at 21°C for six days. A 25% loss of the vitamin was observed during the six hours refrigerated transportation.

4.12 Retention of Chlorophyll During Storage

Tables 10a and 10b show that nitrogen had no significant effect ($p< 0.05$) on the retention of chlorophyll in the pods during storage. The trend of chlorophyll retention was not well established in both experiments. However, the extra fine grade generally lost

Table 10a Percent retention of Chlorophyll During Storage

SEASON 1								
Storage temperature	23 ± 1°C				4 ± 1°C			
Days in store	2		4		4		8	
Nitrogen rate (kg/ha)	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine
0	84.07 (12.44)	75.72 (6.67)	55.04 (14.97)	-	78.17 (8.47)	72.53 (8.04)	54.93 (8.08)	52.58 (7.87)
26	86.31 (7.93)	85.41 (13.41)	70.40 (23.09)	-	86.44 (13.60)	76.31 (10.42)	65.08 (11.23)	58.33 (10.20)
52	83.09 (16.38)	83.50 (9.90)	63.24 (21.94)	-	85.59 (13.05)	79.54 (13.86)	59.07 (3.40)	52.38 (2.07)
78	76.86 (6.82)	65.29 (14.91)	57.38 (5.50)	-	79.44 (12.95)	79.95 (16.11)	63.89 (7.88)	59.42 (11.61)

(-) Not determined because materials had already perished

( ) standard deviation (N=3)

Table 10b Percent retention of Chlorophyll During Storage

	SEASON 2											
Storage temperature	25 ± 1°C						4 ± 1°C					
Days in store	1		2		3		4		6		8	
Nitrogen rate (kg /ha)	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine	Fine	Extra fine
0	80.01 (2.19)	74.37 (8.28)	77.66 (2.90)	73.35 (4.96)	65.57 (5.93)	-	87.81 (5.19)	83.37 (14.59)	80.32 (12.19)	81.91 (3.58)	69.22 (16.93)	72.23 (14.63)
26	76.19 (8.25)	81.20 (4.42)	70.49 (2.79)	67.78 (16.69)	61.50 (9.28)	-	87.63 (8.39)	86.18 (2.55)	77.12 (9.15)	79.80 (6.93)	69.96 (18.29)	72.15 (8.97)
52	85.26 (12.49)	79.96 (4.26)	75.85 (7.84)	67.08 (14.14)	73.32 (4.15)	-	84.79 (13.09)	90.59 (3.52)	82.89 (14.75)	79.24 (10.12)	75.56 (7.56)	74.79 (3.15)
78	76.53 (5.62)	80.81 (6.23)	73.73 (10.38)	71.57 (7.82)	54.29 (1.74)	-	83.12 (12.41)	81.11 (2.03)	77.88 (16.00)	79.35 (6.05)	67.05 (15.65)	74.04 (1.24)

(-) Not determined because material had already perished

( ) standard deviation (N=3)

chlorophyll slightly faster than the fine grade pods at both temperatures in both experiments, but the difference was not significant. After two days of storage, change in colour was visually noticed in the extra fine grade and after three days in the fine grade at room temperatures (Plate 2). As shown in plates 3 and 4, pods stored at 4°C retained their green colour better than those stored at room temperatures. Even after the eighth day, the pods were still appreciably green except for the brown discoloration.

Shewfelt et al. (1985) reported significant yellowing in French beans of all grades after four days of storage at 21°C, 70% RH. In another study, no significant difference in hue was observed in beans before storage, but after storage at 5°C and 21°C for six days, more yellowing was observed at the higher temperature (Shewfelt et al. 1986). Similar observations were made by Watada and Morris (1966) in several French bean cultivars. Phan (1977) working on pea pods also observed some chlorophyll degradation in pods placed in cold store immediately after harvest and also in those held at room temperature. However, more degradation was observed at room temperature than in cold storage.

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH WORK

5.1 Conclusions and Recommendations

From the results of this study, the following conclusions can be made.

Topdressing French beans of the Monel variety with 26kgN/ha significantly increased the dry matter of the leaves at both the blooming and podding stages in the first season. Application of more than 26kgN/ha, significantly increased the leaf and stem dry matter during podding only.

Although application of nitrogen significantly increased dry matter of the leaves and stems, it had no significant effects on both the total and marketable pod yields. Therefore, it would not be economical to topdress the Monel bean variety with such N levels on soils and climatic conditions similar to those of Kabete for optimal pod yields.

Results from the storage study showed that the pods have a very brief shelf-life especially at room temperatures. The pods showed signs of senescence after only one day of storage at room temperatures. Therefore, it would be advisable to airfreight the pods on the day of harvest while they are still turgid and fresh according to the standard specifications for the export market. The extra-fine and the fine grade pods could maintain their salable value for at

most two and three days respectively at room conditions. The produce intended for fresh local market could therefore be vended for this number of days at the same temperatures.

Storage at 4 ± 1°C was found to slightly extend the shelf-life of the produce although chilling injury terminated the shelf-life before other quality deteriorative factors came into play. The extra-fine grade pods were more susceptible to the chilling injury than the fine grade pods. Chilling symptoms were observed on the third and fourth days on the two grades respectively. Therefore, while awaiting airfreighting, fresh pods of the extra-fine and the fine grades can be held for maximum of two and three days respectively before chilling injury sets in. Materials for home consumption, however, can be kept at this temperature for as long as six days.

5.2 *Suggestions for Further Research Work*

More trials need to be done on various soil types and under different climatic conditions.

A study is also necessary on the actual N requirement by the crop at various stages of growth, over and above the atmospheric nitrogen fixed by the nodules.

The pod yields obtained in the present study (15-16 tons/ha) were much higher than the 4-8ton/ha recorded by the Horticultural crops Development Authority (HCDA), Kenya. This shows that the Monel variety could have a higher yield potential, which has not yet been realized in the country. Therefore, more work needs to be done to identify the factors limiting pod production.

In the storage study, only one storage temperature was used due to limitations of facilities. Further work needs to be done at different refrigeration temperatures especially with the aim of establishing the optimum temperature for storage, which allows for refrigerated shipment of the beans to the importing countries.

There is need to establish the effect of storage on the cooking quality and the degradation of vitamin C in the produce. This would probably constitute an additional criterion for evaluation of the quality of stored French beans.

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Appendix 1 Mean monthly weather record - Field Station, Kabete, between July 1988 - April, 1989

Month	Mean radiation MJM^{-2}	Mean sun-shine hrs/day	Temperature °C			Total Rainfall mm/month	Mean evaporation mm/day	% RH (mean)	Total wind-run km/day
			Max.	Min.	Mean				
1988									
July	15.58	3.3	20.7	11.6	16.1	18.7	2.5	77	48.2
August	10.89	3.7	20.9	11.9	16.4	64.9	2.4	76	50.6
September	13.15	4.6	22.6	12.1	17.3	27.1	2.9	71	67.9
October	16.27	7.6	24.5	12.8	18.5	16.7	4.6	64.5	97.5
November	15.07	6.9	22.1	13.5	17.8	105.3	3.7	68.2	-
December	15.27	7.8	22.0	13.0	17.5	139.1	-	71.4	-
1989									
January	16.57	7.5	22.3	13.0	18.10	134.60	-	67.5	75.0
February	18.92	9.4	23.9	12.3	18.1	45.1	-	57.0	110.3
March	18.87	8.8	24.9	13.7	19.3	93.1	-	61.5	87.9
April	13.1	5.4	22.0	13.8	17.9	210.5	-	78.0	72.0

- Data not recorded.

Appendix 2 Soil chemical characteristics before planting

Nutrient / soil reaction	Season one	Season two
pH water	6.5 (0.24)	6.6 (0.21)
CEC (me/100g soil)	28.4 (3.41)	29.4 (3.44)
Total N (µg/g soil)	2635.38 (214)	2962.1 (324.2)
% Carbon	3.01 (0.21)	3.01 (0.23)

( ) standard deviations

Appendix 3 Analysis of variance (ANOVA) for effect of nitrogen fertilizer on dry matter accumulation in leaves, stems and nodules of French bean plants.

Stage of sampling (weeks from planting)	Source of variation	df	Mean sums of squares					
			Leaves		Stems		Nodules	
			A	B	A	B	A	B
5	Nitrogen (N)	3	0.08	17.22*	0.07	4.95	0.002*	0.08
	Replication (R)	2	1.69	3.79	0.09	3.36	0.001	0.02
	Error (E)	6	2.11	3.34	0.50	5.82	0.0003	0.03
6	N	3	4.19	13.36	1.20	21.71*	0.01**	0.04
	R	2	2.02	5.58	2.18	20.15	0.001	0.16
	E	6	4.88	7.85	1.49	3.09	0.0003	0.07
7	N	3	47.54**	4.04	5.78	3.73	0.15	0.04
	R	2	2.64	7.65	5.18	18.03	0.075	0.05
	E	6	3.46	24.90	5.49	35.65	0.035	0.02
8	N	3	187.07**	58.14	56.3*	57.18	0.027	0.03
	R	2	13.03	20.4	12.64	66.69	0.03	0.00
	E	6	14.92	35.87	6.57	61.9	0.01	0.006*

A - Season one
B - Season two

*, ** - significant at P< 0.05 and P < 0.01 respectively. The rest are not significant (N.S.)

Appendix 4 Analysis of variance (ANOVA) for marketable pod yields.

Source of variation	df	Mean sums of squares			
		Fine		Extra fine	
		A	B	A	B
Nitrogen	3	2.479^{ns}	0.136^{ns}	0.100^{ns}	0.554^{ns}
Blocks	2	0.322	0.519	0.276	0.197
Error	6	2.087	3.375	0.319	0.370
Total	11	1.873	1.973	0.227	0.389

n.s. - not significant at $P \leq 0.05$

A - season one

B - season two