EFFECT OF PHOSPHORUS AND NITROGEN APPLICATION AND INOCULATION ON GROWTH, NODULATION AND POD YIELD AND QUALITY OF FRENCH BEAN (*Phaseolus vulgaris* L.) PLANTS

BY

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DEDICATION

To my family and especially my late father for his love and encouragement.

DECLARATION

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

J. ODERA — 31st May 1998

J.M. ODERA — **Date**

This thesis has been submitted for examination with my approval as University supervisor.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABSTRACT

An experiment was conducted at Kabete Field Station, the Faculty of Agriculture, University of Nairobi for two seasons (between November 1991 and March 1992 and between July 1992 and August 1992). to investigate the effect of nitrogen (0, 52 kg N/ha) and phosphorus (0, 45, 90, 135 kg P/ha) application and inoculation with Rhizobium leguminosarum on plant growth, nodulation and pod yield and quality of French bean (Phaseolus vulgaris L. var. Monel) plants. The factorial experiment was laid down in a randomized complete block design with three replications.

Phosphorus application significantly increased plant height, nodulation and pod yield. However, the nitrate content decreased significantly with the application of phosphorus fetilizer. There was no significant effect of phosphorus fertilizer application on the protein content of the pods.

Nitrogen application caused a significant increase only in the yield of extra fine pods in the second season . The application did not siginificantly affect plant height, dry matter accumulation, nodulation and pod quality.

Inoculation significantly decreased plant height, pod yield and nitrate content of the pods.

Interaction between phosphorus, nitrogen and

inoculation was significant for plant height during the first season. In the second season, an interaction of nitrogen and inoculation caused a significant increase in plant height. In the same season a significant increase in pod yield occurred as a result of an interaction between phosphorus and inoculation. Phosphorus in combination with nitrogen and inoculation caused a significant increase in total pod yield in the second season. The protein content of the pods decreased significantly as a result of an interaction between phosphorus, nitrogen and inoculation. Phosphorus in combination with inoculation significantly decreased the nitrate content.

CHAPTER ONE

1.0 INTRODUCTION

There has been a tremendous change in agricultural practices in Kenya in the last decade or more. Large acreage of wheat and maize lands in the Rift Valley and areas have been subdivided to provide land for small scale farming (Anon. 1990). Yields of cereals in the marginal areas have fallen due to the multipurpose use of the rather marginally poor soils. In other areas such as central Kenya, northern Rift Valley and eastern slopes of Mt. Kenya where the soils are more fertile, high population has led to maximum utilization of available land (Anon. 1990). The fall in world prices of cash crops and non-profitability of livestock farming due to decrease in grazing land and supplementation with exorbitantly priced feeds have resulted in farmers turning to the production of horticultural crops. Consequently, the most profitable farming to date in Kenya is horticulture (Anon. 1990).

Horticulture is now one of Kenya's major foreign exchange earners. The industry is reported by Horticultural Crops Development Authority (HCDA) to be steadily growing. In 1965 only K 10,000 worth of horticultural produce was exported from Kenya. In 1993, Kenya exported horticultural products worth K 100,000

(HCDA, 1993). The main crops exported are vegetables (French beans and courgettes), fruits and flowers (Munyinyi, 1987). French beans (Phaseolus vulgaris L.) and courgettes (Cucurbita spp) are the main off-season vegetables in Kenya which are exported to Europe. French beans have become one of the country's most important export crop and in 1986 was the major single green vegetable item shipped to Europe from Kenya (Leny, 1986). In 1988 the country exported about 9800 tonnes of French beans, mainly to the US, France and Belgium (Njururi, 1988). In 1992 and 1993 about 15 000 tonnes and 14 000 tonnes were exported respectively (HCDA, 1993).

Beans in general are a popular staple food for Kenyans. With the increase in population, the demand for and consumption of beans has increased tremendously (including consumption in its immature form as pods). On the local market especially in urban areas, there is a limited but growing demand for beans as immature pods. It would therefore be an error to regard horticultural crop in Kenya only in terms of export potential and as a source of foreign exchange.

In Kenya, French beans are mainly grown for their fresh green pods either for export, processing or local market (Anon. 1990). The mature dry beans are cooked and consumed as whole grain. In East Africa the young leaves are also used as green leafy vegetable (Tindall, 1983). The immature green pods consist of approximately 94%

edible matter with a composition as shown in Table 1.

Table 1: Composition of French bean pods:

	Vegetable nutritive value (per 100 g of edible portion)
Food energy (calories)	32
Protein (g)	1.9
Carbohydrates (g)	7.1
Ash (g)	0.7
Calcium (mg)	56
Phosphorus (mg)	44
Iron (mg)	0.8
Sodium (mg)	2.0
Potassium (mg)	132
Vitamin A (mg)	600
Thiamine (mg)	0.08
Riboflavin (mg)	0.11
Ascorbic acid (mg)	19

Source: Quality of Horticultural Products (Arthey, 1975).

1.1 Production of French beans in Kenya

There is very little or almost no information on French bean production in Kenyan Agriculture. Most of the data on production are still to be published. The two major types of French beans grown in the world are dwarf or bush and the climbing cultivars. In Kenya only the dwarf cultivars which are fast maturing, are grown (Anon. 1990). The Monel variety is by far the most important dwarf variety in Kenya. It is mainly grown for export and to a lesser extent for canning (HCDA, 1993).

The traditional horticultural areas, where French beans were first grown on a commercial basis are, Naivasha, Thika and Machakos but now production also takes place in marginal areas such as Athi River, Matuu (Yatta Furrow), Mwea Tebere, Kibwezi and Loitokitok under irrigation.

Originally French bean production was by companies on large scale farms. This has changed now and small scale farmers are increasingly taking over French bean production. This type of production is to be recommended in view of the labour management problems encountered on large scale farms (HCDA, 1993).

The acreage under French beans in Kenya in 1990 was estimated at 25,000 ha (Anon. 1990) compared to 3,310 ha in 1986 (Anon. 1986). The average yield in 1990 was 4 - 8 tonnes/ha/year depending on the level of management.

Though small scale farmers can produce French beans for export, the major constraint is the high production cost. This is due to the high susceptibility of the crop to the common bean pests and diseases; high cost of packaging and lack of proper handling and pre-export cooling facilities (Mulandi, 1990).

Research is currently being conducted at the National Horticultural Research Station, Thika, to develop new varieties with the same high yielding potential as Monel but with resistance to major diseases. Agronomic research has been carried out to determine the effect of spacing on the yield and growth of French bean plants (Anon. 1990). The reason for this is because the recommendations given by HCDA are based on data from dry beans. Little has so far been done in the area of fertilizer requirements and on biological nitrogen fixation and inoculation. Fertilizer recommendation for French beans is at present based on recommendations for dry beans (Anon. 1990).

French beans have been found to respond to application of nitrogen fertilizer (Tindall, 1983) and both the inorganic and symbiotic sources of nitrogen seem necessary for maximum yields (Westermann et al., 1980). Work by Gravas (1981) indicated the requirement of phosphorus fertilizer application with nitrogen application for relative high yields in French beans. The interaction of nitrogen and phosphorus with nitrogen-fixation, is also an important factor (Gravas, 1981).

With the above in mind, this study was conducted with following objectives:

1) Investigate effect of nitrogen and phosphorus

application on plant growth, nodulation and pod yield and quality of French beans

(2) Study effect of inoculation with <u>Rhizobium</u> on plant growth, nodulation and pod yield and quality of French beans.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin

The French bean (*Phaseolus vulgaris* L.) is also known as kidney bean, haricot bean, snap bean, navy bean or pole ban (Tindall, 1983). It originated from the 'New World', possibly South or Western Mexico and was introduced into Europe in the sixteenth century and brought to Tropical Africa as a dry bean (Tindall 1983). The bean has only acquired importance as a green bean in Tropical Africa in the last four decades.

2.2 Botany of Plants

The species is highly variable and plants can range from twining cultivars, with stems with 20 to 30 nodes and a length of upto 3 m, to determinate bush varieties with only four to eight nodes which are little more than 40 cm in height. Intermediate types between these two extremes also occur. Following germination, which is epigeal, the plant develops a tap root which may penetrate to a depth of one metre. An extensive lateral root system, which is confined to the top 15 cm of soil, is also formed. The leaves are alternate and trifoliate although the first leaves formed after emergence of the cotyledons are simple. The leaves are borne on long petioles and may be covered in fine hairs. The leaflets are ovate and entire with pointed tips, and the two lateral leaflets are asymmetrical. The individual leaflets can be up to 15 x 10 cm in size.

Flowers are borne on short axillary racemes and form near the apex of the peduncle on short pedicles. Flower colour can be white, cream, pink or violet with the standard about 1cm in diameter. Pods when formed are long and slender up to 20 x 1.5 cm in size. The pods usually contain four to eight seeds but on occasion they may be as many as 12. Pods may range from circulate to oval in section. Varieties which are selected for use as green vegetables have extensive parenchyma deposition in pod wall. Pods are green in colour.

2.3 Distribution

The French beans are a well known *Phaseolus* species (Kay, 1979) and are grown in many parts of the tropics, subtropics and temperate regions. In the tropics the main areas of cultivation are East Africa (especially Kenya), South Africa, West Africa, Caribbean, South America (Brazil, Chile) and the southern states of the U.S.A. In the tropics European cultivars or forms are normally cultivated at elevations over 600 m but a wide range of tolerance to climate exists (Tindall, 1983). Most cultivars adopted to tropical conditions grow well from sea level up to 1000 m above sea level. Suitable areas for French bean production in East Africa are the medium to high altitudes areas with moderate precipitation.

2.4 Climatic Requirements

For optimum growth, French bean plants require average temperatures of between 16 and 24 C (Kay, 1979). Growth stops at temperatures below 10 C and the plant is killed by frost. At temperatures above 30 C blossom drop is very serious. Above 35 C there is complete failure of seed set (Kay, 1979). Water requirements vary with the stage of growth. At planting up to 10 days post emergence the plants require 35 mm/week/per plant (HCDA, 1993). From 10 days after emergence to the onset of flowering they require 50 mm/week/per plant and from flowering onwards the requirement is 35 mm/week/per plant. In Kenya, French beans can be produced in areas with average annual rainfall ranging between 500 and 1500 mm. This has to be well distributed during the growing season because a constant supply of moisture is very essential in the growth and development of the bean plants (HCDA, 1993). Daylength sensitivity occurs mainly in the climbing varieties, some of which are short-day plants. Most of the dwarf cultivars are daylength neutral (Tindall, 1983).

2.5 Soil Requirements

French beans can be grown successfully on most soil types ranging from light sands to heavy clays. However, a friable deep and well-drained soil is preferable (Kay, 1979). The soil should have an optimum pH of about 6.5. Very acid soils should be avoided because they inhibit nitrogen fixation by rhizobium (Tindall, 1983).

2.6 Nutrient Requirement

Nitrogen, phosphorus and potassium should be applied before planting to stimulate early growth, and this should be followed by top dressing by potash and nitrogen (Tindall, 1983). Magnesium deficiency which may occur in well-drained arid soil results in stunting of plants and chlorotic leaves (Tindall, 1983). Zinc deficiency induces poor pod setting (Tindall, 1983) and should be corrected by foliar sprays application. The crop is also sensitive to high levels of boron, aluminium and sodium. Excessive nitrogen should be avoided since it may promote vigorous vegetation growth at the expense of reproductive growth (HCDA, 1993).

2.6.1 Phosphoroua

With the exception of nitrogen, no other element is as essential in plant growth as phosphorus (Brady, 1984). Phosphorus is essential for numerous metabolic processes and plays a fundamental role in a number of enzymic reactions (Russell, 1983). The more significantly beneficial effects (Brady, 1984) of phosphorus on plants are:

- cell division and fat and albumin formation
- flowering and fruiting, including seed formation
- crop maturation, in which phosphorus counteracts the effects of excess nitrogen applications
- root development, particularly of lateral and fibrous rootlets
- strength of strain in cereal crops, thus helping to prevent lodging
- improvement of crop quality, especially of forages and vegetables

2.6.1.1 Effect of Phosphorus on Plant Growth

Tamaki and Naka (1971) reported poor growth in broad bean plants in treatments where no phosphorus was applied before flowering. Withholding phosphorus after flowering had only small adverse effects. In French bean plants, growth is highly enhanced by high levels of phosphorus (Burton et al., 1961; Lunin and Gallatin, 1965). Low phosphorus levels produce small plants with dull green leaves (Osawa and Lorenz, 1968).

Plant dry matter and production (Paz et al., 1982), leaf:root ratios (Wallace et al., 1976), shoot dry weight (Pereira and Bliss, 1987; Rehim et al, 1987) and leaf area and leaf area index (Sader, 1979) have been reported to increase with increased application of phosphorus.

El-Leboudi et al (1974) however, found no effect on growth of plants due to phosphorus application.

2.6.1.2 Effect of Phosphorus on Nodulation and Nitrogen fixation.

In soils frequently deficient in both phosphorus and nitrogen, appropriate strategy for efficient fertilizer use by French bean plants depends on the amount of phosphorus applied. The application of the correct amount of phosphorus enhances plant growth, nodule development and nitrogen fixation (Graham and Rosas, 1979).

In trials involving the common bean, initial phosphorus availability was found to be a factor that determined the magnitude of nodulation (Floor, 1982). The bean plants needed more phosphorus when they depended on nitrogen fixation for nitrogen supply than when inorganic nitrogen fertilizer was applied (Floor, 1982). Phosphorus in nitrogen-poor soils influences *Rhizobium* activity and nitrogen fixation (Anon. 1986). Domborari (1977) while doing investigations on nitrogen fixation in soya bean and bean plants, tells of increase in atmospheric nitrogen fixation by 19% in a meadow soil and 26% on a sandy soil. The increase was attributed to phosphorus application. The same is reported by Paz *et al* (1982). Graham and Rosas (1979), when investigating phosphorus fertilization and symbiotic nitrogen fixation in bean plants, found that nodule dry weight rose markedly with increasing rates of phosphorus application. An increase in the amount of phosphorus applied to a French bean plant will cause an increase in the nodule dry weight (Almeida et al., 1973; Graham and Rosas, 1979).

Phosphorus is needed to enhance nodule activity in French beans (Hera et al., 1985). It has been observed that nodule fresh weight at flowering increases with phosphorus fertilization (Sader, 1979). Hera et al. (1985) report a greater proportion of green ineffective nodules than red active nodules, at lower phosphorus than at the high phosphorus concentration. Nodule weight in French bean plants, has been found to increase nine-fold over a range of phosphorus application rates (Graham and Rosas, 1979). Keya and Ssali (1983) agree that availability of phosphorus can be an important factor in symbiotic biological nitrogen fixation in bean plants. Hungria and Neves (1987a) found that nitrogen fixation after phosphorus fertilization, supplied 58-72% of the total N assimilated by the plant during the growth cycle. Similar results were reported by Lalande (1986 et al).

2.6.1.3 Effect of Phosphorus on Pod Yield

Phosphorus application significantly affects number of pods and pod length in beans (Fageria, 1989). Increase in the amount of phosphorus applied increases the pod number per plant (Thung et al., 1983; Pande et al., 1974; Mahatanya, 1976; Srinivas and Naik, 1990).

Mousri et al. (1975) attribute this to the increase in number of flowers produced, improvement in fruit set and reduced percentage of both flower and fruit abortion. Increased amounts of phosphorus applied also increases the pod size (Peck and Buren, 1975). An increase in the level of phosphorus applied, increases the pod yield (Almeida et al., 1973, Mascarenhas ,1969, Palaniyandi ,1976).

Only in a few cases has foliar application of phosphorus has been found to have a positive effect on pod yield (Midian et al., 1980a). Some workers have found no response in the pod yield (Midian et al., 1980c; Costigan, 1987), with an increase in phosphorus fertilization levels nor in the weight of pods. Asif and Greig (1972) even reports a reduction in pod yield when phosphorus is in combination with potassium.

2.6.1.4 Effect of Phosphorus on Market and Nutritive Qualities of Pods.

Excess application of phosphorus fertilizer causes an increase rate of maturity therefore resulting in a decrease in marketable yield and increase in reject grade pods (Arthey, 1975).

Phosphorus fertilization increases the total nitrogen content in pods (Saito and Ruschel, 1978) due to an increase in the accumulation of nitrogen (Fageria, 1989). This leads to an increase in the crude protein in the whole plant, pods and seeds inclusive (Koinov and

Petkov 1975; Awad et al 1982). The nitrate content also increases. Phosphorus content increases in all parts of the plant with an increase in phosphorus application (Graham and Rosas, 1979; Awad et al, 1982; Kastovi et al, 1977; Parodi et al, 1977). This is due to an increase in phosphorus uptake (Prabhakar et al, 1986) and phosphorus utilization efficiency (Midian et al., 1980b).

The mineral content of the French bean plants also increases due to the application of higher rates of phosphorus fertilizer. These minerals include magnesium, iron, calcium (Fageria, 1989), manganese and zinc (Palaniyandi, 1976).

2.6.2 Nitrogen

Nitrogen is an integral component of many compounds in plants (Brady, 1984) and therefore is essential for plant growth (Russell, 1983; Brady, 1984).

There are three main sources of nitrogen in mineral soil, organic nitrogen associated with the soil humus, ammonium nitrogen fixed by certain clay minerals and soluble inorganic ammonium and nitrate compounds. Most of the nitrogen in surface soils is associated with the organic matter (Brady, 1984). The amount of nitrogen in the form of soluble ammonium and nitrate is seldom more than 1-2% of the total present, except where large applications of inorganic nitrogen fertilizers have been made.

Nitrogen is required in much greater quantities than any other essential mineral nutrient for good yields (Barke, 1978). Plants receiving insufficient nitrogen are stunted in growth and possess restricted root systems (Barke, 1978). The leaves turn yellow or yellowish green and tend to drop off. Application of nitrogen greater than optimal cause the leaves to become dark green in colour. Excess vegetative growth and delayed crop maturity also occur (Brady, 1984). The plants become more susceptible to diseases and insect pests (Brady, 1984; Barke, 1978).

Nitrogen has the greatest effect of all the nutrients on vegetative growth of plants. Nitrogen encourages above ground vegetative growth and causes a deep green colour in leaves (Brady, 1984).

2.6.2.1 Effect of Nitrogen on Plant Growth

In French bean plants, nitrogen has been reported to cause increased growth (Hardwick and Innes, 1975). Dose et al. (1977) reported increase in growth and final height of plants supplied with nitrogen fertilizer. An increase in the total weight of the plant due to increased root, shoot and leaf dry weight also occur (Ruschel and Saito, 1991, Leidi et al., 1980).

2.6.2.2 Effect of Nitrogen on Nodulation and Nitrogen Fixation.

Reports indicate that French bean plants seem to respond positively to application of nitrogen. This is because the plants are not efficient in utilizing the nitrogen-fixing resources of the Rhizobium bacteria (Tindall, 1983). According to Franco and Munns (1982), the application of nitrogen to the plants prevents nitrogen deficiency stress before the onset of nitrogen fixation. This is because seedling growth of the plants is generally poor until they start fixing their own nitrogen (Sinha, 1977).

Inspite of the need for supplementary nitrogen application to bean plants, the application is reduced when inoculated seed is used (Brakel and Manel, 1964). The question is, therefore, how to supplement the nitrogen fixed most efficiently without impairing root nodule activity. In an experiment to determine the effects of certain mineral nutrients on growth and nitrogen fixation of inoculated French bean plants, Burton et al. (1961) reported an increase in symbiotic nitrogen due to the presence of 200 ppm of nitrogen. Most results, however, indicate that application of high levels of nitrogen suppresses nitrogen-fixation (Sundstrom et al. 1982). Taylor et al. (1983b) reported a decrease in nitrogen-fixation at nitrogen application levels of 120 kg N/ha. Nitrogen-fixation was greatest at a lower level of 25 kg N/ha (Sundstrom et al. 1982).

It is possible that maximum yields of pulses may only be obtained when natural nitrogen fixation is supplemented with nitrogenous fertilizer application

(Smartt, 1976). Greenhouse pot grown French bean plants, supplied with various strains of Rhizobium phaseoli, produced a greater number of nodules than those that were not supplied with rhizobia, only after application of 23 ppm nitrogen at planting (Goss and Dubereiner, 1972). Abou El-Fadl et al. (1959) reported that application of 50 kg/ha of calcium nitrate had a stimulating effect on nodule formation and number. Heavier applications, however, had an inhibitory effect on nodule formation and number. The nodules partially or completely disappeared. Chui (1987) and Crespo et al (1987) report a similar finding in separate experiments. Crespo et al. (1987) observed that nitrogen at 22 kg/ha in combination with R. phaseoli increased plant nodulation. Higher nitrogen rates however reduced the number and size of nodules.

Nitrogen has also been reported to delay nodule growth in French bean plants (Franco and Munns, 1982) resulting in decreased nodule dry weight (Rosas, 1984; Sundstrom et al., 1982). These observations seem to indicate that the application of high rates of nitrogen suppresses both nodulation and nitrogen fixation (Sinha, 1977). Higher rates of application are reported to completely inhibit nodulation in French bean plants (Vakhaniya et al., 1990, Hine and Sprent, 1988).

2.6.2.3 Effect of Nitrogen on Pod Yield

The heaviest demands for nitrogen occur during the pod and seed development stages. A shortage of nitrogen at this stage results in pod abscission. lower yields and poorer quality seed (Barke, 1978). Nitrogen has been found to affect pod set and development (Paterson et al., 1966). Reports on pod yield indicate a general increase with addition of nitrogen applied as a topdress (Smittle, 1976). Sangarkhara and Marambe (1989) found that pod yields of plants inoculated with Rhizobium and where nitrogen was applied ranged from 130.6 to 184.6 g/plant as compared to those without nitrogen (81.8 to 84.4 g/plant). Asif and Greig (1972), Doss et al (1977), Hansen (1978) found that increased nitrogen application resulted in increased pod yields but the effect on pod length and weight was negligible. In a field trial, Hedge and Srinivas (1989) found the highest green pod yield to be from plants supplied with highest N rate (120 kg N/ha) and irrigated.

2.6.2.4 Effect of Nitrogen on Market and Nutritive Qualities of Pods

Doss et al (1977) reported nitrogen application led to a reduction in the percentage marketable pods of half-runner French beans, though this was counteracted by increase in pod yield due to increase in growth rate. The authors observed no consistent effect of nitrogen application on grade or size of pods. Mullins (1987) reported an increase in number of pods with rotten ends at high nitrogen rates.

Nitrogen has been found to affect total nitrogen levels in pods (Njeru. 1989). Smith et al. (1988) found an increase in the nitrogen concentration in seeds as well as in other plant tissues with application of nitrogen. Peck and Macdonald (1984) found that nitrogen application increased the concentration of total nitrogen in all plant tissues at pod stage. In later stages of growth the total nitrogen content decreased in all plant parts.

The nitrate content of pulses varies between 30 and 600 ppm, with beans having the upper limit (Taisser et al., 1986). Hansen (1978) on the other hand reported a minimal effect on nitrate content in beans due to nitrogen application. This was in contrast to the effect on gherkins, lettuce, spinach, cauliflower and broccoli in which there was an increase in nitrate content. Cantliffe (1972), however, reported a decrease in nitrate-N concentration of French bean pods with additional application of nitrogen fertilizer.

2.7 Inoculation

2.7.1 Effect of Inoculation on Plant Growth

There are numerous reports suggesting that increase in nodulation brought about by inoculation leads to increased plant growth in French bean plants (Chandra et al., 1987). Dry matter production in French bean plants, has been found to increase with inoculation with Rhizobium (Khachani, 1981; Million, 1989). Buttery et al. (1987), however, report different findings. They found that Rhizobium inoculation had no discernible effects on dry weight of French bean plants, though there was a significant decrease in plant maturity time.

Inoculation, however, seems not to have any effect on plant heights of French beans (Endo et al., 1988).

2.7.2 Effect of Inoculation on Nodulation and Nitrogen fixation.

There are claims from researchers in Kenya that profusely nodulated bean plants can fix adequate nitrogen to meet their nitrogen nutritional requirements (Anon.1986). More modest estimates from Kabete give a calculated value of 55 kg N/ha in 120 days (Keya and Ssali, 1983). Taylor et al. (1983b) in more precise estimates from nitrogen response curves of bean plants showed that nitrogen fixation due to inoculation supplied the fertilizer equivalent of 70-105 kg N/ha. Bacteria of the genus Rhizobium, in association with legume plants, provide the major biological source of fixed nitrogen in agricultural soils (Brady, 1984).

Inoculation has been reported to enhance nodulation in French bean plants (Duque et al., 1985; Taylor et al., 1983b) and nitrogen fixation in Phaseolus vulgaris (Abdel-Ghaffar et al., 1981). The increase in nodulation resulted in greater nitrogen fixation (Duque et al., 1985). Salez and Saint Macary (1987) found an increase in the number and weight of plant nodules due to inoculation with *Rhizobium phaseoli*. Sparrow (1981) also reported similar findings. Velazquez *et al*. (1988), however, found that inoculation treatments had no significant effect on nodule weight.

2.7.3 Effect of Inoculation on Pod Yield

Black (1968) suggested that higher grain yield in food legumes inoculated with *Rhizobium*, was due to an increase in nodulation. Khachani (1981) and Million (1989) reported an increase in pod yield due to inoculation of French bean plants. Inoculation doubled seed yields in an experiment carried out by Taylor *et al.* (1983a). Fresh weight yields of pods are also reported to increase with inoculation (Soos and Balent, 1979). However, inoculation has not been found to affect either pod number per plant or pod length (Amare and Birhanu, 1985; Endo *et al.*, 1988).

2.7.4 Effect of Inoculation on Market and Nutritive Qualities of Pods.

Inoculated plants have been found to contain significantly higher protein and amino acid concentration in all plant parts, than those that are not inoculated (Pacovsky and Fuller, 1991). Inoculation, can therefore, be said to increase total nitrogen content in the plants (Saito and Ruschel, 1978; Farouk, 1978). Samtservich *et al.* (1980) reported an increase in protein content in plant cell sap at the flowering stage due to inoculation. No information on the effect of inoculation on market quality of pods was obtained.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 General

The study was carried out in two seasons, from November 1991 to March 1992 and from April to August 1992. Chemical analysis of dried pods from the two seasons was done at the end of the second season. The French bean variety Monel was used in the study. The seeds were obtained from the Horticultural Crops Development Association (HCDA) in Nairobi.

3.2 Experimental Site

The experiments were carried out at the Field Station of the Faculty of Agriculture, University of Nairobi, Upper Kabete Campus. The station is situated at latitude 1 15´S, longitude 36 44´E and at an altitude of approximately 1940m above sea level.

The station has a bimodal pattern of rainfall with a mean average rainfall of about 1006.2 (Gachene, 1989). The two main rainy seasons are March to May (long rains) and October to December (short rains). The long rains account for 56% of the annual average rainfall while the short rains account for 18%. The rainfall in the long rains is usually heavier and more reliable than that of the short rains. During the study both the short rains and the long rains were unreliable. In fact the short rains were heavier than the long rains (Appendix 1). The mean monthly maximum temperature is 23 C, while the mean minimum temperature is about 13 C. A mean evapotranspiration of 1363 mm is reported by Brown et al.(1969) and Wamburi (1973). The daily mean temperature during the study was between 15 and 20 C (Appendix 1).

3.3. Soils

Soils at the site are developed from Nairobi trachyte parent rock and are categorized as Kikuyu friable loams (Keya and Ssali, 1984). They have also been described as humic nitosols according to the FAO/UNESCO (1984) classification. The soils have a moderate organic carbon content in the top soil and the base saturation is below 50%. The pH (0-30 cm) was 5.6-6.0 while available nutrients at this same depth according to Gachene (1989) is Na-0.2 m.e%; K-1.27 m.e%; Ca-13.2; Mg-3.9; P(p.p.m.-12; N%-0.22 and C%-2.13. The soil seems to be adequately supplied in bases but is generally low in phosphorus. The organic carbon content and total nitrogen levels are moderate (Gachene, 1989).

Before planting, composite samples were taken at the two experimental plots, at depths of 0-20 and 20-40 cm, for analysis. The results are shown in Appendix 2. The results show that the soil is slightly acidic, pH about 5.8, with a high phosphorus content (between 20-30 p.p.m.) and a nitrogen content of between 0.22-0.28%. In the second experimental site the nitrogen content was a bit low (0.14-0.18%).

3.4 Treatments and Experimental Design

The treatments in the study consisted of four (0, 45, 90 and 135 kg P/ha) levels of phosphorus supplied in the form of triple superphosphate (20% P_2O_5), two (no inoculation and inoculation with *Rhizobium legominosarous* biovar *phaseoli* NUM 446 strain) levels of inoculation and two (0 and 52 kg N/ha) levels of nitrogen supplied in the form of calcium nitrate (21% N). The various factor levels were combined factorially to give sixteen treatments.

The sixteen treatments were laid out in a randomized complete block design with three replications. Each block measured 60m x 3m and was sub divided into 16 plots giving a total of 48 plots. Each plot measured 3.5m by 3.0m. A planting rate of 210 plants per plot with a spacing of 50 cm between and 10 cm within rows was used. A central area of 2m by 2m was demarcated for harvesting of pods. The outer rows were used in sequential harvesting for dry matter determination and growth analysis. Two guard rows were planted all around each experimental plot.

The seeds to be inoculated were first washed so as to remove any seed dressing then inoculated by immersion in a mixture of sugar, water and the inoculum. The sugar solution served to ensure adherence of the inoculum to the seed.

The nitrogen was applied as top-dressing application with half rate being applied at the two leaf stage, about 3 weeks after planting and the second half at the onset of flowering or `blooming' (4-5 weeks later). The phosphorus was applied at planting along the rows and thoroughly mixed with the soil before seed sowing so as to prevent seed injury.

3.5 Crop Husbandry

The land was irrigated immediately after planting and thereafter periodically whenever necessary. During the second season there was no water for irrigation and watering was done by hand using cans.

Control of diseases and insect pests was done according to the recommendations given by Kenya Agricultural Research Institute in their handout (KARI, 1991) on French bean cultivation. The following were done.

(i) Soil application of Furadan 5G at planting at a rate of 5g/m to control cutworms.

(ii) Spraying with Karate 17 EC at 35 ml in 20 l of water at the two-leaf stage (2 weeks after sowing) to further control cutworms. Cutworms were observed inspite of all the precautions taken. A few plants were destroyed.

(iii) Spraying at two weeks interval of:

(a) Rogor E at 1.5 l/ha to control bean fly (Ophiomyia phaseoli). During flowering and podding stages, Ambush was substituted for Rogor E due to its shorter safe period of 1-2 days. The recommended rate for Ambush of 100ml/20 litres of water was used.

(b) Baycor-EC was applied at rates of half teaspoon in 14 litres of water to control bean rust caused by Uromyces phaseoli typica. In the first season there was a severe attack from bean rust and the plants were sprayed with Baycor-EC every week. In the second season, bean rust was observed during harvesting period.

(c) Copper fungicide was applied to control common bacterial blight caused by Pseudomonas phaseolicola, though this was not observed until a few weeks before harvest.

(d) Aphids (Aphid fabae) which were observed in both seasons were controlled using Thiodan 35 at the recommended rate of 2 l/ha.

Weeding was done by hand four times, at the two-leaf stage and three times before harvesting at intervals of three weeks.

3.6 Sampling Procedures and Data Collection

3.6.1 Growth analysis and determination of dry matter

Weekly height measurements were done from the twenty-first to the eighty-fourth day after sowing. Sampling for dry matter determination was done in the third, fourth, sixth, eigth, tenth and twelfth weeks after planting. The weekly interval between the third and sixth weeks was due to the high growth rate of the plants. After the sixth week a decline in plant growth rate was observed so data collected on a fortnightly basis. Five plants were uprooted carefully at random from each plot and separated into stems, leaves, pods and nodules. The leaves of the 5 plants were put together and the leaf area determined using a Li-COR model 3100 leaf area meter. The nodules were carefully separated from the roots, counted and weighed to obtain their fresh weight. Dry weight of the nodules could not be measured due to their small sizes and lack of proper equipment to dry and obtain their weight.

The plant parts were put in paper bags and dried in an oven at 75 C for 2 days to a constant dry weight .

3.6.2. Determination of total and marketable pod yields

When to pick was determined visually together with pod size measurement. Harvesting was done for about seven weeks starting from the fifty-sixth day after planting. At the end of the seven weeks the pod production became too low to be of economic value.

The harvestable mature pods were handpicked at intervals of every two days. The pods at every harvest were graded according to their size. The length and diameter of the first pod were measured using a vernier calliper after which visual judgement was used to grade the pods. Pods in the first category (extra-fine grade) had a width of less than 0.6 cm and minimum length of 10 cm; those in the second grade (fine grade) had a width between 0.6 cm and 0.9 cm with a minimum length of 10 cm. Any pods with width beyond 0.9 cm were categorized as over mature and thus referred to as rejects. The fresh weight of each grade was obtained using a pan balance. The total sum of these weights gave the total yield while the total sum of the first two grades gave the total marketable yield.

3.6.3 Chemical analyses for nutritive quality

Chemical analyses of dried pods of marketable quality for four harvests (at intervals of 1 1/2 weeks) were carried out in the Department of Food Technology and Nutrition, Faculty of Agriculture, University of Nairobi. The pods were analyzed, in duplicate, for crude protein and nitrate contents. The dried pods were first ground using Janke and Kunkel Model A10 laboratory hammer mill, to pass through a 500 micron sieve before carrying out the analyses.

3.6.3.1 Determination of crude protein

Crude protein was determined as total nitrogen by the micro-Kjeldahl method with a few modifications. Two hundred milligrammes of sample was weighed accurately on a nitrogen-free filter paper. The paper was folded carefully and placed in a Kjeldahl flask together with anti-bumping pumice, 1 Kjeldahl catalyst tablet and 10 ml of concentrated sulphuric acid. The mixture was heated slowly and carefully on a Kjeldahl heating plate, in a fume chamber until all frothing stopped and a clear solution remained. Heating was then changed to a higher setting and the mixture left to digest for another two hours. After cooling to room temperature, the residue was dissolved in a minimum amount of distilled water, then transferred to a distillation flask. Hundred millilitres of distilled water was added to the flask together with a few drops of phenolphthalein indicator. After connecting the Kjeldahl flask to the distillation unit, a 250 ml conical flask containing 50 ml of 0.1N hydrochloric acid solution and some drops of methyl orange indicator was placed under the outlet of the distillation unit. Next an amount of 40% sodium hydroxide solution, sufficient to make the mixture alkaline to phenolphthalein indicator, was added. The mixture was then heated on an electric mantle to distil off the ammonia into the 250 ml conical flask. Distillation was considered complete when 200 ml of ammonia had been collected. The quantity of nitrogen in the distillate was determined by back-titration with 0.1N sodium hydroxide solution. The percentage of total nitrogen was converted to percentage protein using the formula shown below:

$$\% \text{ Crude protein} = \frac{14.007 \times 6.25 \times (B-S) \times 100 \times 0.1}{1000 \times \text{weight of sample}}$$

Where B = ml of 0.1 NaOH solution used for blank

S = ml of " " " " " sample

Weight of sample = 0.2g.

3.6.3.2 Determination of nitrates

Nitrate content of the pods was determined by the method described by Cataldo et al. (1975) with a few modifications. Dried and ground samples were re-dried overnight in an oven at 70 C. Ten milligrams of the dry sample were then suspended in 10 ml distilled water in a 50 ml beaker and incubated for 1 hour at 45 C. After that the suspension was filtered through Watman No. 41 filter paper. Two hundred millilitres of the filtrate were pipetted into a 50 ml conical flask and 0.8 ml of 5% (w/v) solution of salicylic acid in concentrated sulphuric acid added. This was mixed thoroughly with the filtrate. The mixture was allowed to stand for 20 minutes at room temperature after which, 19 ml of 2N sodium hydroxide solution were added. After letting the mixture cool for about 30 minutes, its absorbance was read at 410 nm against a common blank (0.2 ml distilled water + 0.8 ml of salicylic acid in concentrated sulphuric acid + 19 ml 2N sodium hydroxide) using a Beckman model 25 spectrophotometer. The above was done in duplicate to get more accurate results.

Using a standard curve drawn from different concentrations of potassium nitrate solution, the nitrate-nitrogen content was calculated as equivalent milligrams per 100 grams dry matter.

3.7 Statistical Analysis of Data Collected

The data obtained were subjected to analysis of variance (ANOVA) and F values were significant (at 5% probability level). Means were separated using either the Duncan's Multiple Range Test ~~and~~ or Least Significant Difference (LSD) Test using methods illustrated by Gomez and Gomez (1984).

CHAPTER 4

4.0 RESULTS

4.1 Effect of phosphorus and nitrogen application

4.1.1 Plant growth

In both seasons application of phosphorus increased plant heights (Fig.1 and Table 2). In both seasons. there was successive increase in plant height with successive increase in plant phosphorus application upto 90 kgP/ha and thereafter, further application resulted in reduced growth. In the first season the effect of phosphorus application was seen after the ninth week after planting. In the second season, the effect of phosphorus application was seen between fifth and eleventh weeks after planting. Application of 90 kg P/ha produced significantly taller plants than application of 45 kg P/ha between the seventh and eleventh weeks after planting. In the second season, the effect of applying 90 kg P/ha was similar to that of applying 135 kg P/ha. Nitrogen application had no significant effect on plant heights.

Neither the application of phosphorus nor nitrogen had a significant effect on dry matter accumulation or on the total leaf area in both seasons.

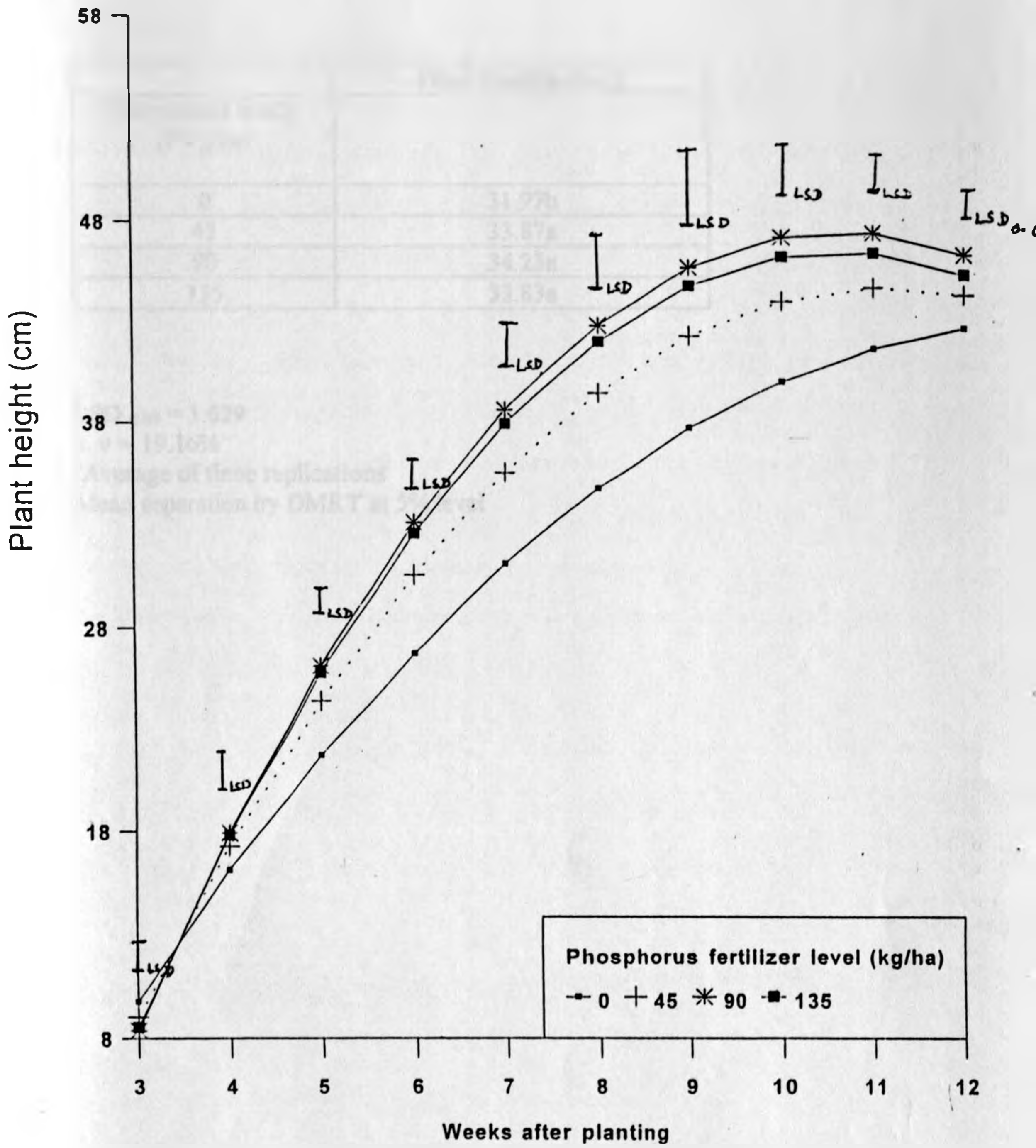

Figure 1 . Effect of phosphorus fertilizer application on plant heights of French bean (*P. vulgaris* (L)) in second season (April-August)

Table 2: Effect of phosphorus fertilizer application on plant heights of French beans (*P. vulgaris* (L) in first season

Phosphorus levels (P kg/ha)	Plant heights (cm)[a]
0	31.97b
45	33.87a
90	34.23a
135	33.83a

$LSD_{0.05} = 1.629$
c. v = 19.16%
[a]Average of three replications
Mean separation by DMRT at 5% level

4.1.2 Plant nodulation

In the first season phosphorus application did not have a significant effect on total weight of nodules. However, in the second season the application had a significant effect observed from the fourth week after planting (Fig. 2). Application of phosphorus significantly increased nodulation in the plants. Applying 45 kg P/ha resulted in the heaviest nodule weight. Applying higher rates was not significant. Nodule weight increased up to the eighth week after planting after which it began to decrease.

Nitrogen application did not have a significant effect on nodulation in both seasons.

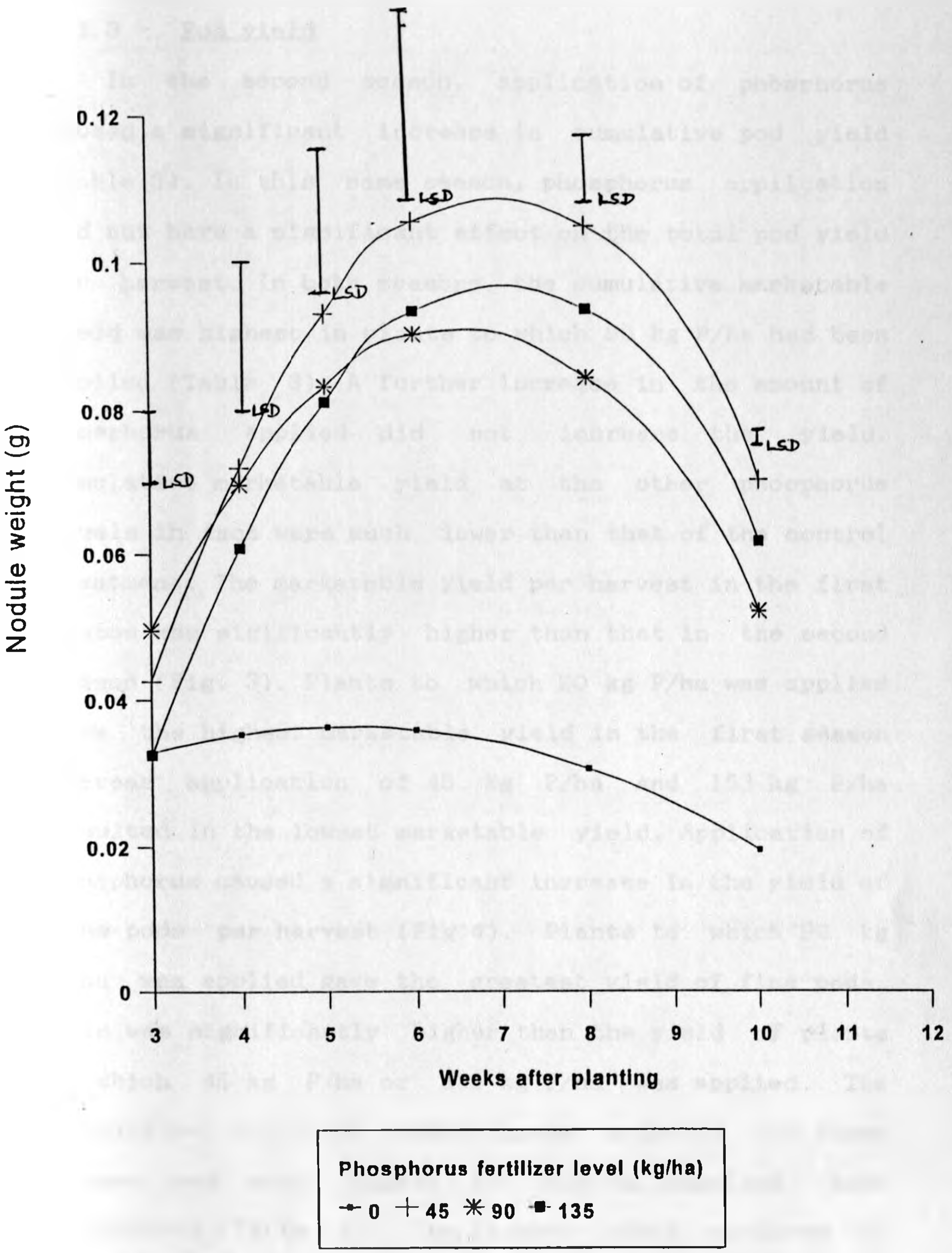

Figure 2: Effect of phosphorus fertilizer application on nodule weight of French beans (*P. vulgaris* (L)) in the second season (April-August).

4.1.3 Pod yield

In the second season, application of phosphorus caused a significant increase in cumulative pod yield (Table 3). In this same season, phosphorus application did not have a significant effect on the total pod yield per harvest. In both seasons, the cumulative marketable yield was highest in plants to which 90 kg P/ha had been applied (Table 3). A further increase in the amount of phosphorus applied did not increase the yield. Cumulative marketable yield at the other phosphorus levels in fact were much lower than that of the control treatment. The marketable yield per harvest in the first season was sigificantly higher than that in the second season (Fig. 3). Plants to which 90 kg P/ha was applied gave the highest marketable yield in the first season whereas application of 45 kg P/ha and 153 kg P/ha resulted in the lowest marketable yield. Application of phosphorus caused a significant increase in the yield of fine pods per harvest (Fig.4). Plants to which 90 kg P/ha was applied gave the greatest yield of fine pods. This was significantly higher than the yield of plants to which 45 kg P/ha or 135 kg P/ha was applied. The cumulative yield of reject grade pods in the first season was much higher in plants supplied with phosphorus (Table 3). The highest yield occurred at phosphorus levels of 90 kg P/ha. There was no significant effect on the yield of reject grade pods per harvest in the first season.

Table 3: Effect of phosphorus fertilizer application on cumulative pod yield of French beans during the first and second season

	Cumulative yield (kg /ha)				
Phosphorus levels (P kg/ha)	Total	Marketable	Extra Fine	Fine	Reject
First season					
0	60.9a	8.2b	2.7a	5.2a	44.7a
45	70.8a	7.6b	2.8a	5.1a	51.1a
90	77.0a	9.5a	3.8a	6.3a	53.7a
135	68.6a	7.8b	2.8a	5.0b	46.3a
Second season					
0	19.3a	8.3a	0.35a	6.8a	4.7b
45	29.3b	11.1a	0.22a	6.7a	8.6a
90	31.7b	12.0a	0.31a	7.1a	10.0a
135	28.6b	11.6a	0.24a	7.3a	8.9a

Mean separation by DMRT at 5% level
Marketable yield = Extra fine + Fine
Total yield = Marketable + Reject

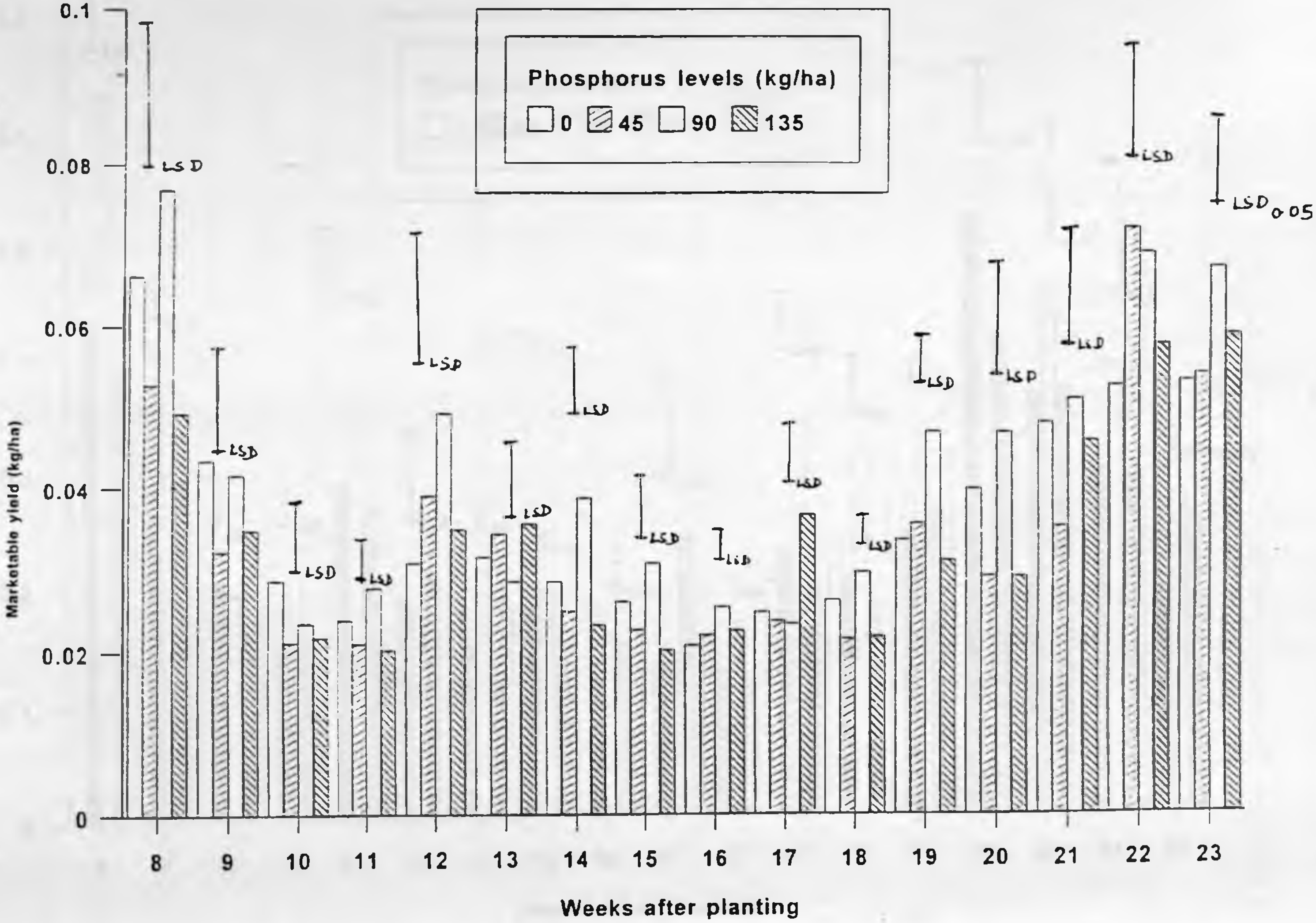

Figure 3: Effect of phosphorus fertilizer application on yield of marketable pods of French beans (*P. vulgaris* L.) plants in the first season (November – March) .

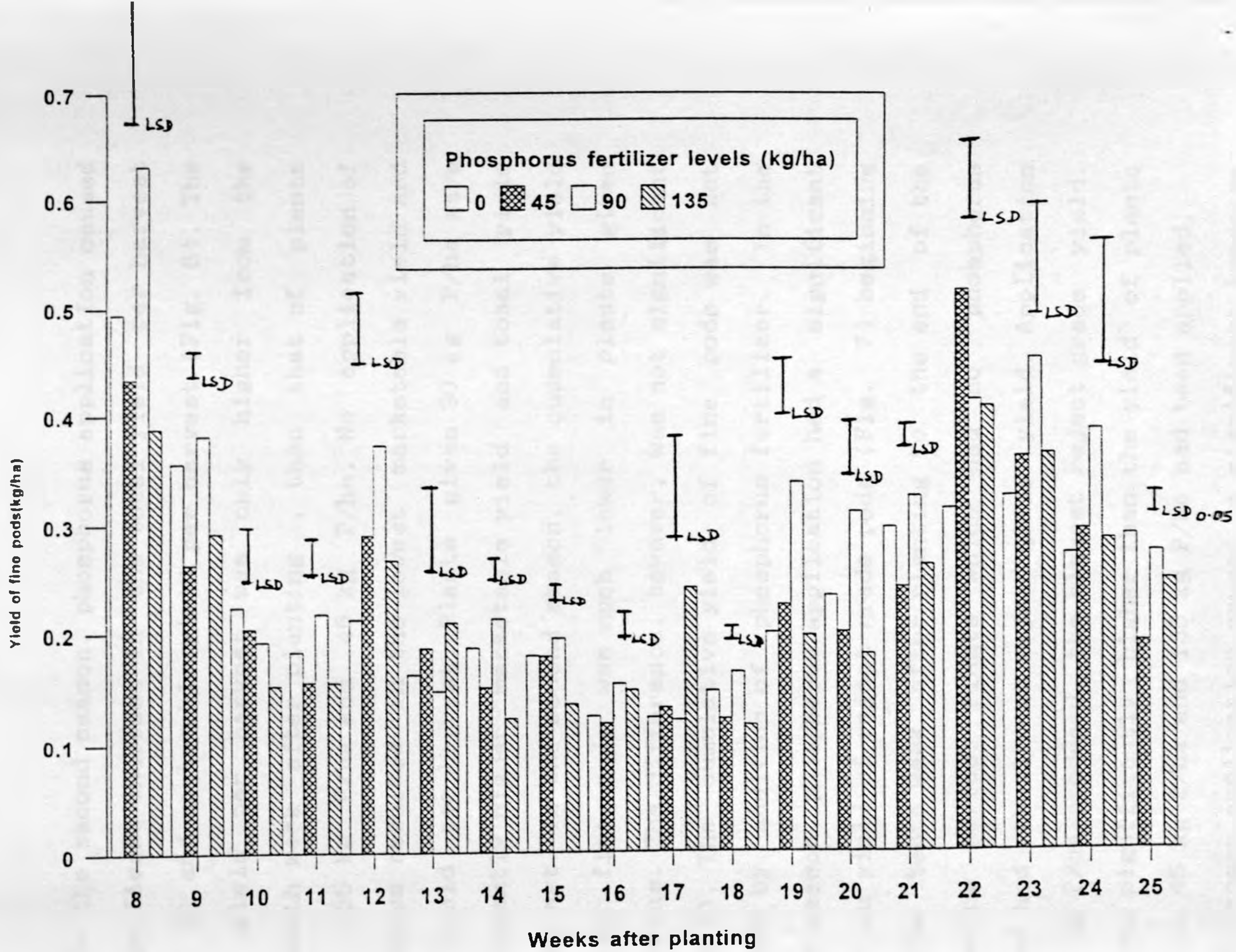

Figure 4: Effect of phosphorus fertilizer application on yield of fine grade pods of French beans (*P. vulgaris* L.) plants in the first season (November – March).

In the second season, phosphorus application caused a significant increase in the total yield per harvest (Fig. 5) and marketable yield per harvest (Fig. 6). The total yield per harvest was only higher from the thirteenth week after planting , than that of plants given 135 kg P/ha and 45 kg P/ha. No application of phosphorus resulted in the lowest marketable yield and total yield per harvest. Plants given 90 kg P/ha gave significantly higher marketable yield and total yield per harvest. In the second season, the cuumulative yield of extra fine pods was much lower in plants given phosphorus. The difference, however, was not significant (Table 3). The cumulative yield of fine pods was not affected by addition of phosphorus fertilizer. In the second season, phosphorus application had a significant effect on yield of reject grade pods (Fig. 7) beginning from the tenth week after planting to the end of the harvesting period. Plants which had no phosphorus applied had the lowest reject grade yield. Application of 90 kg P/ha produced the highest reject grade yield. This was significantly higher than the yield of plants to which 45 kg P/ha and 135 kg P/ha had been applied.

Nitrogen application caused a significant increase in cumulative yield (Table 4) and yield per harvest of extra fine pods in the second season (Fig 8). There was no significant effect on the the total and marketable pod yield in both seasons.

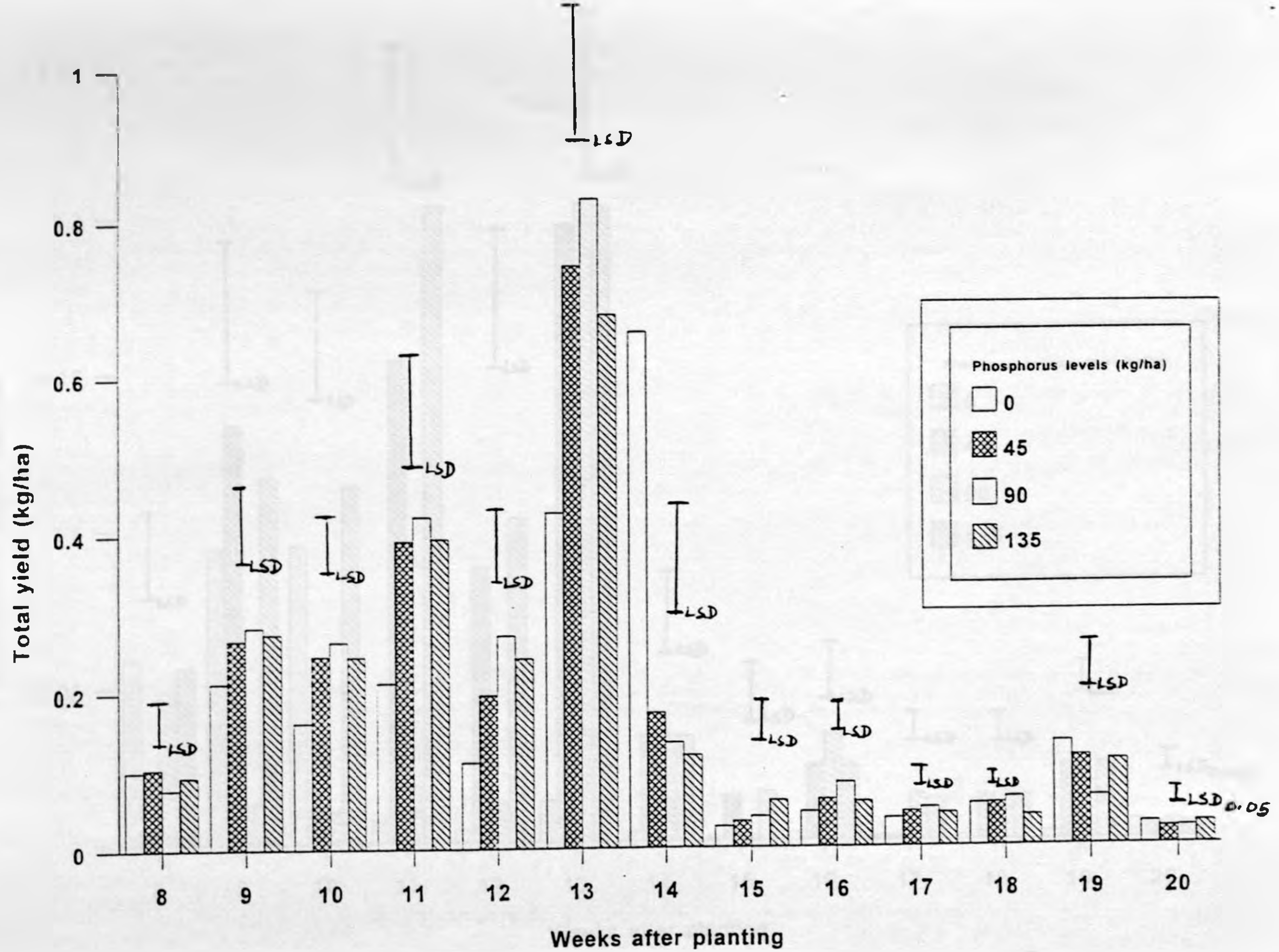

Figure 5: Effect of phosphorus fertilizer application on total pod yield of French beans (*P. vulgaris* L.) plants in the second season (April – August)

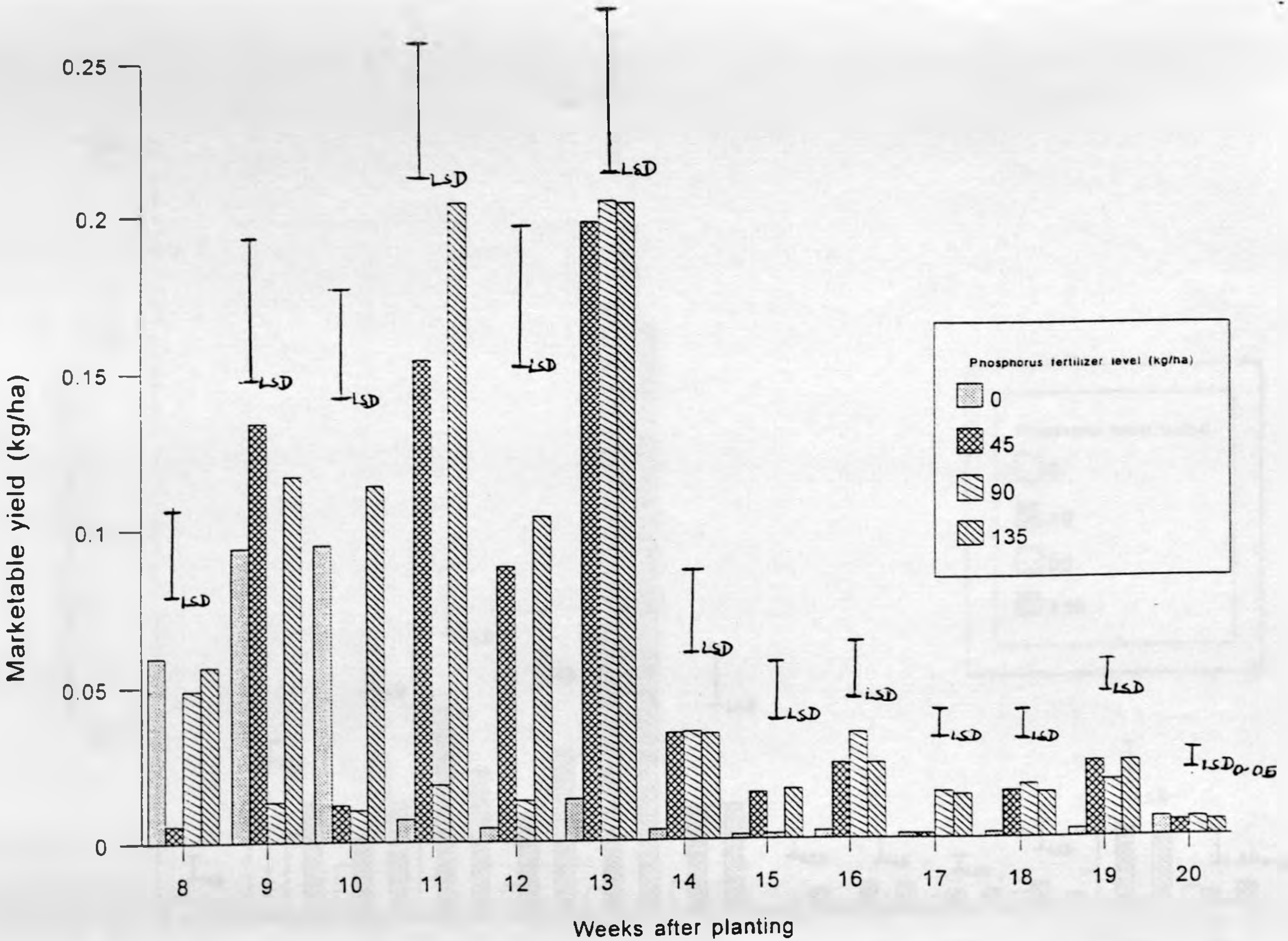

Figure 6: Effect of phosphorus fertilizer application on marketable pod yield of French beans (*P. vulgaris* L.) plants in the second season (April – August).

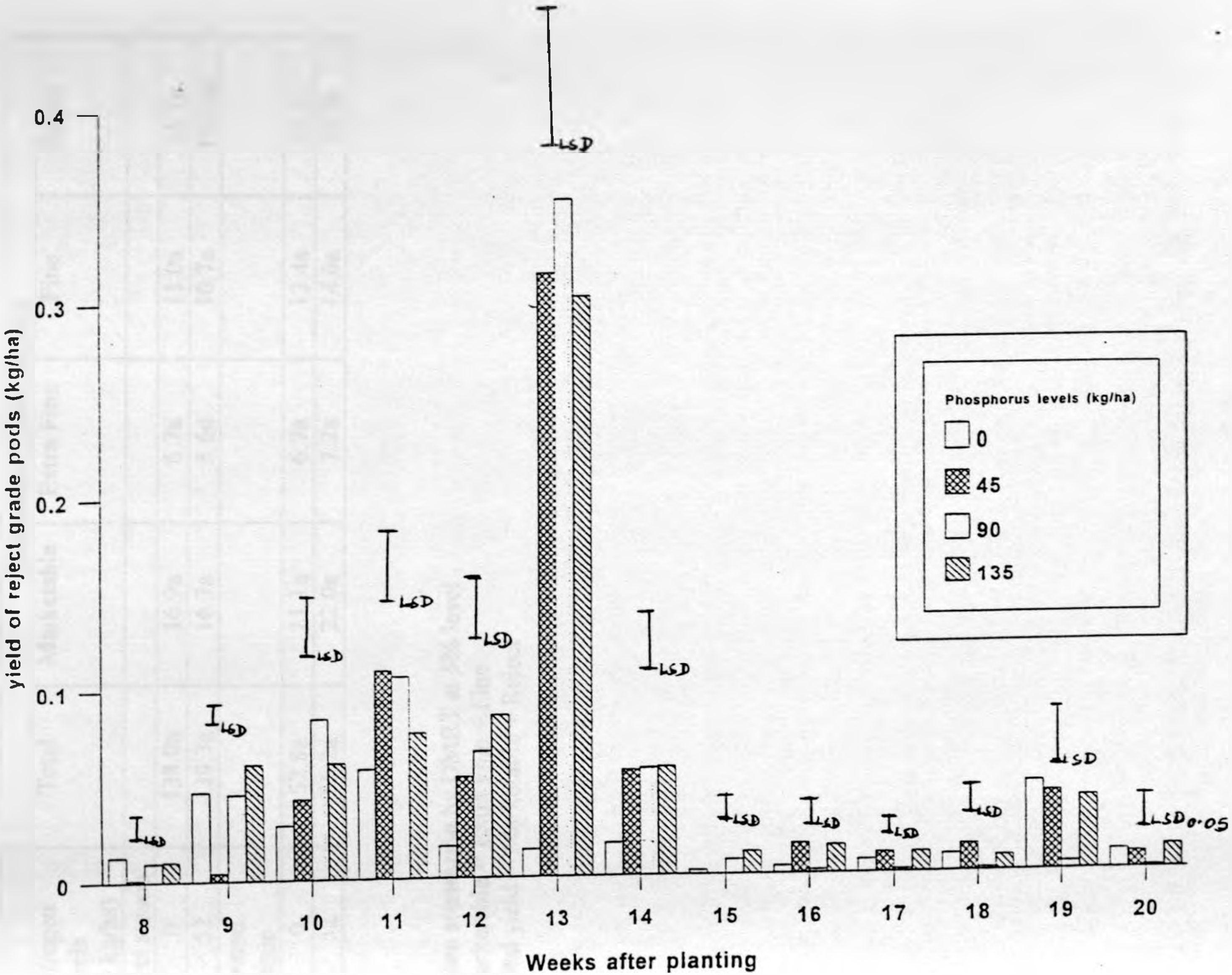

Figure 7: Effect of phosphorus fertilizer application on yield of reject grade pods of French beans (*P. vulgaris* L.) plants in second season (April – August).

Table 4: Effect of nitrogen application on cumulative pod yield of French beans during first and second season

	Cumulative yield (kg/ha)				
Nitrogen levels (N kg/ha)	Total	Marketable	Extra Fine	Fine	Reject
First season					
0	138.0a	16.9a	6.7a	11.0a	95.1a
52	139.3a	16.3a	5.6a	10.7a	100.8a
Second season					
0	52.8a	21.1a	6.7a	13.4a	15.1a
52	56.2a	22.0a	7.7a	14.6a	16.9a

Mean separation by DMRT at 5% level
Marketable = Extra Fine + Fine
Total yield = Marketable + Reject

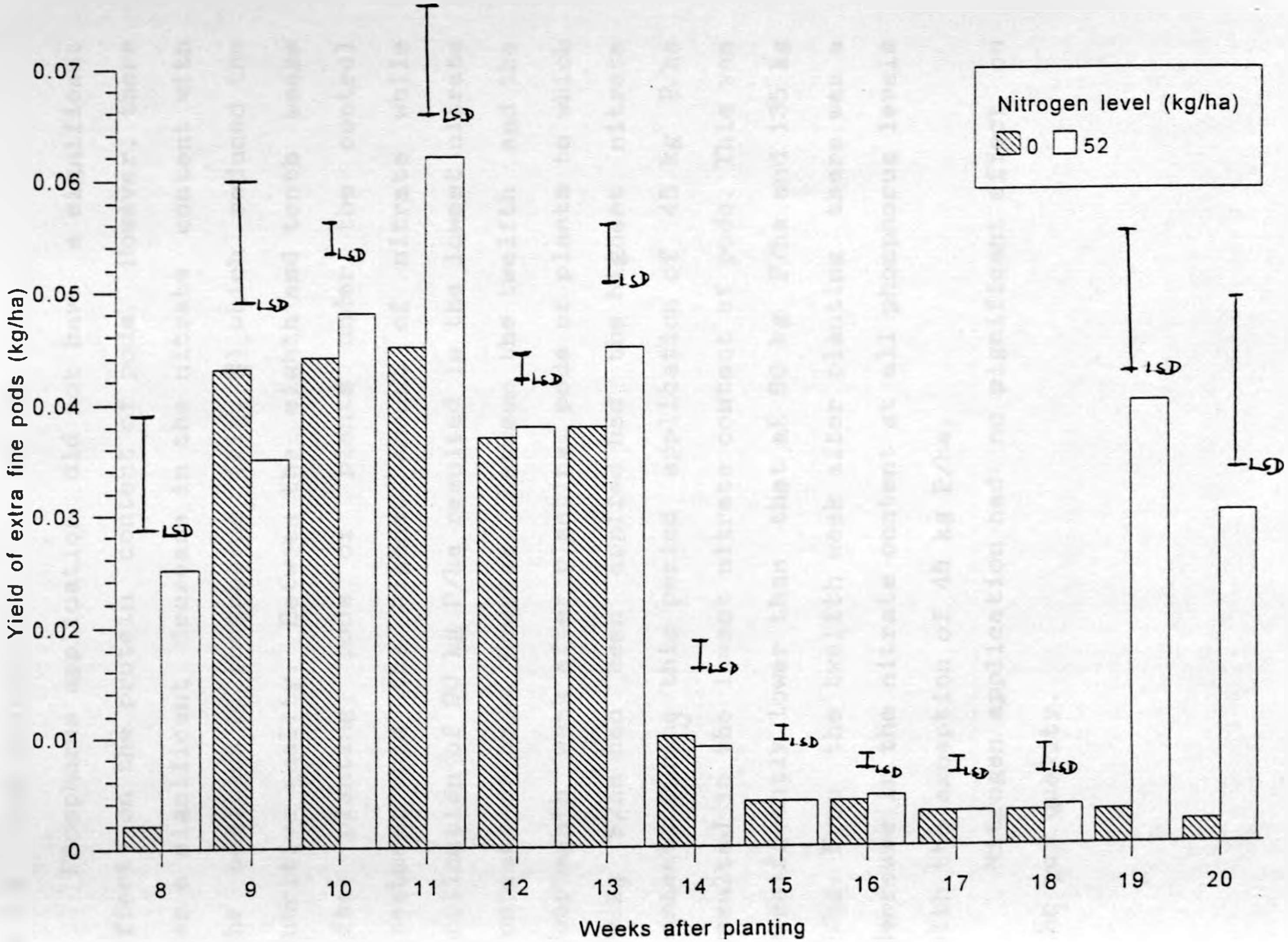

Figure 8: Effect of nitrogen fertilizer application on yield of extra fine grade pods of French beans (*P. vulgaris* L.) plants in the second season (April – August).

4.1.4 Pod quality

Phosphorus application did not have a significant effect on the protein content of pods. However, there was a significant decrease in the nitrate content with the addition of phosphorus (Fig. 9) which reduced the nutritive quality. Between the eighth and tenth weeks after planting, pods of plants under the control treatment had the highest amount of nitrate while application of 90 kg P/ha resulted in the lowest nitrate content of pods. However, between the twelfth and the fourteenth week after planting, pods of plants to which 90 kg P/ha had been applied had the highest nitrate content. During this period application of 45 kg P/ha resulted in the lowest nitrate content of pods. This was significantly lower than that at 90 kg P/ha and 135 kg P/ha. From the twelfth week after planting there was a decrease in the nitrate content at all phosphorus levels with the exception of 45 kg P/ha.

Nitrogen application had no significant effect on the pod quality.

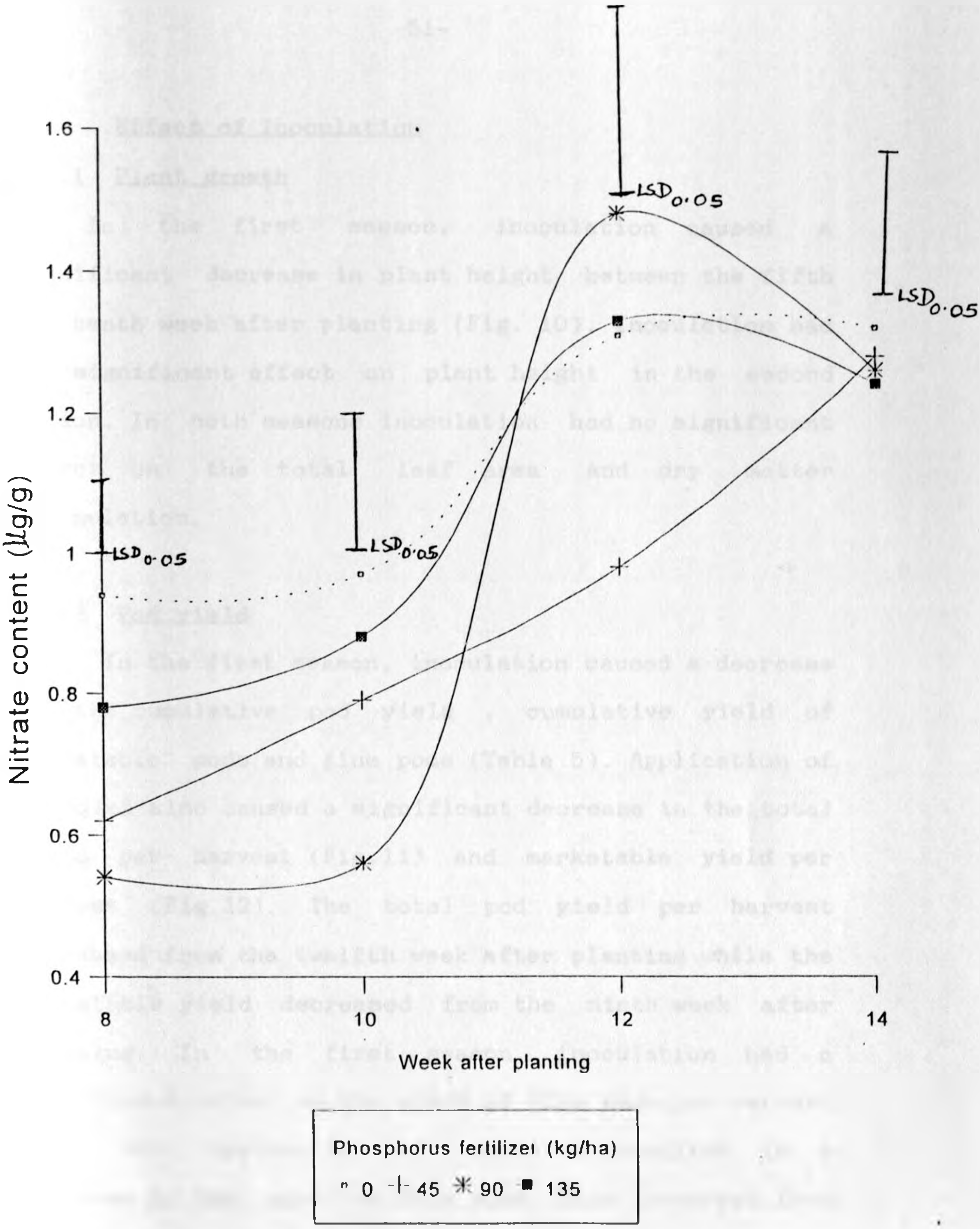

Figure 9: Effect of phosphorus fertilizer application on nitrate content of French bean (*P. vulgaris* L.) pods in second season (April – August).

4.2 Effect of Inoculation

4.2.1 Plant growth

In the first season, inoculation caused a significant decrease in plant height between the fifth and tenth week after planting (Fig. 10). Inoculation had no significant effect on plant height in the second season. In both seasons inoculation had no significant effect on the total leaf area and dry matter accumulation.

4.2.2 Pod yield

In the first season, inoculation caused a decrease in the cumulative pod yield , cumulative yield of marketable pods and fine pods (Table 5). Application of inoculum also caused a significant decrease in the total yield per harvest (Fig.11) and marketable yield per harvest (Fig.12). The total pod yield per harvest decreased from the twelfth week after planting while the marketable yield decreased from the ninth week after planting. In the first season, inoculation had a significant effect on the yield of fine pods per harvest (Fig. 13). Application of inoculum resulted in a decrease in the yield of fine pods. This occurred from the twelfth week after planting. There was no significant effect on the yield of extra fine pods and that of reject grade pods. In the second season inoculum caused a decrease in the cumulative yield of fine pods

(Table 5), but had no effect on the other yield parameters.

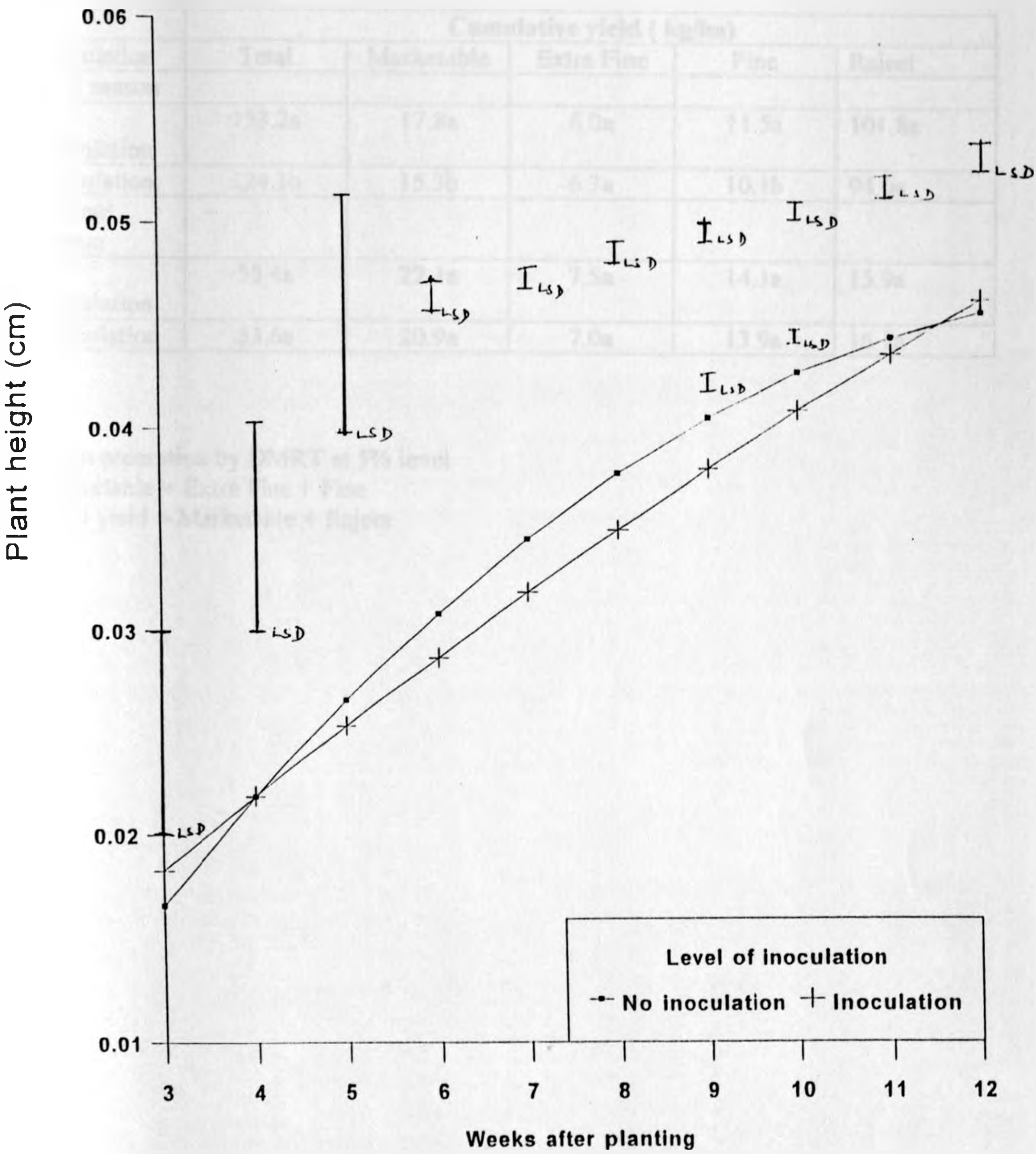

Figure 10: Effect of inoculation on plant heights in French beans (*P. vulgaris* (L)) in the first season (November-March).

Table 5: Effect of inoculation on cumulative pod yield of French beans during first and second season

	Cumulative yield (kg/ha)				
Inoculation	Total	Marketable	Extra Fine	Fine	Reject
First season					
No inoculation	153.2a	17.8a	6.0a	11.5a	101.8a
Inoculation	124.1b	15.3b	6.3a	10.1b	94.0a
Second season					
No inoculation	55.4a	22.1a	7.5a	14.1a	15.9a
Inoculation	53.6a	20.9a	7.0a	13.9a	16.1a

Mean separation by DMRT at 5% level
Marketable = Extra Fine + Fine
Total yield = Marketable + Reject

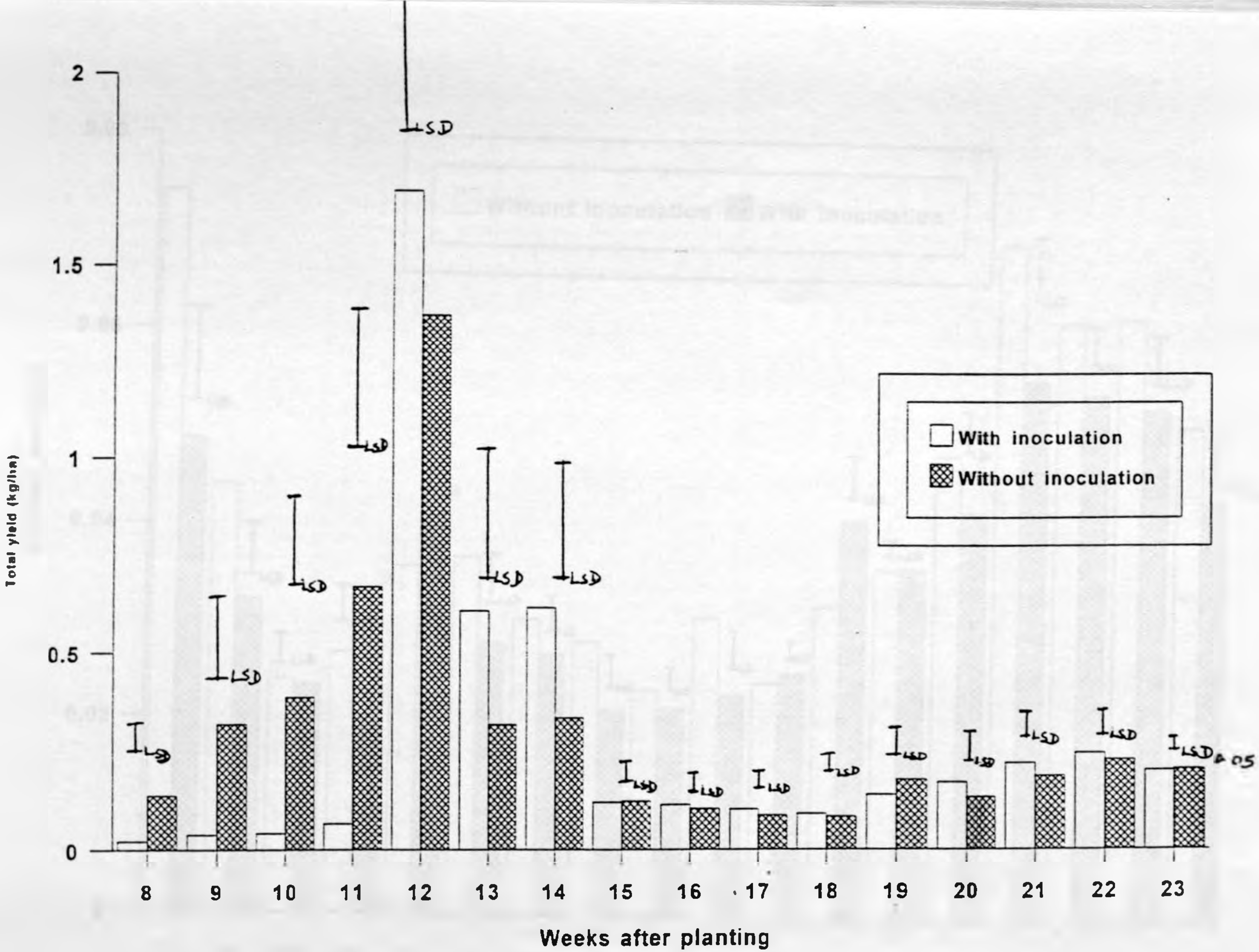

Figure 11: Effect of inoculation on total pod yield of French beans (*P. vulgaris* L.) plants in the first season (November – March).

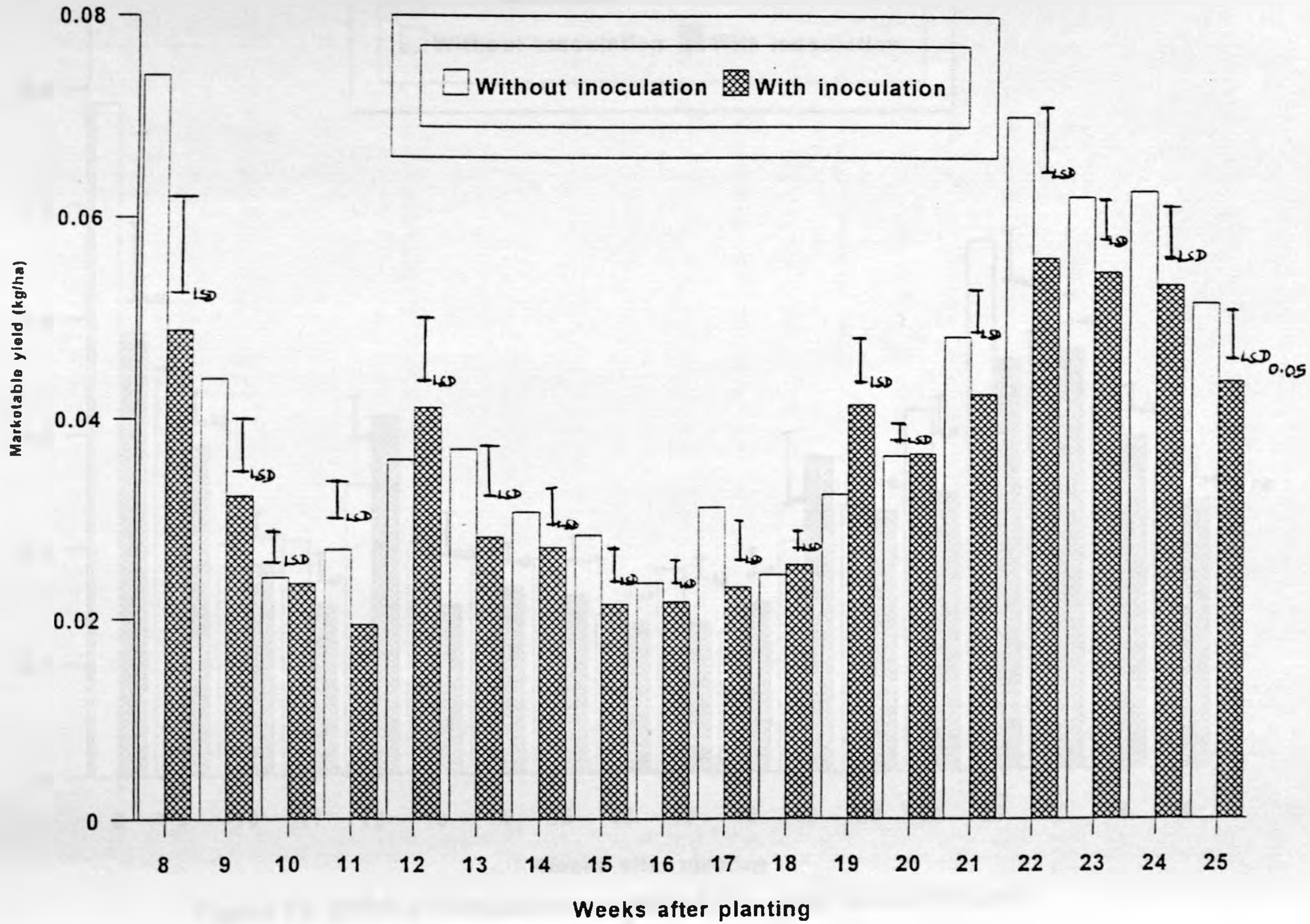

Figure 12: Effect of inoculation on marketable pod yield of French beans (*P. vulgaris* L.) plants in the first season (November – March).

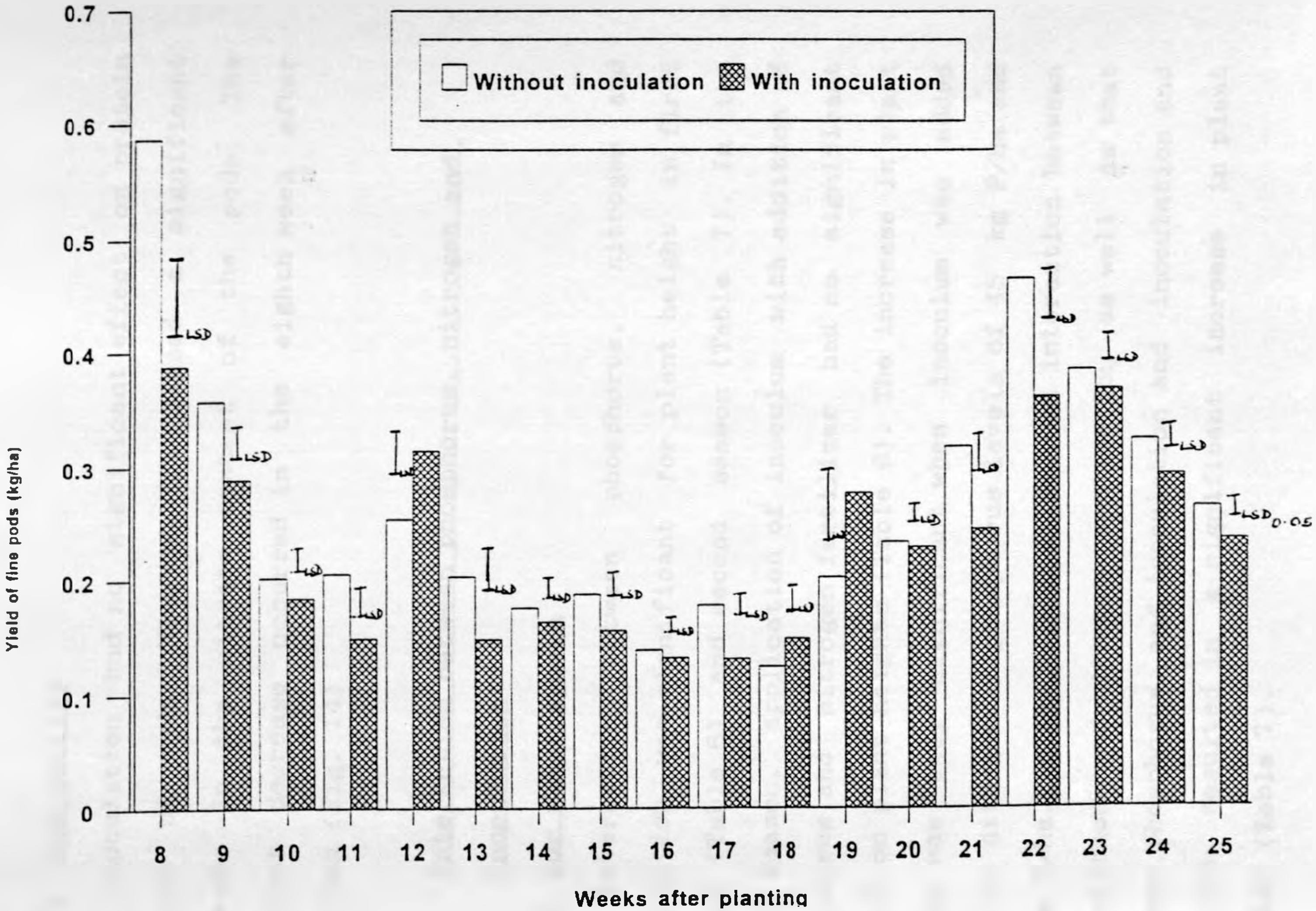

Figure 13: Effect of inoculation on yield of fine grade pods of French beans (*P. vulgaris* L.) plants in the first season (November – March).

4.2.3 Pod quality

Inoculation had no significant effect on protein content of pods. However, it caused a significant decrease in the nitrate content of the pods. The greatest decrease occurred in the eighth week after planting (Fig. 14)

4.3 Interaction between phosphorus, nitrogen and inoculation

4.3.1 For plant growth

Interaction between phosphorus, nitrogen and inoculation was significant for plant height in first season (Table 6) and second season (Table 7). In the first season, application of inoculum with addition of phosphorus and nitrogen fertilizer had no significant effect on plant heights (Table 6). The increase in plant height was only significant when inoculum was added without nitrogen at phosphorus levels of 45 kg P/ha and 90 kg P/ha. In the second season, an interaction between inoculation and nitrogen application as well as that between phosphorus and inoculation and inoculation and nitrogen resulted in a significant increase in plant heights (Table 7).

4.3.2 For plant nodulation

There were no significant interactions between the various factors for plant nodulation.

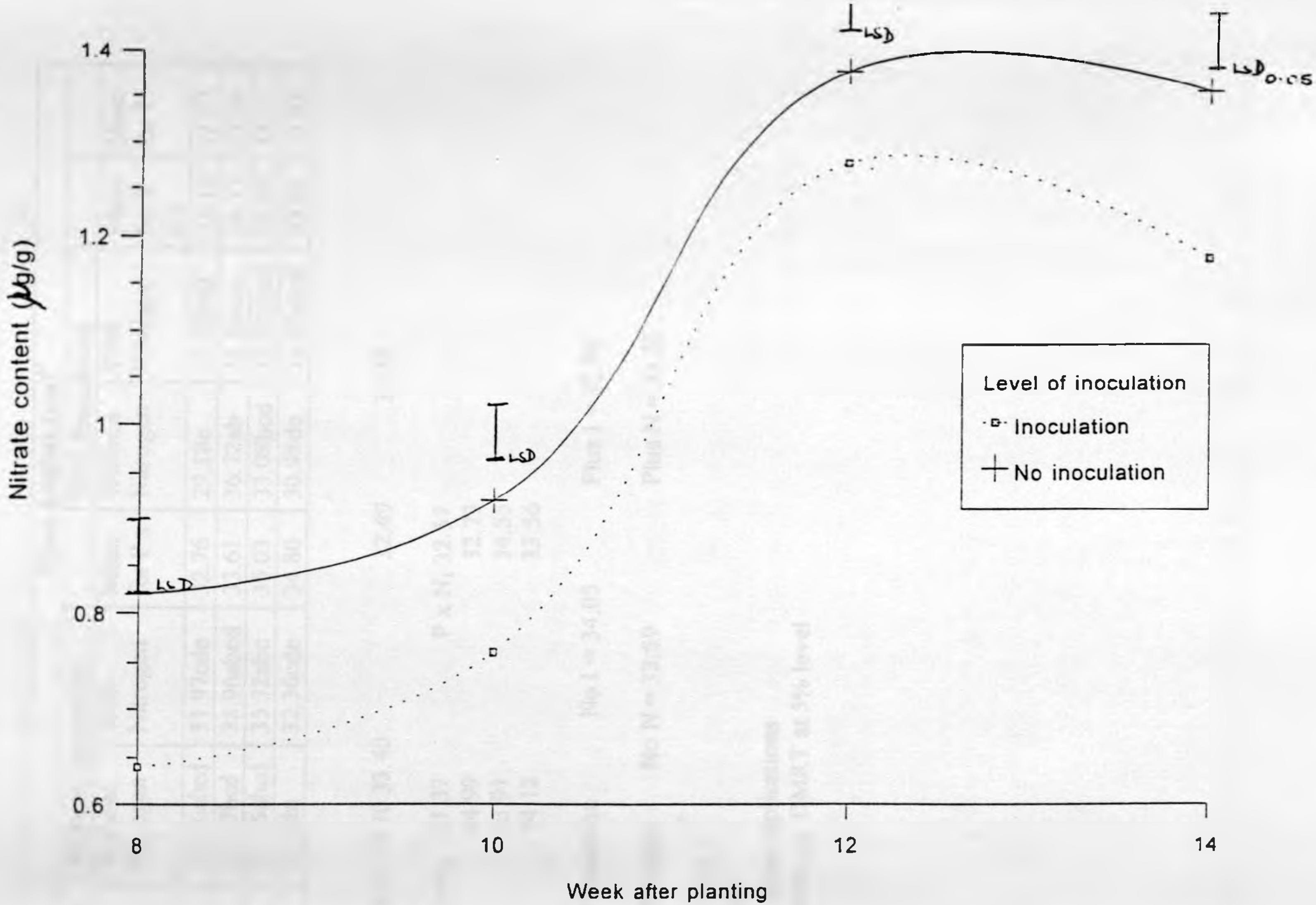

Figure 14: Effect of inoculation on nitrate content of French beans (*P. vulgaris* L.) pods in the second season (April – August).

Table 6: Interaction between phosphorus, nitrogen and inoculation for plant height of French bean plants in first season (November 1991 to March 1992)

	Plant heights (cm)[a]						
Phosphorus Level (kg P/ha)	Without Inoculation			With Inoculation			
	Without Nitrogen	With Nitrogen	Mean for P x I	Without Nitrogen	With Nitrogen	Mean for P x I	Mean for P
0	33.56abcd	31.97cde	32.76	29.18e	33.18bcd	31.18	31.97
45	33.27bcd	33.96abcd	33.61	36.72ab	31.50cde	34.11	33.86
90	34.75abcd	35.32abc	35.03	33.08bcd	33.77abcd	33.43	34.23
135	37.23a	32.36cde	34.80	30.98de	34.75abcd	32.86	33.83

Mean for I x N 34.70 33.40 32.49 33.30

Mean for P x N_0		P x N_1
	31.37	32.57
	34.99	32.73
	33.91	34.55
	34.12	33.56

Means for Inoculation No I = 34.05 Plus I = 32.89

Means for Nitrogen No N = 33.59 Plus N = 33.35

$LSD_{0.05} = 3.527$
c. v = 19.16%
[a]Average of three replications
Mean separation by DMRT at 5% level

Table 7: Interaction between phosphorus, nitrogen and inoculation for plant heights of French bean plants in the second season (April to August 1992)

	Plant heights (cm)[a]						
Phosphorus level (kg P/ha)	Without Inoculation			With Inoculation			
	Without Nitrogen	With Nitrogen	Mean for P x I	Without Nitrogen	With Nitrogen	Mean for P x I	Mean for P
0	31.14h	31.07h	31.11	32.94fg	31.91gh	32.43	31.77
45	35.70cd	34.60ef	34.95	33.60ef	35.87bcd	34.74	34.84
90	38.06a	36.50bc	37.28	37.32ab	36.80abc	37.06	37.17
135	38.08a	36.59abc	37.34	34.84de	36.80abc	35.82	36.58

Mean for I x N 35.74 34.59 34.68 35.35

Mean for P x N_o 32.04 P x N_1 31.49
34.65 35.03
37.69 36.65
36.46 36.70

Means for Inoculation No I = 35.17 Plus I = 35.01

Means for Nitrogen No N = 35.21 Plus N = 34.97

$LSD_{0.05}$ = 1.326
c. v = 8.15%
[a]Average of three replications
Mean separation by DMRT at 5% level

4.3.3 For yield

In the first season, addition of phosphorus and nitrogen fertilizer together with inoculation had a significant effect on yield of extra fine pods (Table 8). When inoculum was added without nitrogen, there was a significant increase in yield at 90 kg P/ha. The yield of fine pods per harvest in the second season increased significantly at 90 kg P/ha when nitrogen fertilizer was added without inoculation (Table 9). At 45 kg P/ha a significant increase in yield of fine pods occurred when inoculum was added without nitrogen application. Two-way interactions between phosphorus and inoculation, phosphorus and nitrogen and inoculation and nitrogen also resulted in significant yield in fine pods (Table 9).

Interaction between phosphorus, nitrogen and inoculation interaction was for the marketable yield in the first season (Table 10). When nitrogen was added without inoculation, there was a significant increase in the marketable yield at phosphorus levels of 90 kg P/ha. Without application of nitrogen, inoculation at phosphorus level of 45 kg P/ha caused a significant increase in the marketable yield. Two - way interactions between phosphorus and inoculation, phosphorus and nitrogen and inoculation and nitrogen resulted in a significant increase in marketable yield (Table 10) in the first season.

Table 8: Interaction between phosphorus, nitrogen and inoculation for yield of extra fine pods of French bean plants in first season (November 1991 to March 1992)

	Yield of extra fine pods (kg/ha)[a]						
Phosphorus level (kg P/ha)	Without Inoculation			With Inoculation			
	Without Nitrogen	With Nitrogen	Mean for P x I_0	Without Nitrogen	With Nitrogen	Mean for P x I_1	Mean for P
0	11.55b	12.87b	12.12	15.45b	10.95b	13.20	12.71
45	16.91b	14.73b	15.82	10.36b	10.32b	10.34	13.08
90	9.06b	16.41b	12.73	25.39a	10.32b	22.86	17.80
135	14.90b	15.31b	15.12	10.70b	12.27b	11.47	13.30

Mean for I x N 13.11 14.83 17.98 10.97

Means for P x N_0 13.50 P x N_1 11.91
13.63 12.52
22.22 13.37
12.80 13.79

Means for Inoculation No I = 13.97 Plus I = 14.47

Means for Nitrogen No N = 15.54 Plus N = 12.90

$LSD_{0.05}$ = 13.56
c. v = 10.5%
[a]Average of three replications
Mean separation by DMRT at 5% level

Table 9: Interaction between phosphorus, nitrogen and inoculation for yield of fine pods of French bean plants in second season (April to August 1992)

	Yield of fine pods (kg/ha)[a]						
Phosphorus level (kg P/ha)	Without Inoculation			With Inoculation			
	Without Nitrogen	With Nitrogen	Mean for P x I_0	Without Nitrogen	With Nitrogen	Mean for P x I_1	Mean for P
0	27.92abcde	23.44cdef	39.78	18.1f	26.46abcdef	49.02	44.40
45	23.09cdef	21.03def	40.03	27.93ab	22.64cdef	46.12	43.07
90	30.58abc	33.85a	48.67	23.93abcdef	29.10abcd	42.01	45.34
135	34.25a	19.38ef	52.30	17.17f	21.41def	41.07	46.69

Mean for I x N 43.07 47.32 42.84 46.28

Means for P x N_0 43.16 P x N_1 45.64
43.16 43.00
43.61 47.08
41.89 51.49

Means for Inoculation No I = 45.20 Plus I = 44.56

Means for Nitrogen No N = 42.95 Plus N = 46.80

$LSD_{0.05} = 7.475$
c. v = 35.87%
[a]Average of three replications
Mean separation by DMRT at 5% level

Table 10: Interaction of phosphorus, nitrogen and inoculation for marketable yield of French bean plants in the first season (November 1991 to March 1992)

	Marketable yield (kg/ha)[a]						
Phosphorus level (kg P/ha)	Without Inoculation			With Inoculation			
	Without Nitrogen	With Nitrogen	Mean for P x I_0	Without Nitrogen	With Nitrogen	Mean for P x I_1	Mean for P
0	44.48abcd	38.92cdefg	41.70	26.14h	41.17cdef	40.32	37.82
45	35.02cdefgh	31.35fgh	33.18	41.07bcdefg	32.20defgh	32.27	35.16
90	46.28abc	50.93ab	48.60	36.09cdefgh	43.20abcde	47.06	44.12
135	53.06a	29.34gh	41.20	29.94fgh	32.44efgh	30.89	36.20

Mean for I x N 44.71 37.64 33.31 37.64

Means for P x N_0 35.31 38.04 41.18 41.50 | P x N_1 33.92 37.14 39.85 31.19

Means for Inoculation No I = 41.17 Plus I = 35.48

Means for Nitrogen No N = 39.01 Plus N = 37.64

LSD $_{0.05}$ = 4.969
c. v = 18.09%
[a]Average of three replications
Mean separation by DMRT at 5% level

An interaction between phosphorus and inoculation resulted in a significant increase in the total yield per harvest in the first season (Table 11) at phosphorus levels of 45 kg P/ha and 90 kg P/ha.

In the second season. interactions between phosphorus, nitrogen and inoculation brought about a significant increase only in the total pod yield per harvest (Table 12) .Addition of nitrogen and inoculum, caused a decrease in total pod yield per harvest at 45 kg P/ha.

An interaction between phosphorus application and inoculation resulted in a significant incresae in yield of fine pods in the first season (Table 13). The yield of fine pods of inoculated plants when compared to that of uninoculated plants only showed a significant decrease at phosphorus levels of 135 kg P/ha. Nitrogen interacting with inoculation brought about a significant increase in marketable yield (Table 14) in the first season. Addition of inoculum caused a decrease in the marketable yield when there was no fertilizer added. With addition of nitrogen, there was no significant effect on the marketable yield of inoculated plants.

Table 11: Interaction between phosphorus and inoculation for total yield of French bean plants in first season (November 1991 to March 1992)

	Total yield (kg/ha)[a]	
Phosphorus level (kg P/ha)	Without Inoculation	With Inoculation
0	339.90a	223.80c
45	304.90abc	350.50a
90	387.30a	352.70ab
135	386.40a	249.00bc

$LSD_{0.05} = 80.63$
c. v = 24 %
[a]Average of three replications
Mean separation by DMRT at 5% level

Table 12: Interaction between phosphorus, nitrogen and inoculation for total pod yield of French bean plants in the second season (March 1992 to August 1992)

	Total yield (kg/ha)[a]						
Phosphorus level (kg P/ha)	Without Inoculation			With Inoculation			
	Without Nitrogen	With Nitrogen	Mean for P x I_o	Without Nitrogen	With Nitrogen	Mean for P x I_1	Mean for P
0	186.60bcde	168.30cdef	108.54	151.70defg	192.10abcde	140.09	124.32
45	97.81h	109.10g	192.19	148.80efg	131.30fg	183.59	187.89
90	212.60abc	171.80cdef	211.03	165.50cdef	201.70abcd	195.46	203.24
135	222.80ab	199.20abcde	198.03	151.30defg	239.60a	168.57	183.30

Mean for I x N 128.40 120.20 189.0 186.8

Means for P x N_o 128.42 P x N_1 120.22
189.02 186.75
187.08 219.40
172.17 194.43

Means for Inoculation No I = 177.45 Plus I = 171.93

Means for Nitrogen No N = 169.18 Plus N = 180.20

LSD $_{0.05}$ = 43.40
c. v = 55.82%
[a]Average of three replications
Mean separation by DMRT at 5% level

Table 13: Interaction between phosphorus and inoculation for yield of fine pods of French beans in the first season (November 1991 to March 1992)

	Yield of fine pods (kg/ha)[a]	
Phosphorus level (kg P/ha)	Without Inoculation	With Inoculation
0	39.78b	49.02ab
45	40.03b	46.12ab
90	48.67ab	42.01ab
135	52.30a	41.08ab

$LSD_{0.05} = 9.816$
c.v = 69.49%
[a]Average of three replications
Mean separation by DMRT at 5% level

Table 14: Interaction between nitrogen and inoculation for marketable yield of French beans in the first season (November 1991 to March 1992)

	Marketable yield (kg/ha)[a]	
Nitrogen level (kg N/ha)	Without Inoculation	With Inoculation
0	73.81a	67.74ab
52	61.10b	73.05a

$LSD_{0.05} = 8.850$
c.v = 68.60%
[a]Average of three replications
Mean sum of separation by DMRT at 5% level

4.3.4 For pod quality

The amount of protein in the pods decrease with application of nitrogen at phosphorus level of 90 kg P/ha. without inoculation (Table 15). Interaction between phosphorus, nitrogen and inoculation for nitrate content of pods was not significant. However, an interaction between phosphorus and inoculation was significant (Table 16). Addition of phosphorus caused a decrease in the nitrate content of the pods from plants that were inoculated.

Table 15: Interaction of phosphorus, nitrogen and inoculation for protein content of French bean pods in first season (November 1991 to March 1992)

	Protein content (%N)[a]						
Phosphorus level (kg P/ha)	Without Inoculation				With Inoculation		
	Without Nitrogen	With Nitrogen	Mean for $P \times I_o$	Without Nitrogen	With Nitrogen	Mean for $P \times I_1$	Mean for P
0	24.50abcd	27.59a	26.05	25.34abc	24.94abcd	25.14	25.60
45	27.08ab	25.30abc	26.19	22.69cd	26.03abc	24.36	25.27
90	23.89bcd	21.82d	22.86	25.04abcd	25.04abcd	25.24	23.95
135	25.77abc	24.21abcd	24.99	24.30abcd	24.20abcd	24.25	24.62

Mean for I x N 25.31 24.73 24.34 25.05

Mean for $P \times N_o$	24.92	$P \times N_1$	26.27
	24.88		25.66
	24.47		23.43
	25.04		24.21

Means for Inoculation No I = 25.02 Plus I = 24.69

Means for Nitrogen No N = 24.83 Plus N = 24.90

$LSD_{0.05} = 2.841$
c. v = 24%
[a]Average of three replications
Mean separation by DMRT at 5% level

Table 16: Interaction between phosphorus and inoculation for nitrate content of French bean pods in the first season (November 1991 to March 1992)

	Nitrate content (ug/g)[a]	
Phosphorus level (kg P/ha)	Without Inoculation	With Inoculation
0	1511.00a	808.00c
45	864.80c	1031.00bc
90	924.50c	1008.00bc
135	1193.00b	955.70c

$LSD_{0.05} = 212.5$
c.v = 35.87%
[a]Average of three replications
Mean separation by DMRT at 5% level

CHAPTER 5

5.0 DISCUSSION

5.1 Phosphorus and nitrogen application

5.1.1 Plant growth

Phosphorus application significantly increased height of the plants. This is in agreement with results obtained by Burton et al.(1961) and Lunin and Gallatin (1965). Increase in plant heights of French beans is found to be enhanced by high levels of phosphorus (Srinivas and Naik, 1990).

Since phosphorus is mainly required for root development (Tamaki and Naka, 1971) and thus has little effect on vegetative growth, a significant effect on dry matter accumulation and total leaf area was not to be expected, which is what happened. In some cases, however, and increase in dry matter accumulation due to application of phosphorus fertilizer has been found (Parodi et al. 1977).

Nitrogen application did not have a significant effect on plant height, dry matter accumulation or total leaf area in the plants. In French bean plants, nitrogen has been reported to cause increased growth (Hardwick and Innes, 1975; Doss et al. 1977). Doss et al. (1977) also reported an increase in plant height. French bean plants .unlike other legume plants respond to nitrogen application. This is because the plants are not as efficient in utilizing the nitrogen-fixing resources of the Rhizobium bacteria (Tindall, 1983).

5.1.2 Plant nodulation

In the second season, increase in nodulation occurred in the sixth week after sowing which corresponded to the stage of rapid growth in plants (Salisbury and Ross, 1980, Hedge and Srinivas, 1989). Phosphorus application results in an increase in the number, size (Bonetti et al. 1984) and weight of nodules (Saito and Ruschel, 1978) in French bean plants. The lack of response in the first season could have been due to the initially high phosphorus content (34 ppm) of the soil at depths of 20 - 40 cm. The initial phosphorus available in the soil is an important factor in determining the magnitude of nodulation (Keya and Ssali, 1983).

Nitrogen application had no significant influence on nodulation even though a reduction in nodulation was expected as reported by Crespo et al. (1987).This could have been due to the fact that the amount of nitrogen applied was not high and thus did not inhibit nodule formation. French bean plants also require a little nitrogen since they do not fix nitrogen as efficiently as the other legumes (Tindall,1983). As a consequence of this, the formation of nodules will not be adversely affected by nitrogen application. Guss and Dubereiner (1972) and Smartt (1976) reported an increase nodulation with application of nitrogen to French beans.

5.1.3 Pod yield

Phosphorus application increased the total, marketable and fine pod yields. This could have been due to increase in plant growth (Srinivas and Naik, 1990, Tamaki and Naka, 1990).

There was an increase in the yield of extra fine pods in the long rains with the application of nitrogen fertilizer. Nitrogen application has been reported to increase the rate of growth and of pod maturity in French beans (Tindall, 1983, Njeru, 1989). Hedge and Srinivas (1989) reported the highest green pod yield in French bean plants given the highest nitrogen rate. Sangarkhara and Marambe (1989) found that pod yields of plants given nitrogen was higher than those to which there was no nitrogen applied. This because French plants require an initial application of nitrogen before nitrogen fixation is established.

5.1.4 Pod quality

Application of phosphorus had no significant effect on the protein content of the pods. There was, however, a significant decrease in the nitrate content of the pods. This was not expected since phosphorus has been reported to increase the protein content of French bean .pods (Midian et al. 1980a; Wistinghausen and Richter, 1983) and to have no effect on nitrate content

(Brady, 1984, Pacovsky and Fuller, 1991). However, in a few cases an increase in nitrate content has been reported (Fageria, 1989). The lack of response in terms of protein content could be explained by the increase in growth rate caused by application of phosphorus. This may have required the mobilisation of nitrogen for protein synthesis in the vegetative organs (Salisbury and Ross, 1980, Srinivas and Naik, 1990). Phosphorus application may cause an accumulation of nitrates in pods if nitrogen is applied in excess due to increased uptake brought about by greater root development (Berger et al. 1982).

Nitrogen application did not have an effect on protein or nitrate content of the French bean pods. Hansen (1978) reported similar findings. He found that out of all the crops he used, French beans were the least affected in terms of nitrate accumulation on pods when nitrogen was applied. This could be because the nitrogen applied is used for growth since French beans are not very efficient at nitrogen fixation.

5.2 Inoculation

5.2.1 Plant growth and nodulation

Inoculation decreased the plant height of French bean plants. This is unlike what has been reported by Khachani (1981), who reported an increase in plant height of French bean plants inoculated with *Rhizobium* bacteria. Buttery et al. (1987), however reported a decrease in plant heights.The decrease in plant height could have been due the fact that the plants were not as efficient as many legumes in nitrogen-fixing (Tindall, 1983, Pereira and Bliss, 1989). There may therefore have been an insufficient quantity of nitrogen fixed where inoculation by Rhizobium occurred without use of fertilizer, hence the reduction in growth. A lack of sufficient intial nitrogen will result in the bacteria utilizing nitrogen from the plant (Tindall, 1983). This reduced the amount of nitrogen available for formation of new tissue (Salisbury and Ross, 1980, Srinivas and Naik, 1990). The lack of response to inoculation in the second season could have been caused by poor inoculum establishment (Andrew, 1977).

There was no significant effect on either total leaf area or on dry matter accumulation. This is in agreement with findings reported by Buttery et al. (1987) who found that inoculation with Rhizobium had no discernible effect on dry weight or leaf area of French bean plants. Million (1989), however reported an increase in dry weight in French beans due to inoculation.

Response of plants to inoculation depends on a number factors. These include soil pH, temperature and moisture, nutrition of the host plant and pre-sowing conditions such as seed treatment (Andrew, 1977). Rhizobia start drying out as soon as they are put on the seed and thus require a lot of moisture immediately the seeds are sown. In the second season, irrigation was done two days after sowing and, probably by this time, some of the rhizobia may have died. As a result, probably fewer rhizobia could have colonised the roots and nodulation was therefore poor. Moisture stress may some times result in nodule formation being impeded. Other than poor nodulation lack of response to inoculation in terms of nodulation could have been also due to reason cited above or to the presence of native Rhizobium in the soil. These compete with the applied inoculum for the colonisation of the host (Brady, 1984, Vakhaniya et al. 1990) and interfere with the applied bacterial inoculum activity. Velazquez et al. (1988) reported similar findings. They found that inoculation treatments had no effect on nodulation where there is native Rhizobium in the soil.

5.2.2 Pod Yield

Inoculation with Rhizobium caused a significant decrease on the total yield of fine pods, total marketable yield and total yield. This decrease was because inoculated plants require application of a little nitrogen fertilizer before they can begin to fix nitrogen (Sundstrom et al. 1982). Sangarkhana and Marambe (1989) report similar findings. They found that the yield of inoculated French bean plants increased only when nitrogen was applied at planting.

phosphorus and nitrogen to inoculated plants. This may have been that the treatments instead of influencing plant growth were used by the plant for improving reproductive growth and development as seen by the increase in pod yield.

5.3.2 Plant nodulation

The interaction between phosphorus, nitrogen and inoculation for nodulation was not significant. This was not to be expected since phosphorus application increase nodulation (Brady, 1984). The lack of response could be attributed to death of rhizobia caused by the inoculated seeds coming into contact with the superphosphate (Marshalls and Phipolts, 1980).

5.3.3 Pod yield

In the first season, phosphorus and nitrogen application and inoculation interacted to bring about a significant increase in yield of extra fine pods, fine pods and marketable pods. The addition of nitrogen increases the uptake and utilization of phosphorus to certain extent (Brady, 1984, Lalande et al, 1986), which in turn increases the yield of pods in French bean plants. The effect of phosphorus was enhanced with the application of nitrogen since it ensures proper establishment of the French bean plants (Anon. 1990).

In the second season, the interaction between the three factors was not significant for pod yield. This could have been due to the low and irregular rainfall experienced during the flowering period. Drought stress during the flowering and harvesting period can reduce yields considerably (Tindall, 1983, Khachani, 1981, Njeru, 1989) even when sufficient fertilizer is applied. Nitrogen application and inoculation in the same season caused a significant increase in the yield. This is similar to what has been reported by Sangarakhara and Marambe (1989) who found out that pod yield of inoculated French bean plants increased with addition of nitrogen. This is because nitrogen is of benefit to French bean plants during the period of establishment of Rhizobium and early phase of growth (Anon.1990).

5.3.4 Pod quality

Phosphorus when applied together with nitrogen and Rhizobium inoculum did not affect the protein content of the pods. Nodulated plants however, have been reported to accumulate a greater proportion of total N as protein-N (Pacovsky and Fuller, 1991).

Phosphorus application and inoculation caused an decrease in the nitrate content of the pods. Phosphorus enhanced the establishment of rhizobia(Bonetti et al., 1984) and therefore increased the growth rate and utilisation of nitrogen in the plants (Pereira and Bliss, 1987;1989).

CHAPTER 6

6.0 CONCLUSIONS, RECOMMENDATIONS AND SUGGESTIONS FOR FURTHER RESEARCH WORK

6.1 Conclusions and Recommendations

From the results of this study several conclusions can be made. Phosphorus fertilizer application caused an increase in growth rate of French bean plants in terms of plant heights.There was no significant influence on phant height between the three phosphorus levels. An inccrease in nodulation also occurred as a result of phosphorus application. The greatest increase in nodulation was aat 45 kg P/ha. Nitrogen application did not affect either the plant heights, or nodulation in French beans.

Phosphorus application also increased the pod yield. Applying 90 kg P/ha had the greatest effect on pod yield and any further increase in the amount applied resulted in a decrease in yield and increase in reject grade pods. Nitrogen caused an increase in the yield of extra fine pods. Nitrogen can, therefore, be said to favour production of pods of a high quality in French beans.

A decrease in nitrate content of the pods occurred with application of phosphorus. The decrease did not vary significantly at different phosphorus levels. From this it can be concluded that when phosphorus is applied alone, high levels favour plant growth while a level below the recommended rate for French bean plants i.e 90 kg P/ha, enhances nodulation. High yields of better grade pods is favoured by application of phosphorus at 90 kg P/ha with application of nitrogen.

Inoculation caused a decrease in plant heights but had no effect on dry matter accumulation or total leaf area. It can, therefore be, concluded that application of inoculum results in a decrease in growth rate of French beans. Inoculation also decreased the pod yield of French beans especially that of the high quality. Therefore, French bean plants should not be inoculated. The nitrate content also decreased when inoculum was added.

When phosphorus, nitrogen and inoculum were applied together ,there was an increase in plant heights but not in dry matter accumulation or in the total leaf area. The greatest increase occurred at 45 kg P/ha. It can therefore be concluded that only plant heights are affected by phosphorus and nitrogen fertilizers application together with inoculation. The increase occurs when phosphorus is applied at levels lower than the recommended rate of 90 kg P/ha.

Phosphorus application at the recommended rate together with nitrogen and inoculum application increased the total pod yield of French beans. There was no increase at 45 kg P/ha. The yield of higher grade pods and the total marketable yield increased when phosphorus was applied at a rate of 90 kg P/ha with 52 kg N/ha without inoculation. It can therefore be concluded that for an increase in pod yield to occur, inoculation and phosphorus application is not enough and that French beans do not obtain enough nitrogen through atmospheric nitrogen fixation. Some nitrogen fertilizer is, therefore, required.

A lower protein content was obtained at 90 kg P/ha with addition of nitrogen but without inoculation. Without inoculation, addition of phosphorus fertilizer decreased the nitrate content of French bean pods.

From all that has been stated above, the following recommendations can be made in relation to pod yield and quality. The reason for limiting the recommendations to these two factors is because in the cultivation of French beans, one is interested mainly in the pod yield and pod quality. Inoculation without addition of any nitrogen is to be recommended since French beans are not as efficient in nitrogen-fixation as other legumes. French beans therefore require a little starter nitrogen. However, in the case where inoculum is added, a lower level of nitrogen than the recommended rate of 52 kg N/ha, could be applied. The amount of phosphorus fertilizer to be used in the above case, is 90 kg P/ha. The decision to apply inoculum with a resultant decrease in the amount of phosphorus and nitrogen fertilizer applied, will depend on the availability and cost of labour. This is because application of inoculum requires a large labour force whose cost will have to be weighed against the cost of applying nitrogen and phosphorus at the recommended rates. Adequate and reliable irrigation facilities is also an important determining factor. Application of inoculum may therefore only be practical on small-scale farms.

6.2 Suggestions for further research

Having seen the different recommendations and their limitations further research in the following areas can give a deeper insight and more solid recommendations. Trials should include:

a. The effect of different nitrogen fertilizer application levels below and above the recommended rate of 52 kg P/ha with inoculation on growth, pod yield and quality of French bean plants. This is because the rate of nitrogen application in French bean production is based on that of dry beans. It could, therefore, be interesting to know the correct nitrogen application rate for French bean plants and to see the effect a combination of this rate and inoculation has on French bean plants.

b. The effect of use of different phosphorus sources such as SSP, NPK etc. on growth, yield and quality of French beans with or without inoculation. This will give an insight into the effect of other phosphorus sources on inoculum and maybe come up with the best phosphorus source to use together with inoculum.

c. The effect of different watering regimes on nodulation and pod yield of French bean plants since we know that moisture affects inoculum establishment in French beans.

R E F E R E N C E S

Abdel-Ghaffar, A.S., El-Attar, H.A.; El-Halfawl, M.H.; Abdel Salam, A.A. 1981. Effects of inoculation, nitrogen fixation, salinity and water stress on symbiotic N2 fixation by Vicia faba and Phaseolus vulgaris In "Biological Nitrogen Fixation Technology for Tropical Agriculture (eds). P.H. Graham and S.C. Harris: 209 - 255.

Abou El-Fadl, M.M.; El-Sherbeni, M.F. Fahmy, M. 1959. An analysis of some factors affecting root-nodule formation in garden bean in Egypt. Agric. Res. Review. 37(2): 269-272.

Almeida, D.L., De; Pessanha, G.G., Penteado, A. De. F. 1973. The effect of lime phosphate and nitrogen fertilization on the nodulation and yield of beans. Pesquisa Agroprecuaria Brasileira, Agronomia 8(7): 127-130.

Amare, A. and Birhanu, A. 1985. Nitrogen fixation of two Phaseolus vulgaris varieties at different rates of inoculation. In 1st Conference of African Association for Biological Nitrogen fixation, Nairobi. Kenya. eds.

H. Ssali, S. O. Keya. pp 313-333.

Andrew, C.S. 1977. Effect of Ca, pH, and nitrogen on growth and chemical composition of tropical and temperate pasture legumes. I. Nodulation and growth . Aust. J. Agric. Res. 29. pp 611-623.

Anon. 1986 Kenya Farmer No.57 pp 15 - 16

Anon. 1990 Farmer's Guide January/February pp12

Arthey, V.D. 1975. Quality of Horticultural Product: 30-35 Macmillan Publishing Company.

Asif, M.I. and Greig, J.K. 1972. Effects of seasonal interactions of nitrogen, phosphorus and potassium fertilizers on yield and nutrient content of snap beans (Phaseolus vulgaris L.). J. Amer. Soc. Hort. Sci. 97(1): 44-47.

Awad, F.; Aziz, M.A. and Omar, M.S. 1982. Interaction of phosphorus fertilization and soil moisture depletion on kidney bean (Phaseolus vulgaris L.) I. Yield of seeds and their N, P, K and protein content. Egyptian J. Soil Sci. 22(2): 135-142.

Barke, R.E. 1978. The influence of nutrition and irrigation on yield and quality of French bean seed. Bean improvement Workshop, Sydney, Australia: 57 -59.

Berger, P.G, Vieira, C., Chagas, J.M, Cardoso, A.A. 1982. Response of beans (Phaseolus vulgaris L.) to nitrogen and phosphate fertilizer. In Anais. I reuniao nacional de pesquisa de feijao: 110 - 114

Black, C.A. 1968. Soil plant water relationships. John Wiley & son, Inc.,New York: 86 - 89

Bonetti, R., Montanheir, M.N.S. Saito, S.M.J. 1984. The effect of phosphate and soil moisture on the nodulation and growth of Phaseolus vulgaris. J. Agri. Sci. 103(1): 95-102.

Brady, N.C. 1984. The nature and property of soils:32-39 Macmillian Publishing Company.

Brakel, J. and Manel, P. 1964. Nitrogen manuring and symbiotic nitrogen fixation in Phaseolus vulgaris. Rev. Agric. Brux. 17: 465-482.

Brown, J.R, Lambet, V.N. and Blevins, D.G. 1969. Nutrient interaction effects on yield and chemical composition of spinach and green beans. Mo. Agric. Expt. Stat. Res. Bull. 963:334 - 337.

Burton, J.C.; Allen, D.N. and Berger, K.C. 1961. Effects of certain mineral nutrients on growth and nitrogen fixation of inoculated bean plants, Phaseolus vulgaris L. Agricultural and Food Chemistry. 9(3): 187-190.

Buttery, B.R., Parks, S.J.; Findlay, W.I. 1987. Growth and yield of white bean (Phaseolus vulgaris L.) in response to nitrogen, phosphorus and potassium fertilizer and to inoculation with Rhizobium. Canadian J. Plant. Sci. 67(2): 425-432.

Cantliffe, D.J. 1972. Nitrate accumulation in vegetable crops as affected by photoperiod and light duration. J. American Society Hort. Sci. 97 (3) 414-418

Cataldo, D.A., Harron, M., Schrader, L.E. and Youngs, V.L. 1975. Rapid calorimetric determination of nitrates in plant tissue by nitration of salicyclic acid. Commn. Soil Sci. and Plant Analy. 6(1):71.

Chandra, R; Rajput, C.B.S; Singh, K. P. and Singh, J.P. 1987. A note on the effect of nitrogen, phosphorus and fertilization on the growth and yield of French (Phaseolus vulgaris L.) cv contender. Haryana J. Hort. Sci: 425 - 430.

Chui, J.N. (1987). Nodulation, dry matter production and yield of Phaseolus vulgaris and Vigna uniguiculata as influenced by granular and peat inoculum application in a soil uncultivated for 15 years. E. Afric. Agric. and For. J. 51(2): 71-77.

Costigan, P. A. 1987. A comparison of the effects of residual and freshly applied fertilizer on the growth and yield of dwarf French beans. Acta Horticulturae No. 220: 281-288.

Crespo, G. M; Kluson, R and Schroder, E. C. (1987) Nitrogen levels and Rhizobium inoculation and yields of native white beans (Phaseolus vulgaris L.). J. Agric. Sci. (103)1: 111 - 113

Doss, B.D., Evans, C.E. and Turner, J.L. 1977. Irrigation and applied nitrogen effects on snap beans and pickling cucumbers. J. Americ. Soc. Hort. Sci. 102(5): 654-657.

Dombovari, J. 1977. Investigations on the nitrogen supply of soya bean and bean plant. Novenytermeles. 26 (5). 415-423

Duque, F.F; Neves, M. C. P; Franco, A.A. 1985. The response of field grown Phaseolus vulgaris to Rhizobium inoculation and the quantification of nitrogen fixation using 15N. Plant and Soil. 88(3) pp. 333-343.

El-Leboudi, A.; Maksoud, A.; Midan, A., Mitkees, A. 1974. Response of snap bean plants to fertilization with phosphorus, potassium and manganese agric. res. review. 52(5): 149-159.

Endo, R.M.; Fornasieri Fulho, D.; Malheiros, E.B. and Fornasieri, J.L. 1988. Effects of inoculants, nitrogen and micro-nutrients on yield components of bean (Phaseolus) in Brazil. Cientifica 16(1): 141-150.

Fageria, N.K. 1989. Effects of phosphorus on growth, yield and nutrient accumulation in the common bean. Trop. Agric. 66(3): 249-255.

FAO/UNESCO. 1984. Fertilizer Programme. Ministry of Agric. Kenya. Crop Production division. Report Nos. 3 and 4: 226 - 300.

Farouk, A.S. 1978. Food legume research and development in the Sudan. In "Proc. of a workshop on Food Legumes Improvement and Development" (eds) Geoffrey C. Hawtin and George J. Chancellor: 52 - 60.

Floor, J. 1982. Effect of soil fertility status, moisture and application of fertilizer and inoculum on nodulation and growth of dry beans in Kenya. In "Proc. 1st. Conference of the African Asso. for Biological Nitrogen Fixation" (eds) H. Ssali and S.O. Keya: 2 - 9.

Franco, A.A. and Munns, D.N. 1982. Acidity factors limiting nodulation, nitrogen fixation and growth of *Phaseolus vulgaris* L. Diss. Abst. Int. B. 42(9): 63 - 70.

Guss, A. and Dobereiner, J. 1972. The effect of nitrogen fertilization and soil temperature on nitrogen fixation by French bean

(Phaseolus vulgaris). Pesquisa Agropecuaria 17: 87-92.

Graham, P.H. and Rosas, J.C. 1979. Phosphorus fertilization and symbiotic nitrogen fixation in common bean. Agron. J. 71: 925-926.

Gravas, M. 1981. The influence of mineral nutrition, stage of harvest and flower position on seed yield and quality of Phaseolus vulgaris L. PhD thesis. University of Bath. England.

Hansen, H. 1978. The influence of nitrogen fertilization on the chemical composition of vegetables. Qualitas plantanum. 28(1): 45-63.

Hardwick, R.C. and Innes, N.L. 1975. It´s by no means an easy start for the bean seed. Commercial Grower. No. 4158: 416-417.

Hedge, D.M. and Srinivas, K. 1989. Effect of irrigation and nitrogen on growth, yield and water use of French beans. Ind. J. Agro. 34(2): 180-184.

Hera, C; Popescu, A.; Burlacu, G.; Petre, M.; Idriceanu, A; Stanciu, a. Bologia, M.; Timirgaziu, E. 1985. Some aspects on the nitrogen and phosphorus nutrition of Phaseolus vulgaris. Analele Institutuli de cercetari pentru ceneaci si plante Tehnice Fundulea. 52: 163-181.

Horticultural Crops Development Authority (HCDA). 1993 Production Guide for French beans: 1 - 2.

Hungria, M. and Neves, M.C.P. 1987a. Partitioning of nitrogen from biological fixation and fertilizer in Phaseolus vulgaris. Physiologia plantarum. 69(1): 55-63.

Hungria, M. and Neves, N.C.P. 1987b. Cultivar and Rhizobium strain effect on nitrogen fixation and transport in Phaseolus vulgaris L. Plant and soil. 103: 111-121.

Kastovi R; Petrovic, N. Ognjanov. V. 1977. Phosphorus content and translocation in young bean plants receiving different rates of phosphorus. Savremena poljoprivreda 25: 51-61.

Kay, D.E. 1979 Food Legumes. Tropical Products

Institute. London: 20 - 21

Keya, S.O and Ssali, H. 1983. The effect of phosphorus on nodulation, growth and dinitrogen fixation by beans. Biological Agriculture and Horticulture. 1 (2). 135-144

Khachani, M. 1981. Study on the response of green beans to inoculation. Thesis. Ing. Agr.: 49 - 52

Koinov, G. and Petkov, P.S. 1975. The effect of fertilization on the chemical composition, cooking quality and flavour of beans. Rasteniev'dni Nauki 12(2): 100-109.

Lalande, R.; Anton, H.; Pare, T.; Joyal, P. 1986. Effects of inoculation with strains of Rhizobium leguminosarum biovar phaseoli on yield and nitrogen content of wax bean (Phaseolus vulgaris). Naturaliste Canadien. 113 (4). 337-346

Leny. A. 1986. Kenya's Vibrant Horticultural Industry. Kenya Farmer No. 61. pp 17 - 18

Leidi, E.O. and Gomez, M. 1980. Study of the influence of nitrates on the growth and symbiotic nitrogen fixation in bean (Phaseolus vulgaris L.) plants. Anales da Edafologia y Agrobiologia. 39(11/12): 2175-2197.

Lunin, J. and Gallatin, M. H. 1965. Salinity - fertility interactions in relation to the growth and composition of beans. I. Effect of N, P and K. II. Varying levels of N and P. Agron. J. 57: 339-345.

Mahatanya, E.T. 1976. The effect of phosphorus and copper on the bean plant (Phaseolus vulgaris L.). Mysore J. of Agric. Sci. 10(2): 214-225.

Mascarenhas, A.A. 1969. The mineral fertilizing of beans. XII Effects of liming and of nitrogen and phosphorus on a reddish yellow latosol soil in the Ribeira Valley. Braganha 28: 71-83.

Midian, A.A.; El-Bakry, A.M.; Omran, A.F.; Malash, N.M. 1980a. Effects of phosphate, as localized or foliar applications and nitrogenous fertilizer along with their interaction on snap beans. I. Growth and chemical constituents. Monoufeia J. of Agric. Res.

3: 311-338.

Midian, A.A.; El-Bakry, A.M.; Omran, A.F.; Malash, N.M. 1980b. Effects of phosphate, as localized or foliar applications and nitrogenous fertilizer along with their interaction on snap beans. II. Intake rate and efficiency of utilization of phosphate and nitrogen. Monoufeia J. of Agric. Res. 3: 339-353.

Midian, A.A.; El-Bakry, A.M.; Omran, A.F.; Malash, N.M. 1980c. Effects of phosphate, as localized or foliar applications and nitrogenous fertilizer along with their interaction on snap beans. III. Yield and yield components. Monoufeia J. of Agric. Res. 3: 355-368.

Million, J.B. 1989. Rhizobium-related constraints to grain legume production in St. Kitts, West Indies. Dissertation Abstracts. International, B. (Sci. and Eng.). 48(8): 2937B.

Moursi, M.A., Nour-El-Doin, N.A.; Mansour, M.A. 1975. Flowering and fruit set of bean (Phaseolus vulgaris L.) as influenced by ammonium sulphate and calcium superphosphate. Egyptian J. of Hort. 2(1): 23-37.

Mulandi, M. S. 1990. Help for Horticulture. African Farmer.:5 - 7

Mmnyinyi, J. 1987. A garden of delights. Kenya Farmer No. 69: 29 - 30.

Mullins, C. A. 1987. Effects of nitrogen fertilization level on yield and pod quality of mechanically harvested snap beans. HortScience. 22 (1). 34-36

Njeru, L. W. 1989. Influence of nitrogen rates and storage conditions on quality and shelf-life of French beans (Phaseolus vulgaris .L). M. Sc. thesis. University of Nairobi: 21 - 35.

Njururi, B. 1988. Produce pays dividend African Farming and Food Processing Nov/Dec. 1988: 9 - 10.

Osawa. T. and Lorenz, O.A. 1968. Effect of nitrite and phosphorus levels in nutrient solution on growth of vegetable crops. Amer. Soc. for

Hort. Sci. Proc. 92: 595-602.

Pacovsky, R.S. and Fuller, G. 1991. Nitrogen assimilation and partitioning in two nitrogen-fixing cultivars of Phaseolus vulgaris L. Plant and soil. 132(1): 139-148.

Palaniyandi, R. 1976. Nutrient interaction studies in snap beans (Phaseolus vulgaris L.). Ph.D. Thesis. University Park, Pennsylvania State University: 93 - 101.

Pande, G. K.; Seth, J. N.; Phogat, P. S.; Tiwari, S. N. 1974. Effect of spacing and P205 on the green pod yield of dwarf French bean (Phaseolus vulgaris. L) variety Black Prince. Progressive Horticulture. 6 (2/3). 41-47.

Parodi, A. E.; Opazo, A. J. D.; Mosjidis, C. H. J. 1977. The effect of phosphorus application on yield and nitrogen, phosphorus and potassium contents of bean plants. Agricultura Tecnica. 37 (1). 12-18

Paterson, D.R., Downes, J.D., Peck, N.H.. Ozaki, H., Tyler, K.B. and Wiggans, S.C. 1966.

Effects of nitrogen on yield, quality and mineral uptake of harvester snap beans. Texas Agric. Exp. stn. (College Station). Mis. Publ. 808: 330 - 337.

Paz, L.G,; Da Rushel, A.P., Malovolta, E. 1982. Effect of combined N, Ph and P. Ca. Al and Mn concentrations in a culture solution on growth and N2 fixation in beans (Phaseolus vulgaris L.). Anais da Escola superior de Agricultura "Luiz de Queiroz". 39(1): 189-201.

Peck, N.H and MacDonald, G.E. 1984. Snap bean plant response to nitrogen fertilization. Agron. J. 76:247.

Peck, N.H.; van Buren, J.P. 1975. Plant response to concentrated superphosphate and potassium chloride fertilizers v. snapbean (Phaseolus vulgaris var. humilis). Search, Agric. 5(2): 1-32.

Pereira, P.A.A. and Bliss, F.A. 1987. Nitrogen fixation and plant growth of common bean (Phaseolus vulgaris L.) at different levels of phosphorus availability. Plant and soil 104(1): 79-84.

Pereira, P.A.A. and Bliss, F.A. 1989. Selection of common bean (Phaseolus vulgaris L.) for N2 fixation at different levels of available phosphorus under field and environmentally-controlled conditions. Plant and Soil. 115(1): 75-82.

Prabhakar, B.S., Srinivas, K., Subramanian, T.R. 1986. Phosphorus fertilization in sequence cropping of vegetables. Indian Journal of Agricultural Sciences (1986). 56(10) 710 - 716.

Rosas, J.C. 1984. Partitioning of dry matter, nitrogen fixation and seed yield of common bean (Phaseolus vulgaris L.) influenced by plant genotype and nitrogen fertilization. Diss. Abst. Int. B. (Sci. and Eng.) 44: 12.

Ruschel, A. P and Saito, M. T. 1991. Efficiency of Rhizobium inoculation on Phaseolus vulgaris L. a. Effect of nitrogen sources and varieties. Pesquisa Agropecuaria Brasileira 10 (11): 18-24.

Russell, E.W. 1983. Soil conditions and plant growth. Ed. Alan Wild. Longman Group (UK) Ltd: 42

- 55.

Sader, R. 1982. Effect of N and P fertilizers on growth, nitrate reductase activity, seed production and seed quality of snap bean. (Phaseolus vulgaris L.). Dissertation Abst. Int. 1979 (40): 5.

Saito, S.M.T. and Ruschel, A.P. 1978. Effect of lime phosphate fertilizer and trace elements on natural nodulation of beans (Phaseolus vulgaris L.). Anais da Escola superior de Agricultura. "Luiz de Queiroz": 115 - 117.

Salez, P. and Saint Macary, H. 1987. Bean (Phaseolus) inoculation with Rhizobium phaseoli in Cameroon. Agronomie Tropicale. 42(4): 269-274.

Salisbury, F.B. and Ross, C.W. 1980. Plant physiology. 2nd edition. Wadsworth Pub. Co. Inc. Belmont, California: 65 - 74.

Samtservich, A.A., Revinskaya, L.S. and Khodovstov, I.R. 1980. Effect of Rhizobium and nitrogen fertilizers on nitrogen uptake and productivity of beans.

Sel'skokhozyalstvennaya Biologiya. 15(1): 123-126.

Sangakhara, U.R. and Marambe, B. 1989. Effect of method of inoculation and nitrogen fertilization on nodulation and yield of selected tropical legumes. J. Agron. and Crop Sci. 162(5): 305-309.

Sinha, S.K. 1977. Food legumes; distribution, adaptability and biology of yield. FAO Plant production and protection. No. 3: 85 - 90.

Smartt, J. 1976. Tropical pulses. Longman Group Limited (London): 98 - 115.

Smith, D.L.; Dijak, M. Home, D.J. 1988. Effect of irrigation and fertilizer on accumulation and partitioning in white bean and soya bean. Canadian J. Plant Sci. 68(1): 31-39.

Smittle, D.A. 1976. Response of snap bean to irrigation, nitrogen fertilization and plant population. J. American Soc. Hort. Sci. 101(1): 37-40.

)os, T. and Balent, G. 1979. Field response to Rhizobium inoculation as well as to the joint application of ammonium molybdate and boric acid on brown forest soils in beans (Phaseolus vulgaris L.). Novenytermeles. 28(1): 53-56.

Sparrow, S.D. Jr. 1981. Survival of Rhizobium phaseoli in inoculants and inoculation of field grown navy beans. Dissertation Abst. Int. B. 42(1): 26.

Srinivas, K. and Naik, L. B. 1990. Growth, yield and nitrogen uptake in vegetable French beans (Phaseolus vulgaris L.) as influenced by nitrogen and phosphorus fertilization. Haryana. J. Horticultural Sci. 19 (1-2). 100-167.

Sundstrom, F.J.; Morse, R.D.; Neal, J.L. 1982. Nodulation and nitrogen fixation of Phaseolus vulgaris L. grown in mine soil as affected by soil compaction and N-fertilization. Comm. in Soil. Sci. and Plant Analysis 13(3). 231-242.

Taisser, M.A.B, El Iraqui, S.M. and Hussein, M.H. 1986. Nitrate content of some fresh and processed Egyptian vegetables. J. Food Chem. 19. 265

Tamaki, N. and Naka, J. 1971. Physiological studies of the growing process of broad bean plants. IV. Effects of N, P and K nutrient element on the growth and the chemical components in the various organs. Kagawa Daigaku Nogakubu Gakuzyuto Hokoko 23(1): 200 - 205.

Taylor, J.D.; Day, J.M.; Dodley, C.L. 1983a. The effect of Rhizobium inoculation and nitrogen fertilizer on nitrogen fixation and seed yield of dry beans (*Phaseolus vulgaris*). Annals of Applied Bio. 103(3): 419-429.

Taylor, J.D.; Day, J.M.; Dudley, C.L. 1983b. Rhizobium inoculation of dwarf beans. Annals of Applied Biol. 103(4): 435 - 444

Tindall, H.D. 1983. Vegetables in the tropics. ELBS. Macmillan: 32 - 45.

Thung, M.; Ortega, J.; Rodriguez, R. 1983. Response and advantage of phosphorus applied at two depths and its effect on yield of beans (*Phaseolus vulgaris*). Field Crop

Abstracts: 66 - 69.

Vakhaniya, N.A.; Abashidze, N.D.; Chokheli, M.D.; Nutsubidze, N.N. 1990. Influence of nitrate and molybdate on nitrogen fixation and productivity of kidney beans. Fiziologiya Rastenii. 37(4): 636-641.

Velazquez, Y.A.; Kluson, R.A. and Schroder, E.C. 1988. Rhizobium inoculation of Phaseolus vulgaris in Layas. J. Agric. Univ. of Puerto Rico v. 72(3): 427-443.

Wallace, A.; Soufi, S.M.; Cha, J.V.; Romney, E.M. 1976. Iron-phosphorus interactions in bush beans. Communications in Soil Sci. and Plant. Analysis 7(1): 101-104.

Wamburi, W.K. 1973. Notes on the Kabete Field Station, Faculty of Agriculture, University of Nairobi: 1.

Westermann, D. T.; Kleinkopf, G. E.; Porter, L. K.; Leggett, G. E. 1980. Nitrogen sources for bean seed production. Agronomy J. 73 (4). 660-661.

Wistinghausen, E.V.; Richter, M. 1983. Fertilizer type and the quality of vegetables. Revistade la Facultad de Agronomia (Univ. of Buenos Aires). 4(2): 123-124.

APPENDICES

Appendix 1: **Mean monthly weather record - Field Station, Kabete between November 1991--July 1992.**

Month	Mean radiation	Mean sunshine	Temperature °C			Total rainfall	Mean evaporation	% RH (mean)		Total wind-run
	MJM⁻²	hrs/day	Max	Min	Mean	mm/month	mm/day	Morning	Night	km/day
1991										
October	16.77	7.6	25.0	13.0	19.0	21.6	-	77	43	104.6
November	14.16	6.70	22.7	13.5	18.1	199.4	-	88	57	-
December	15.04	6.9	22.8	13.3	18.05	50.7	-	88	58	-
1992										
January	18.46	9.3	24.0	12.8	18.4	4.7	-	79	48	136.4
February	20.20	10.0	26.6	13.2	19.9	70.2	-	72	37	120.7
March	17.96	9.1	26.2	14.2	20.2	5.6	-	77	39	148.2
April	16.34	7.6	24.3	14.8	19.55	401.7	31.3	82	54	95.7
May	14.05	6.3	22.5	13.4	17.95	216.5	96.5	87	62	40.1
June	11.54	3.7	21.3	12.4	16.85	20.6	75.1	87	62	55.0
July	11.57	3.1	19.9	11.3	15.60	29.4	72.9	89	62	42.3

Appendix 2: Soil chemical characteristics before planting

Nutrient/soil reaction	1st Experiment		2nd Experiment	
	0-20	20-40	0-20	20-40
pH water	5.8	5.8	6.3	5.8
Na (m.e.%)	0.88	0.78	1.06	0.76
K (me.%)	1.06	1.00	1.88	1.28
Ca (m.e %)	8.00	8.00	11.00	8.00
Mg (m.e %)	1.2	1.6	2.3	1.6
Mn (me. %)	2.20	2.44	1.90	2.44
P (p.p.m.)	20	34	30	20
% N	0.28	0.22	0.14	0.18
% C	2.22	1.77	2.34	1.75

Appendix 3: Analysis of variance for plant heights of French bean plants.

Source of variation	df	Mean sum of squares	
		Season 1	Season 2
Blocks	2	138.01	71.40
Phosphorus (P)	3	124.48*	847.39***
Inoculation (I)	1	160.43*	3.56ns
P X I	1	37.23ns	48.34**
Nitrogen (N)	1	7.13ns	8.31ns
P X N	3	70.40ns	16.21ns
I X N	1	134.09ns	119.51***
P X I X N	3	308.00***	44.29**
Error	318	41.11	8.19
TOTAL	479		

*** significant at P<0.001

** significant at P<0.01

* significant at P<0.05

ns not significant

Appendix 4: Analysis of variance for total dry weight of French bean plants.

Source of variation	df	Mean sum of squares	
		Season 1	Season 2
Blocks	2	20.08	2761.79
Phosphorus (P)	3	28.90ns	3737.84ns
Inoculation (I)	1	0.89ns	3102.16ns
P X I	3	49.95ns	3148.73ns
Nitrogen (N)	1	39.81ns	2652.58ns
P X N	3	11.12ns	3074.80ns
I X N	1	35.57ns	3406.84ns
P X I X N	3	41.82ns	2733.69ns
Error	125	18.67	2890.83
TOTAL	190		

ns not significant

Appendix 5: Analysis of variance for total leaf area of French bean plants.

Source of variation	df	Mean sum of squares	
		Season 1	Season 2
Blocks	2	36976.88	8229.85
Phosphorus (P)	3	265430.21ns	1173390.86ns
Inoculation (I)	1	8835.79ns	363329.47ns
P X I	3	131979.26ns	858334.47ns
Nitrogen (N)	1	35133.76ns	6134.55ns
P X N	3	119055.05ns	143559.36ns
I X N	1	8029.36ns	8616.36ns
P X I X N	3	100390.66ns	26493.87ns
Error	118	120499.44	113208.37
TOTAL	183		

ns not significant

Appendix 6: Analysis of variance for nodulation in French bean bean plants.

Source of variation	df	Mean sum of squares	
		Season 1	Season 2
Blocks	2	0.003	0.001
Phosphorus (P)	3	0.001ns	0.029**
Inoculation (I)	1	0.001ns	0.014ns
P X I	3	0.002ns	0.002ns
Nitrogen (N)	1	0.001ns	0.002ns
P X N	3	0.003ns	0.012ns
I X N	1	0.003ns	0.004ns
P X I X N	3	0.001ns	0.014ns
Error	85	0.001	0.006
TOTAL	134		

** significant at $P<0.01$

ns not significant

Appendix 7: Analysis of variance for yield of extra fine pods of pods of French bean plants.

Source of variation	df	Mean sum of squares	
		Season 1	Season 2
Blocks	2	1503.88	2075.49
Phosphorus (P)	3	1240.15ns	491.22ns
Inoculation (I)	1	54.82ns	437.25ns
P X I	3	2618.84ns	439.69ns
Nitrogen (N)	1	1508.23ns	1562.14*
P X N	3	994.01ns	142.61ns
I X N	1	116.77ns	842.11ns
P X I X N	3	3535.02*	48.31ns
Error	563	1286.56	318.85
TOTAL	862		

* significant at P<0.05

ns not significant

Appendix 8: Analysis of variance for yield of fine pods of French of French bean plants.

Source of variation	df	Mean sum of squares	
		Season 1	Season 2
Blocks	2	84.03	7030.99
Phosphorus (P)	3	1806.65**	362.85ns
Inoculation (I)	1	2320.27**	63.74ns
P X I	3	1151.54*	3786.63**
Nitrogen (N)	1	132.27ns	2307.01ns
P X N	3	1146.92*	667.44ns
I X N	1	3041.21**	25.12ns
P X I X N	3	1336.12*	1130.37ns
Error	561	347.61	972.52
TOTAL	850		

*** significant at P,0.001

** significant at P<0.01

* significant at P<0.05

ns not significant

Appendix 9: Analysis of variance for total marketable yield of French bean plants.

Source of variation	df	Mean sum of squares	
		Season 1	Season 2
Block	2	72.12	6765.57
Phosphorus (P)	3	10463.95**	18342.86***
Inoculation (I)	1	7011.08**	2138.37ns
P X I	3	6840.29**	2805.63*
Nitrogen (N)	1	407.24ns	1348.33ns
P X N	3	10686.11**	545.01ns
I X N	1	7019.11**	12661.96**
P X I X N	3	8608.09**	2120.51ns
Error	564	38985.96	1581.03
TOTAL	853		

*** significant at P<0.001

** significant at P<0.01

* significant at P<0.05

ns not significant

Appendix 10: Analysis of variance for yield of reject pods of French bean plants

Source of variation	df	Mean sum of squares	
		Season 1	Season 2
Blocks	2	984850.45	7957.84
Phosphorus (P)	3	80568.92ns	32656.47***
Inoculation (I)	1	70744.03ns	104.89ns
P X I	3	204831.74*	1656.99ns
Nitrogen (N)	1	37937.01ns	5442.17ns
P X N	3	7343.37ns	2323.03ns
I X N	1	193128.58ns	11143.35ns
P X I X N	3	20340.79ns	5781.46ns
Error	574	73384.78	2930.43
TOTAL	863		

*** significant at P<0.001

* significant at P<0.05

ns not significant

Appendix 11: Analysis of variance of cumulative yield of French bean plants.

Source of variation	df	Mean sum of squares	
		Season 1	Season 2
Blocks	2	1252969.77	39612.20
Phosphorus (P)	3	205565.13ns	187244.87***
Inoculation (I)	1	980183.72***	4760.84ns
P X I	3	361410.82**	26753.29*
Nitrogen (N)	1	1914.95ns	18960.69ns
P X N	3	11282.70ns	14628.76ns
I X N	1	161894.10ns	134832.81***
P X I X N	3	18725.57ns	29810.92*
Error	574	91001.00	9507.08
TOTAL	863		

*** significant at P<0.001

** significant at P<0.01

* significant a P<0.05

ns not significant

Appendix 12: Analysis of variance for protein content of French bean pods in the second season (April - August)

Source of variation	df	Mean sum of squares
Blocks	2	0.373
Phosphorus (P)	3	25.60ns
Inoculation (I)	1	4.96ns
P X I	3	3.31ns
Nitrogen (N)	1	0.20ns
P X N	3	16.67ns
I X N	1	20.05ns
P X I X N	3	38.17*
Error	126	12.37
TOTAL	191	

* significant at P<0.05

ns not significant

Appendix 13: Analysis of variance for nitrate content of French bean pods in the second season (April - August)

Source of variation	df	Mean sum of squares
Blocks	2	427214.28
Phosphorus (P)	3	469529.71*
Inoculation (I)	1	1431924.80**
P X I	3	1860716.67***
Nitrogen (N)	1	1496.33ns
P X N	3	292275.74ns
I X N	1	6097.52ns
P X I X N	3	142633.68ns
Error	126	138370.54
TOTAL	191	

*** significant at P<0.001

** significant at P<0.01

* significant at P<0.05

ns not significant