THE INFLUENCE OF NITROGEN SOURCE AND RHIZOBIUM SEED INOCULATION ON GROWTH, YIELD AND QUALITY OF FRENCH BEANS [*PHASEOLUS VULGARIS* (L)]

BY

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DECLARATION

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

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DEDICATION

To my parents, Mr. Vincenzo Waithaka and Mrs Jecinta Waigumo, My wife, Mrs Mercy Wambui, My Children, Peter Waithaka and Lucy Waigumo and finally to all my educators.

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ABSTRACT

Field studies were conducted between August, 1987 and January, 1988 at the Field Station, Faculty of Agriculture, University of Nairobi, Kabete, to show the effects of fertilizer nitrogen sources (Diammonium phosphate - DAP and Calcium ammonium nitrate - CAN) and *Rhizobium* seed inoculation on growth, yield and quality of French beans (*Phaseolus vulgaris*) Cvs., 'Monel' and 'Finbel'. Nitrogen fertilizers were applied at the rate of 200 kg CAN or DAP/ ha and a mixture of *Rhizobium leguminosarum* biovar *phaseoli* strains NUM 445+446 was used as the seed inoculant. A treatment where the seeds were not inoculated and no fertilizer applied was included as a control.

The total dry matter production in the French bean plants was mainly due to accumulation of dry matter in the leaves and stems. The use of inoculated seeds and applying DAP at planting resulted in 'Monel' plants accumulating significantly higher total dry matter than those plants from inoculated seeds top dressed later with CAN, CAN top dressing alone or the control. The total dry matter production was increased by 85% compared to the control. Application of DAP at planting followed later with CAN top dressing resulted in a total dry matter production and cumulative leaf area that were significantly higher than that of 'Monel' plants from inoculated seeds top dressed later with CAN, inoculated seeds alone or the control. The total dry matter production and cumulative leaf area increase were 70.5% and 105.5% over the control, respectively. Similarly, using inoculated seeds and applying DAP at planting resulted in 'Finbel' plants accumulating significantly higher

total dry matter and leaf area than those from inoculated seeds top dressed later with CAN, inoculated seeds alone or the control. The total dry matter production and leaf area increase were 154.7% and 112.5% over the control, respectively. Application of DAP at planting followed later with CAN top dressing resulted in Finbel plants with significantly higher cumulative leaf area than those from inoculated seeds alone or the control. The cumulative leaf area was increased by 107.3% compared to the control.

The total, marketable pod yields and quality were not significantly increased by the N-sources and *Rhizobium* seed inoculation. Application of DAP alone at planting, using inoculated seeds and applying DAP at planting followed later with CAN top dressing or top dressing plants from inoculated seeds with CAN resulted in 'Monel' plants producing significantly higher number of pods than using inoculated seeds alone.

The effect of N-sources and *Rhizobium* seed inoculation on the nodulation of French beans was not significant. However, results indicated that using inoculated seeds and applying DAP at planting had a favourable effect on nodulation compared to CAN top dressing.

INTRODUCTION

Phaseolus vulgaris is the best known and widely cultivated species of Phaseolus in the world (Purseglove, 1968; Tripathi and Singh, 1986). Many names are used to describe it. These include French, kidney, haricot, snap, garden, string, bush or pole beans (Acland, 1971; Purseglove, 1968). Beans are grown for their edible dry seeds or immature pods. Immature edible pods of beans is what is known as French, snap, horticultural haricot or green beans. They are commonly known as French beans in Kenya.

In Kenya, French beans are mainly grown for export and local markets. Some are grown for processing (canned). There is a large demand for the French beans in both fresh and processed forms especially in Western Europe during the winter season. According to the export statistics compiled by Horticultural Crops Development Authority (HCDA) between 1981 and 1986 , the beans formed a major export commodity constituting slightly over 20% by volume and value of all fresh horticultural produce exported. In 1986, 9097 metric tons of French beans were exported from Kenya earning KShs. 155 million in foreign exchange (Waithaka, 1987).

French beans are grown mainly under irrigation in several areas in Kenya. The major growing areas are Thika, Upper Athi river, Mwea Tebere, Kakamega and Naivasha (Anon., 1987; Mbatia, 1985). Optimum yields are obtained in areas 900-1500 m above sea level but satisfactory growth can be obtained up to 2000m but the growth period will be slightly prolonged, and disease infestation may be a problem due to prolonged periods of wet conditions (Anon., 1981).

In French beans production, certified seeds are used at the rate of 50-60 kg/ha. Diammonium phosphate is applied at the rate of 200 kg/ha at planting. Calcium ammonium nitrate is top dressed at the rate of 200kg/ha in two equal splits. First split is applied when plants have produced 2-3 true leaves and the second one at the beginning of flowering. The use of farmyard manure (FYM) is also recommended especially on the heavy clay and sandy soils. The manure is applied before planting and is mixed well with the top soil. The beans are planted at a spacing of 30cm between the rows and 10 cm within the row. A constant adequate supply of soil moisture is recommended as water stress affects yield, uniformity and quality of pods. A thorough control against the prevalent pests and disease is followed (Anon., 1987).

The main export season is from October to May. Planting, therefore, should be well scheduled so that the bulk of the crop is ready during the periods from October to mid December and from mid January to end of May. The planting is also staggered so that manageable proportion of the crop is ready for picking at any one time. Harvesting is a continuous practice throughout the growing season (Anon., 1987).

Pods of French beans are graded into two major categories: the extra fine and fine grades.An extra fine pod measures 6 mm or less in width (as determined by the maximum diameter of the pod (Anon., 1987). The pods must be very tender, seedless, stringless and free from any surface or internal defects. The fine pods are a little bigger than the extra fine with the width of the pods being between 6 and 9 mm (Anon., 1987). When grading, all damaged, malformed or dirty pods are removed.

A survey conducted by Mbatia (1985) revealed that the major problem facing French bean growers is the high labour demand especially during the pod picking period. It was also noted that some farmers use FYM as fertilizer and this was a common practice among small scale farmers. Farmers disclosed that imported fertilizer and pesticides had become very expensive and, therefore, their use depended very much on the farmers' financial capability. The farmers also indicated that, in certain instances, the fertilizers were not available at the right time. Mbatia (1985), therefore, concluded that the production of French beans was both labour and capital intensive. Therefore, it is important to find ways and means to reduce the cost of production.

In farming systems, legumes play an important role due to their ability to form a root nodule symbiosis with *Rhizobium* species and to convert abundant atmospheric nitrogen to a form utilizable by higher plants. If this system is properly harnessed, legumes can grow in soils with relatively low fertility without application of costly nitrogenous fertilizers (Ssali and Keya, 1983). Keya *et al* (1981) reported that research efforts have shown that field beans respond to inoculation with rhizobium and that decent yields can be obtained without fertilizers. Therefore, while many factors contribute to the generally low yields of the beans, legume inoculation with *Rhizobium* may serve as an economical means of increasing French bean yield and decrease the use of chemical fertilizer. Therefore, this study was conducted to investigate the effect of nitrogen fertilization and *Rhizobium* seed inoculation on the growth, pod yield and quality of French beans CV 'Monel' and 'Finbel'; evaluate diammonium phosphate(DAP), calcium ammonium nitrate (CAN) and nitrogen fixation from *Rhizobium* seed inoculation as sources of nitrogen.

LITERATURE REVIEW

2.1 Effect of nitrogen on growth, pod yield and quality of French beans.

Nitrogen (N) is a vitally important plant nutrient element. In soil-plant nutrition relations, N has a unique place. Nitrogen is the most unpredictable of the plant nutrient elements in the soil (Viets, 1965). Worldwide, more crops are deficient in N than any other element. The combined forms of N which are most commonly assimilated by plants are nitrate (NO_3^-) and the ammonium (NH_4^+) ions (Tisdale and Nelson, 1975). An adequate supply of N is associated with vigorous growth and deep green colour of plants. Excessive supply of the element usually prolongs the growing period, by retarding maturity, cuts the yield down and reduces quality of some crops (Tisdale and Nelson, 1975; Viets, 1965). Furthermore, excessive quantities of N tend to cause a succulent condition which may increase susceptibility of a plant to disease or lodging. Reduced nitrogen supply limits yields and reduces quality (Tisdale and Nelson, 1975; Viets, 1965). Plants deficient in N have a stunted growth and are yellow in appearance. Although N is well known to affect the vegetative growth of plants more than any other nutrient its availability in the rooting zone is most difficult to manage in a soil-fertilization system (Olson and Kurtz, 1982). This is due to soil variability, unpredictable environment during the growing season and variable demands by the plants in respect to physiological stages of growth. Therefore, soil and fertilizer management must be designed to furnish a continuous adequate supply of available N and other plant growth factors, while withstanding unpredictable plant stress conditions in order to obtain economical, profitable and reliable production of French beans.

There are no reports available on the effect of N on growth, pod yield and quality of French beans in Kenya. However, N fertilization affects the vegetative growth of French bean plants as well as podset and development (Paterson *et al*, 1966). The growth response by French beans to N fertilization may depend on the physiological stage of the plants when N is applied. For example, Peck and Macdonald (1984) reported that N fertilizer applied at planting decreased the dry weight of French bean seedlings but had no effect at the pod stage. It has also been observed that dry weight accumulation in the French bean plants is slow from planting to the seedling stage, more rapid from seedling to bloom stage and reach a more rapid rate of 22 gm $^{-2}$ day $^{-1}$ from bloom to the pod stage (Peck and Macdonald, 1984). In addition, Vencatasamy and Peerally (1981) reported that it is necessary to supplement French bean plants with N after emergence and prior to pod filling due to their short N-fixing cycle which lasts for only a month. They observed that N-fixing activity increased from 29 days after planting (at flowering) and continued until 39 days after planting (pod filling) and then decreased. Nitrogen influences growth of French beans more when combined with phosphorus (El-bakry *et al*, 1980; Palaniyandi and Smith, 1979; Smith, 1977) than when not.

It has been observed that application of N increased the pod yield of French beans (Asif, 1970; Asif and Greig, 1972; Doss *et al*, 1977; Ishimura *et al*, 1985; Mullins *et al*, 1980, 1981; Paterson *et al*, 1966). However, Ishimura *et al*, (1985) while working with French beans on an acid organic soil, reported that although fertilizer N increased the number of French bean pods, the average pod weight remained constant. Moreover, there is an optimal level of N above which yield of vegetable dwarf French beans (Sharma *et al*, 1976) and French bean seeds (Midan *et al*, 1980) declines. Smittle (1976) reported that irrigated French bean yield is increased by additional N applied as a topdress. Nitrogen also increases French bean (Smith, 1970, 1977) and bush bean yield (Stolberg-Wernigerode and Grafzu, 1977) more when in combination with phosphorus. According to Smith (1977) this increase in yield is contributed by both nitrogen and phosphorus, with nitrogen having a stronger effect on vine weight and phosphorus on yield.

Nitrogen fertilization increases the dry weight of field beans (Edje *et al*, 1975; Chui, 1985; Sundstrom *et al*, 1982) and the increase increases with the amount of fertilizer added (Habish and Ishag, 1974; Koinov and Petkov, 1975; Leidi and Gomez, 1980; Molina, 1979). Paz *et al*, (1982) similarly reported that in a culture solution, the growth of beans increased with N concentration. Leidi and Gomez (1980), and Ruschel and Reuszer (1975) also reported that in nutrient solution, N increased the bean plant dry weight. However, N fertilization has been reported to significantly delay maturity and increase aerial growth of field beans (Roberts and Weaver, 1971). Nitrogen fertilization does not always promote growth of field beans as reported by Eira *et al*, (1973). Ssali and Keya (1986) also reported minor increases in dry matter yield of field beans as a result of a high N fertilization.For legume seeds that are inoculated with effective strains of *Rhizobium phaseoli*, a starting dose of N fertilizer may be necessary for positive results (Eaglesham *et al*, 1983; Gibson, 1981; Van Rensburg and Strijdom, 1981; Westermann *et al*, 1981). Application of N fertilizers has been reported to increase seed yield of field beans (Almeida *et al*, 1973; Cardoso *et al*, 1978; Castro and Perera, 1975; Cunha *et al*, 1980; Edje *et al*, 1975; Haag *et al*, 1978; Molina, 1979; Novais and Bragafilho, 1971; Roberts and Weaver, 1971; Rubes, 1976; Scarisbric *et al*, 1982; Sistachs, 1970). The increase of bean yield as a result of N fertilization was found to be due to an increase in the number of pods per plant (Castro and Perera, 1975; Chui, 1985) or the number of pods per unit area (Scarisbric *et al*, 1982). Similarly, Reis *et al*, (1972) working with beans CV `Rico 23' found that DAP increased yields. However, Eira *et al* (1973) found the response to N and seed yield of field beans fell as a result of N application while Sutton *et al* (1973) found that increasing N rates above minimum did not increase pole bean yield. Similarly, Dow *et al* (1970) while working with irrigated beans reported that N fertilizers did not result in increased bean yield. In addition, nodulation and N-fixation may be depressed by high nitrogen amounts in the soil (Sparrow and Ham, 1983).

Nitrogen fertilization may influence both the chemical and physical quality of French beans due to its effect on the accumulation of other nutrients in the plants and vegetative growth. The physical characteristics which determine the quality of French bean pods were considered by Suresh (1977) as pod shape dimensions, weight and fibre or string content. Peck and Macdonald (1984) reported that N fertilizer decreased both yield of large (fine grade) pods and the percentage of seeds in the pods of French beans. However, Mullins (1987) reported that a high N level resulted in more lodging and with more snap bean pods with rotten ends, thus lowering the quality of the pods. Most of the reports available are on the chemical quality of French beans. These indicate that N fertilization results in the accumulation of nitrates in of field beans (Almeida *et al*, 1973; Cardoso *et al*, 1978; Castro and Perera, 1975; Cunha *et al*, 1980; Edje *et al*, 1975; Haag *et al*, 1978; Molina, 1979; Novais and Bragafilho, 1971; Roberts and Weaver, 1971; Rubes, 1976; Scarisbric *et al*, 1982; Sistachs, 1970). The increase of bean yield as a result of N fertilization was found to be due to an increase in the number of pods per plant (Castro and Perera, 1975; Chui, 1985) or the number of pods per unit area (Scarisbric *et al*, 1982). Similarly, Reis *et al*, (1972) working with beans CV `Rico 23' found that DAP increased yields. However, Eira *et al* (1973) found the response to N and seed yield of field beans fell as a result of N application while Sutton *et al* (1973) found that increasing N rates above minimum did not increase pole bean yield. Similarly, Dow *et al* (1970) while working with irrigated beans reported that N fertilizers did not result in increased bean yield. In addition, nodulation and N-fixation may be depressed by high nitrogen amounts in the soil (Sparrow and Ham, 1983).

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2.2 Effect of Nitrogen source on growth, pod yield and quality of French beans.

There are many N sources and each may have a different effect on the growth, pod yield and quality of French beans. The difference mainly results from the fact that they may contain ammonium (NH_4^+), or nitrate (NO_3^-) ions or they may be in combination with an essential element like phosphorus. Mcelhannon and Mills (1977) while working with French beans, lima beans (*Phaseolus lunatus* L.) and southern field pea (*Pisum sativa*) reported that seedling growth was affected more by NO_3^-/NH_4^+ ratio than by N-concentration. They further reported that French beans grew best with a N source containing 75% NO_3^- and 25% NH_4^+. Palaniyandi and Smith (1979) while working with ammonium sulphate [($(NH_4)_2SO_4$)] ammonium nitrate (NH_4NO_3) and sodium nitrate ($NaNO_3$) as N sources in combination with either P, K, Ca or Mg reported that French bean plants in NP treatments were much more vigorous than others regardless of the nitrogen source. They found that the vine weight of the plants in NP treatments increased by 29% or more compared to those treatments which received N alone.

The N source may, however, have an effect on the yield of French beans. Smith (1980) while working with urea, ammonium sulphate, ammonium nitrate, calcium nitrate or sodium nitrate as nitrogen sources, reported that urea, ammonium sulphate and ammonium nitrate gave higher yields of Lima beans than calcium nitrate or sodium nitrate primarily by hastening maturity. However, Thimmegowda and Krishnamurthy (1975) while working with calcium ammonium nitrate and ammonium sulphate nitrate as sources of nitrogen reported that calcium ammonium nitrate gave the highest yield of Lima beans and that the differences between the other N sources were slight. In addition, Rubes (1976) also reported that ammonium sulphate was a better source of N than calcium nitrate in dry bean production. He observed that after initial depression N improved photosynthesis and symbiotic N fixation. Dry bean yields have been increased by application of diammonium phosphate (Reis *et al*, 1972).

There is hardly any report available in literature on the effect of N source on either the physical or the chemical quality of French bean pods. However, Smith (1980) working with urea, ammonium sulphate, ammonium nitrate, calcium nitrate and sodium nitrate combined with phosphorus as N sources reported that Ca and Mg concentration in leaves of lima beans were enhanced by phosphorus and all sources of N while leaf potassium was lowered.

2.3 Symbiotic N source.

Beans like other legumes utilize inorganic soil N, applied and/or N fixed by a symbiotic relationship with *Rhizobium leguminosarum* biovar *phaseoli*. Both the inorganic and the symbiotic N sources are necessary for maximum yield of seed legumes (Franco, 1979; Hardy *et al*, 1968; Lindemann and Hilbner, 1984; Sistachs, 1970). However, there are no reports available on the contribution of symbiotic N_2- fixation to the N requirement of French beans in Kenya and they are scanty elsewhere. Moreover, the symbiotic N_2- fixation varies depending on the host plant, *Rhizobium* strains and the environment. Guss and Dobereiner (1972) reported that French beans that were given 23 ppm N were able to fix nitrogen equivalent to 92 kg N/ha. Similarly, the symbiotic N_2 - fixation capacity of field beans was reported to be 40kg N/ha as compared to 100 kg/ha for soyabeans (Diebert *et al*, 1979; Hardy *et al*, 1968). Westermann *et al* (1981) while studying the effect of N sources on bean seed production reported that the symbiotic N relationship contributed up to 90 kgN/ha which was 40-50% of the total N found in bean plants near physiological maturity. They further reported that the amount of symbiotic N fixed decreased as the available soil N or fertilizer N increased and as N required by individual cultivars increased. The contribution of N- fixation to N requirement of field beans as estimated using the isotope dilution technique is between 18.4 kgN/ha and 31.7kgN/ha. (Duque *et al*, 1985). Graham and Rosas (1977) also reported that N gains by indeterminate bush and climbing cultivars of *Phaseolus vulgaris* (L) from N-fixation were between 20 and 30 kgN/ha per growing cycle. Infact, legumes such as faba beans (*Vicia faba* L), peas (*Pisum sativa*) and cowpeas (*Vigna unguiculata*) under favourable conditions requirement through N-fixation (Eaglesham *et al*, 1977; Richards and Soper, 1979; Sims *et al*, 1983). In Kenya, Ssali and Keya (1980) reported that field beans can fix between 27.7 and 35.2 kgN/ha at a low dose of N fertilizer .

2.4 Effect of rhizobium seed inoculation on growth, pod yield and quality of French beans.

Beans, like other leguminous crops, are capable of fixing N from the atmosphere in association with soil bacteria of the genus *Rhizobium* infecting their roots. Inoculation of the bean seed, or the planting furrow, with the appropriate strains of *Rhizobium* may help the plant to fix N from the atmosphere. App *et al* (1980) reported that N fertilizer response by tropical grain legumes which are not nodulating or are very poor nodulators can be eliminated if these grain legumes are properly inoculated with effective strains of *Rhizobium* bacteria.

Information on the effect of seed inoculation on growth and pod yield of French beans is lacking. However, there are reports on the effect of seed inoculation on the growth and yield of field beans. Habish and Ishag (1974) working with haricot beans reported that plants from inoculated seeds became green and showed an increased rate of growth about five weeks after sowing. They observed that older plants showed greater increase in growth due to inoculation as the dry matter production in inoculated plants was often as good as or sometimes superior to those that received N fertilizer (Abdel-Ghaffer *et al*, 1982; Ruschel and Ruschel, 1975). Similarly, Leidi and Gomez (1980) reported that shoot and leaf dry matter of beans were higher in plants from inoculated seeds. However, the same workers found that the roots dry

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weight decreased more in plants from seeds that were inoculated than it did in those plants from seeds that were not inoculated.

The yield response to *Rhizobium* seed inoculation varies greatly. This ranges from yield decreases where N is not limiting to substantial yield increases. Some responses to inoculation have been obtained in areas where beans have not been grown before (Desouza, 1969; Macartney and Watson, 1966). In Kenya, Keya *et al*, (1981) in a survey of 68 bean producing regions, reported appreciable responses by Canadian wonder to inoculation in 1979 at Embu (increases of 16%) and 1980 at Kabete (increases of 17%). In addition, Keya (1977) showed that field bean yield increases of upto 20% can be obtained through inoculation. The Ministry of Agriculture's National Horticultural Research Station at Thika (1974) reported that inoculation had a positive significant influence on the yield of Mexican 142 beans. Similarly, Graham *et al*, (1982), in field trials on dry bean inoculation (1978-1979), found significant responses to inoculation in five out of twelve trials including two with relatively high soil *Rhizobium* population. Yields of the best of the inoculated treatments at the five sites were 39.9-61.9% greater than those of control treatments. Habish and Ishag (1974) also reported that inoculation increased seed yield of haricot beans by 14.5 - 20%. Inoculation of *Phaseolus vulgaris* markedly enhanced nodulation and N-fixation, plants dry weight, N-content and final seed yield (Abdel-Ghaffer *et al*, 1982). Chui and Nadar (1984) reported that inoculation of mwezi moja and zebra bean (*Phaseolus vulgaris* L.) seeds increased seed yield with the increase being highest in mwezi moja inoculated with *Rhizobium phaseoli* (NU 439), however, the increase in seed yield was not significant. Beans do not always respond to seed inoculation as shown by

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several reports. Pessanha *et al* (1970) reported that pinto beans (*Phaseolus vulgaris*) did not show a positive significant response to inoculation. Galomo (1978) working with four varieties of field beans, found a response to inoculants only in one out of two trials. According to Desouza (1969), Macartney and Watson (1966), Mughogho (1979) and Stephens (1967), efforts to increase dry bean yield through inoculation in East Africa have not been particularly successful.

Increase in pod yield of groundnuts CV `Robut 33-1' (*Arachis hypogea*) was observed in India after inoculation even in fields where native rhizobia population already existed (Nambiar *et al*, 1982). Similar yield increases after inoculation were reported in cowpea (Mughogho *et al*, 1982), pigeon pea or redgram grain (*Cajanus cajan*) (Muthuvel *et al*,1985; Srivastava and Verma, 1986) and gram (*Cicer arietinum*) and pea (*pisum sativa*) (Rao, 1976).

Information on the effect of seed inoculation on the physical quality of French beans is lacking while reports on the chemical quality of the same are scanty. However, El-Leboudi *et al* (1974) reported that chlorophyll and carbohydrate contents of French bean plants were increased by inoculation. Sistachs (1970) working with black beans (*Phaseolus vulgaris*) concluded that both N fertilization and inoculation were necessary to obtain high seed yields with high protein content. *Rhizobium* inoculation was reported to enhance protein content of field beans (Abdel-Ghaffer *et al*, 1982; Ruschel and Ruschel, 1975). Habish and Ishag (1974) working with haricot beans, reported that inoculated plants became greener compared to the uninoculated ones and were of higher quality.

2.5 Effect of nitrogen fertilizer on nodulation and nitrogen fixation

Although bean plants are legumes, a nitrogen starter dose may be needed for early growth before the onset of symbiotic N fixation (Eaglesham *et al*, 1983; Gibson, 1981; Van Rensburg and Strijdom, 1981; Westermann *et al*, 1981). A starter dose is a low N fertilizer rate that would benefit the legume plant when cotyledon N is depleted and symbiotically fixed nitrogen is still unavailable to the plant (Van Rensburg and Strijdom, 1981). The earlier the nodulation, the earlier the symbiotically fixed N becomes available to the plants. In addition, Gibson (1976) reported that a relatively low amount of available N during initial plant development generally enhanced nodulation and plant growth. In green house, pot grown French beans supplied with various strains of *Rhizobium leguminosarum* biovar *phaseoli* in sand, responded by increased initial growth and nodulation to the application of 23 ppm N at planting and also 20 days after (Guss and Dobereiner, 1972). Peck and Macdonald (1984) however, reported that French beans grown with soil N but without fertilizer N had many nodules on the roots. They found that fertilizer N reduced the number of rhizobia in nodules on the roots.

Several studies have shown that a low rate of N fertilizer increases nodulation and hence N fixation in field beans (Sundstrom *et al*, 1982; Ssali and Keya, 1980,1982,1986). A high dose of N fertilizer decreases nodulation and N fixation (Abdel-Ghaffer *et al*, 1982; Pons *et al*, 1975; Sundstrom *et al*, 1982; Ssali and Keya, 1980, 1982, 1986). Sistachs (1970) working with black beans reported that nodulation was completely suppressed by applied N. All *Rhizobium* strains induce less nodule tissue and lower nitrogenase activity per plant when N is applied but some strains are less sensitive than others (Awonaike *et al*, 1980). Chui (1985) also reported that application of N fertilizer caused significantly high nodule degeneration relative to uninoculated control. Failure of legumes to respond to inoculation has often been attributed to high soil N (Sparrow and Ham, 1983). In addition, if beans find a more easily accessible supply of N in the soil, which may be supplemented by N fertilizer application, their ability to fix N from the atmosphere will be much less (Kenya farmer, 1986). The relatively low amount of N in diammonium phosphate may probably be one of the reasons why it is used at the planting of French beans .

2.6 The effect of Phosphorus on nodulation:

In legumes, phosphorus is said to stimulate root growth and initiation of nodules, affect the extent of nodulation in terms of numbers and mass, and influence the duration and the general efficiency of *Rhizobium*-legume symbiotic system (Andrew, 1976, 1978; Franco, 1977; Freire, 1977). No reports are available on the effect of phosphorus on nodulation and symbiotic N-fixation in French beans. However, several studies have shown that application of phosphorus to field beans can improve nodulation and N_2-fixation with consequent increase in yield (Almeida *et al*, 1973; Anderson, 1973; Dombovari, 1977; Fontes, 1972; Graham and Rosas, 1979; Keya, 1977; Keya and Mukunya, 1979). Ssali and Keya, (1983, 1986) reported that application of phosphorus increased nodulation, drymatter content, tissue N concentration, N-fixation and seed yield of field beans at both low and high levels of fertilizer N application. The increases in nodulation and N-fixation were at the flowering, podfilling and physiological maturity of the plants but the effects of phosphorus were more pronounced at the flowering and pod filling stages.

The positive influence of phosphorus on growth, pod yield of French beans (Peck *et al*, 1964) and nodulation of field beans especially when combined with N (Ssali and Keya, 1986), may be the reason why DAP is so popular with the French bean growers in Kenya.

MATERIALS AND METHODS

3.1 The experimental site.

Two field experiments were conducted between 3rd August, 1987 and 15th February, 1988 at the University of Nairobi (Faculty of Agriculture), Field Station, Kabete. The first experiment was conducted in the off season after the long rains while the second one was done during the short rains. Kabete is situated at latitude 1°15'S and longitude 36° 44'E. It has an altitude of 1800m above sea level with mean annual maximum and minimum temperatures of 23°C and 13°C, respectively. The area has a bimodal rainfall regime with annual average rainfall of just above 1000mm per year. The long rains fall between the months of March and the first week of June while the short rains fall from late October to December. The long rains are more reliable and heavier than the short rains.

Appendix 1 shows the mean temperatures and monthly rainfall received during the experimental period. The rainfall during the experimental period was low and poorly distributed. During the first experiment the rainfall was highest in the month of August (93.9mm) and drastically decreased in the following months of September (17.4mm) and October (5.7mm). The months of November (182.1mm) and January (96.2mm) had the highest rainfall while December (15.3mm) and February (20.5mm) had the lowest rainfall during the second experimental period. The first experimental period had lower mean temperatures than the second.

The soils of the site have been described as nitosol according to the FAO/UNESCO (1974) classification (Siderius, 1976). They are deep-red clays with a stable microstructure Appendix 2 shows the chemical composition of the soils sampled from the sites of the first and second Experiments. The soil chemical analysis showed that the soils were moderately acidic and had an adequate supply of other nutrient elements except phosphorus which was low. The organic matter content and total nitrogen level were quite satisfactory.

3.2 Plant Material

Two French bean varieties, 'Monel' and 'Finbel' were used in the study. They fall under the group of haricot verts. Varieties in this group are mainly grown for fresh pods and to a less extent for canning as whole beans of extra fine grade. Their pods are long, straight and round in cross-section, completely stringless at correct consumption stage. However, towards maturity fibres do develop.

(a) Monel: It is the most important and popular French bean variety in Kenya. The variety is round podded, high yielding and has a long picking season. The pods are quite fleshy, greyish green, straight and long. Seeds are black.

(b) Finbel: It is a relatively new variety in Kenya, having been introduced into the country in 1986 by the H.C.D.A. It was imported from France. The variety is round podded and the pods are quite fleshy, green, straight and longer than those of Monel. However, it has poor germination capacity. Its seeds are also black.

3.3 Nitrogen Sources.

Diammonium phosphate (DAP) which has an analysis of 18:46:0 (N: P_2O_5 and K_2O) was used at planting. Where applicable seeds were inoculated with *Rhizobium leguminosarum* biovar *phaseoli* strains NUM 445 + 446 (University of Nairobi, Micren, 1983) at planting. The inoculant carrier used is filter mud, a by-product of the sugar industry and contains about $9x10^5$ bacteria per gram of inoculant (Anon., 1983). Calcium ammonium nitrate (CAN) which has 26% N, was used for top dressing in two equal splits.

3.4 Experimental treatments and design.

The experiment had eight treatments which were applied to the two varieties. The treatments were as follows.

a) Control (uninoculated and unfertilized).

b) Seed inoculation with *Rhizobium* innoculant.

c) DAP alone applied at planting.

d) CAN alone topdressed at the 2-3 true leaf stage and beginning of flowering.

e) DAP applied at planting followed later with CAN topdressing at the 2-3 true leaf stage and beginning of flowering.

f) Seed inoculation with *Rhizobium* innoculant + DAP applied at planting.

g) Seed inoculation with *Rhizobium* innoculant + CAN topdressing at the 2-3 true leaf stage and beginning of flowering.

h) Seed inoculation with *Rhizobium* innoculant + DAP applied at planting followed later with CAN topdressing at the 2-3 true leaf stage and beginning of flowering.

The eight treatments were combined factorially with the two varieties to give a total of sixteen treatment combinations. A randomised complete block design was used with 3 replicates. Each block consisted of 16 plots each measuring 2.4x3.6m.

3.5 **Plant Culture.**

All bean seeds were washed with tap water to remove all the pest control chemicals which had been used during their storage. The seeds requiring inoculation were inoculated with bean *Rhizobium leguminosarum* biovar *phaseoli* strains (NUM 445 + 446) at the rate of 100g inoculant/15kg seeds (as recommended by the University of Nairobi, Micren, 1983) just before planting. Prior to planting shallow furrows (about 6 cm deep) were dug at a spacing of 30cm for fertilizer application. Fertilizer DAP was applied in the furrows of the plots where it was required, to produce a uniform application rate of 200kg DAP / ha which is an equivalent of 36kgN/ha. and 92kg P_2O_5/ha. The fertilizer was mixed well with the soil in the dug furrows. The beans were planted in furrows at a spacing of 30 x 10 cm to give a plant population of 33 plants per m^2 (or 333,333 plants per hectare).

For the off-season experiment, seeds were sown on 3rd August, 1987 while the in-season experiment started on 18th November, 1987. The first weeding was done on 17th August, 1987 and 2nd December, 1987 for the first and second experiments , respectively. Weeding was done two weeks after planting when the plants had produced 2-3 true leaves. Calcium ammonium nitrate was applied to plots requiring it as a topdress at the rate of 200 kg CAN /ha which is equivalent to 52 kgN/ha. This was applied in two equal splits of 100 kg CAN/ha each. The first split was applied 15 days after sowing while the second one was applied at the beginning of flowering 37 days after planting and 42 days after planting during the first and second experiments, respectively.

Three days after seedling emergence and seven days later Rogor L 40 or Dimethoate (40%) was sprayed at the rate of 1.2 litres/ha to control beanfly (*Melanargromyza phaseoli*). The plants were then sprayed at least once a week using Baycor (Bitertanol) at the rate of 450 ml/ha. and Rogor L 40 at the rate of 1.2 l/ha., for control against bean rust and insect pests, respectively. On 2nd September, 1987 copper oxychloride was sprayed at the rate of 5 kg/ha as a protection against haloblight (caused by *Pseudomonas syringae* PV-*phaseolicola*). During podding stage the plants were sprayed with Dithane-M-45 at the rate of 2kg/ha and Ambush at the rate of 1 l/ha at least once a week to control Anthracnose (caused by *Colletotrichum lindemuthianum*), bean flower thrips and American bollworm, respectively. All the cultural practices recommended by H.C.D.A to the farmers were followed.

The crop was irrigated twice a week in the first experiment,but during the second experiment there was a problem with the irrigation system and the crop was irrigated only once a week. The short rains were also unreliable with the highest rainfall falling in November and very low in the subsequent months (see Appendix 1).

3.6 Sampling procedure.

Sequential sampling of the plants was done on the 39th, 46th, 53rd and 64th days after planting. At every sampling for dry matter and leaf area determination five plants were sampled. This was done starting from one side of the plot and then continuing inwards leaving an area of 1.5mx1.2m for economic yield determination. Five plants were also left in between the areas for sequential sampling and economic yield determination to act as the guard plants. Five plants per sampling were meticulously uprooted with all their root nodules intact and put in paper bags. The plants sampled on the 46^{th} and 64^{th} days after planting were then separated into leaves, stems, flowers or flower buds and pods when they were still fresh and weighed. The surface area of all leaves from the plants was determined using a leaf area meter (Model L1-3100 Area meter). Separated parts were then oven- dried at $70^{o}C$ to constant weight. Root nodules from samples taken at the 39^{th}, 46^{th}, 53^{rd} and 64^{th} day after planting were separated from the roots, washed with tap water and then oven-dried at $70^{o}C$ to constant weight.

Days to 50% flowering were determined by tagging and counting the number of plants with at least one flower open. The number of pods per plant were determined in the 64^{th} day after planting.

Harvesting of the pods started on the 66^{th} day after planting and continued upto the 88^{th} day after planting during the first experiment. Pods were harvested twice a week. After each harvest the pods were graded into the extra fine, fine and rejects and their fresh weights taken separately. The length and maximum diameter of the pods were determined.

The number of pods that snapped cleanly without protruding fibres were determined. The crude fibre content of the pods was also determined using the proximate analysis method (A.O.A.C, 1975) for the harvests of the 74^{th} and 78^{th} day after planting and 68^{th} and 72^{nd} day after planting during the first and second experiments, respectively.

In the second experiment, similar sampling procedure was carried out on the 47^{th}, 56^{th}, 63^{rd} and 77^{th} day after planting. The dry matter yield and leaf area were determined at the 47th and 63rd days after planting while the nodule dry mass was determined at all sampling dates. The harvesting of the pods started 58 days after planting and continued up to the 89th day after planting. All the data were collected as in the first experiment.

3.7 **Data analysis.**

Analysis of variance (ANOVA) was done and linear contrasts (independent) performed when the treatments were significantly different at 5% probability level (Snedecor and Cochran, 1968). Treatment means were separated according to the Duncan's multiple range test at 5% probability level (Gomez and Gomez, 1984). Appendices 3 and 4 shows the analysis of variance tables and linear contrasts performed.

RESULTS

4.1 Plant growth

4.1.1 Dry matter accumulation

Tables 1a and b and 2a and b show the effect of N fertilizer source and *Rhizobium* seed inoculation on the dry matter content of the leaves and stems of 'Monel' and 'Finbel' plants, respectively. In the in-season experiment, the effect of the fertilizer N-source and seed inoculation on the dry matter accumulation in the leaves and stems of both varieties was not significant (Table 1b and 2b). At flowering (46 days after planting) in the off-season experiment, 'Monel' plants that received DAP at planting and later top dressed with CAN accumulated significantly higher leaf dry matter than those plants from the treatments that did not receive DAP (Table 1a). Similarly, the use of inoculated seeds and DAP at planting resulted in 'Monel' plants accumulating significantly higher leaf and stem dry matter than those plants from the treatments that did not receive DAP. 'Monel' plants from inoculated seeds accumulated the lowest amount of leaf and stem dry matter. The linear contrasts showed that the significant increase in leaf and stem drymatter production was mainly due to the application of DAP (Appendix 3.1 and 3.2). At flowering, the effect of fertilizer N-source and seed inoculation on the dry matter accumulation in the leaves and stems of 'Finbel' was not significant. However, all the plants of 'Finbel' from the treatments that included DAP at planting tended to accumulate more leaf and stem dry matter than the others. At podding, the effect of N-source and seed inoculation on leaf and stem dry matter

Table 1: Effect of fertilizer N-source and Rhizobium Seed inoculation on the drymatter content of the leaves (g/plant) of French beans, 'Monel' and 'Finbel'.

a) OFF-SEASON (August-October)

Treatment	Flowering (46)		Podding (64)	
	Monel	Finbel	Monel	Finbel
Control	2.06[cd]	1.97[a]	4.62[a]	2.91[c]
DAP	2.75[abc]	3.12[a]	5.07[a]	4.70[abc]
CAN	2.37[bcd]	1.93[a]	5.60[a]	4.12[bc]
Seed inoculation	1.79[d]	1.64[a]	4.88[a]	3.24[c]
DAP+CAN	3.22[a]	2.68[a]	6.95[a]	6.29[a]
Seed inoculation+DAP	3.10[a]	2.39[a]	5.64[a]	6.48[a]
Seed inoculation+CAN	2.33[bcd]	1.56[a]	5.02[a]	3.68[bc]
Seed inoculation+ DAP+ CAN	2.93[ab]	2.91[a]	6.25[a]	5.64[ab]
S.Emean	0.51	0.59	0.78	1.38
C.V%	14.63	31.94	25.04	22.42

b) IN-SEASON (November-January)

Treatment	Beginning of podding (47)		Podding (63)	
	Monel	Finbel	Monel	Finbel
Control	2.86[a]	2.30[a]	4.80[a]	5.12[a]
DAP	2.29[a]	3.58[a]	3.86[a]	5.46[a]
CAN	2.29[a]	3.08[a]	3.62[a]	4.43[a]
Seed inoculation	2.11[a]	2.89[a]	4.16[a]	4.38[a]
DAP+CAN	2.37[a]	3.16[a]	3.80[a]	6.80[a]
Seed inoculation+DAP	2.40[a]	3.23[a]	4.00[a]	5.82[a]
Seed inoculation +CAN	2.56[a]	2.99[a]	3.92[a]	5.26[a]
Seed inoculation +DAP+ CAN	3.06[a]	3.02[a]	4.15[a]	6.68[a]
S.Emean	0.32	0.36	0.41	0.93
C.V%	42.86	20.27	28.72	28.87

( ) Days after planting. Data are means of 3 blocks.
Means separation within columns by Duncan's Multiple range test, 5% level.

Table 2: Effect of fertilizer N-source and Rhizobium Seed inoculation on the drymatter content of the stems (g/plant) of French beans, 'Monel' and 'Finbel'.

a) OFF-SEASON (August-October)

Treatment	Flowering (46) Monel	Flowering (46) Finbel	Podding (64) Monel	Podding (64) Finbel
Control	1.03[cd]	1.07[a]	4.76[a]	2.47[c]
DAP	1.62[abcd]	1.62[a]	6.25[a]	3.96[abc]
CAN	1.31[bcd]	0.92[a]	5.50[a]	3.28[bc]
Seed inoculation	0.80[d]	0.93[a]	3.85[a]	2.68[c]
DAP+CAN	1.69[abc]	1.55[a]	7.55[a]	5.53[ab]
Seed inoculation+DAP	2.24[a]	1.69[a]	6.02[a]	5.91[a]
Seed inoculation+CAN	1.05[cd]	0.69[a]	4.49[a]	2.79[c]
Seed inoculation+ DAP+ CAN+	1.97[ab]	1.79[a]	7.13[a]	4.31[abc]
$S.E_{mean}$	0.50	0.42	1.29	1.31
C.V%	29.91	46.70	33.23	30.50

b) IN-SEASON (November-January)

Treatment	Beginning of podding (47) Monel	Beginning of podding (47) Finbel	Podding (63) Monel	Podding (63) Finbel
Control	2.27[a]	1.66[a]	4.33[a]	2.93[a]
DAP	1.87[a]	2.30[a]	3.40[a]	4.60[a]
CAN	1.69[a]	2.13[a]	2.87[a]	3.87[a]
Seed inoculation	1.67[a]	1.98[a]	3.67[a]	4.07[a]
DAP+CAN	1.34[a]	1.37[a]	4.53[a]	5.13[a]
Seed inoculation+DAP	2.16[a]	1.93[a]	4.47[a]	4.87[a]
Seed inoculation+ CAN	1.97[a]	1.65[a]	3.73[a]	3.87[a]
Seed inoculation +DAP+ CAN	2.42[a]	2.29[a]	3.80[a]	4.53[a]
$S.E_{mean}$	0.36	0.33	0.57	0.70
C.V%	38.83	20.52	29.81	26.32

( ) Days after planting. Data are means of 3 blocks.
Means separation within columns by Duncan's Multiple range test, 5% level.

accumulation that was significant in 'Finbel' plants only. The use of inoculated seeds and DAP at planting resulted in leaf and stem dry matter production that was significantly higher than from all the treatments that did not receive DAP (Table 1a and 2a). Application of DAP at planting followed with CAN top dressing produced significantly higher leaf dry matter than all those treatments where DAP was not applied (Table 1a). The plants from the treatment where DAP was applied at planting followed with CAN top dressing did not accumulate significantly higher leaf and stem dry matter than those plants from inoculated seeds when DAP was used at planting. At podding the leaf dry matter increase was significant mainly due to the application of DAP at planting followed with CAN topdressing while the stem dry matter increase was significant mainly due to the application of DAP (Appendix 3.1 and 3.2).

The influence of N-source and seed inoculation on the dry matter content of the flowers was significant in the off-season experiment only (Table 3a). At flowering (46 days after planting), the effect of N-source and seed inoculation on the flower dry matter accumulation was significant in 'Monel' plants only. Application of DAP at planting followed later by CAN top dressing resulted in 'Monel' plants having flowers which had significantly higher dry matter than those from seed inoculation alone and the control. The same happened when inoculated seeds and DAP were used at planting. The use of inoculated seeds and DAP at planting followed later with CAN top dressing resulted in 'Monel' plants whose flower dry matter was significantly higher

Table 3: Effect of fertilizer N-source and Rhizobium Seed inoculation on the drymatter content of the flowers (g/plant) of French beans, 'Monel' and 'Finbel'.

a) OFF-SEASON (August-October)

	Flowering (46)		Podding (64)	
Treatment	Monel	Finbel	Monel	Finbel
Control	0.10[bc]	0.11[a]	0.18[a]	0.15[bc]
DAP	0.12[abc]	0.15[a]	0.23[a]	0.25[ab]
CAN	0.12[abc]	0.11[a]	0.24[a]	0.16[bc]
Seed inoculation	0.07[c]	0.12[a]	0.21[a]	0.11[c]
DAP+CAN	0.17[a]	0.13[a]	0.32[a]	0.29[a]
Seed inoculation+DAP	0.17[a]	0.15[a]	0.23[a]	0.16[bc]
Seed inoculation+CAN	0.12[abc]	0.09[a]	0.23[a]	0.20[abc]
Seed inoculation +DAP+ CAN	0.15[ab]	0.18[a]	0.28[a]	0.25[ab]
S.Emean	0.04	0.03	0.04	0.06
C.V%	24.21	49.95	30.07	27.14

b) IN-SEASON (November-January)

	Beginning of podding (47)		Podding (63)	
Treatment	Monel	Finbel	Monel	Finbel
Control	0.23[a]	0.11[a]	0.03[a]	0.02[a]
DAP	0.18[a]	0.16[a]	0.03[a]	0.05[a]
CAN	0.18[a]	0.17[a]	0.01[a]	0.02[a]
Seed inoculation	0.19[a]	0.19[a]	0.00[a]	0.00[a]
DAP+CAN	0.19[a]	0.16[a]	0.04[a]	0.03[a]
Seed inoculation+DAP	0.19[a]	0.17[a]	0.03[a]	0.05[a]
Seed inoculation +CAN	0.12[a]	0.15[a]	0.01[a]	0.01[a]
Seed inoculation+ DAP+ CAN	0.15[a]	0.17[a]	0.01[a]	0.01[a]
S.Emean	0.03	0.02	0.01	0.02
C.V%	25.36	37.66	104.80	131.63

( ) Days after planting. Data are means of 3 blocks.
Means separation within columns by Duncan's Multiple range test, 5% level.

than that from seed inoculation alone. The dry matter of 'Monel' flowers was highest when inoculated seeds and DAP were used at planting and in the plants where DAP was used at planting and later top dressed with CAN. Seed inoculation alone gave the lowest flower dry matter content. Application of DAP at planting followed with CAN top dressing resulted in 'Finbel' plants with flowers which had significantly higher dry matter than those from inoculated seeds and DAP both used at planting, CAN top dressing alone, seed inoculation alone and the control (Table 3a). In addition using inoculated seeds and DAP at planting followed later with CAN top dressing resulted in 'Finbel' plants whose flowers had significantly higher dry matter than those from seed inoculation alone. The use of inoculated seeds alone at planting resulted in 'Finbel' plants with the lowest flowers dry matter production. The increase in flower dry matter was mainly due to the application of DAP at planting and CAN top dressing (Appendix 3.3).

The influence of N-source and seed inoculation on the pod dry matter accumulation was significant in 'Finbel' plants and in the off-season experiment only (Table 4a). The use of inoculated seeds and DAP at planting resulted in 'Finbel' plants producing pods with significantly higher dry matter than those from the other treatments. Application of DAP at planting followed with CAN top dressing resulted with plants with the second highest pod dry matter accumulation. The use of inoculated seeds and DAP at planting followed later by CAN top dressing resulted with 'Finbel' plants whose pods accumulated significantly lower dry matter than those from the other treatments.

than that from seed inoculation alone. The dry matter of 'Monel' flowers was highest when inoculated seeds and DAP were used at planting and in the plants where DAP was used at planting and later top dressed with CAN. Seed inoculation alone gave the lowest flower dry matter content. Application of DAP at planting followed with CAN top dressing resulted in 'Finbel' plants with flowers which had significantly higher dry matter than those from inoculated seeds and DAP both used at planting, CAN top dressing alone, seed inoculation alone and the control (Table 3a). In addition using inoculated seeds and DAP at planting followed later with CAN top dressing resulted in 'Finbel' plants whose flowers had significantly higher dry matter than those from seed inoculation alone. The use of inoculated seeds alone at planting resulted in 'Finbel' plants with the lowest flowers dry matter production. The increase in flower dry matter was mainly due to the application of DAP at planting and CAN top dressing (Appendix 3.3).

The influence of N-source and seed inoculation on the pod dry matter accumulation was significant in 'Finbel' plants and in the off-season experiment only (Table 4a). The use of inoculated seeds and DAP at planting resulted in 'Finbel' plants producing pods with significantly higher dry matter than those from the other treatments. Application of DAP at planting followed with CAN top dressing resulted with plants with the second highest pod dry matter accumulation. The use of inoculated seeds and DAP at planting followed later by CAN top dressing resulted with 'Finbel' plants whose pods accumulated significantly lower dry matter than those from the other treatments.

Table 4: Effect of fertilizer N-source and Rhizobium Seed inoculation on the drymatter content of the pods (g/plant) of French beans, 'Monel' and 'Finbel'.

a) OFF-SEASON (August-October)

Treatment	Flowering (46) Monel	Flowering (46) Finbel	Podding (64) Monel	Podding (64) Finbel
Control	-	-	1.12a	0.80e
DAP	-	-	0.89a	0.95d
CAN	-	-	1.30a	1.13c
Seed inoculation	-	-	0.98a	1.03cd
DAP+CAN	-	-	0.95a	1.52b
Seed inoculation+DAP	-	-	1.26a	3.55a
Seed inoculation+CAN	-	-	1.46a	1.03cd
Seed inoculation +DAP+ CAN	-	-	2.17a	0.65f
S.Emean	-	-	0.41	0.93
C.V%	-	-	40.16	51.38

b) IN-SEASON (November-January)

Treatment	Beginning of podding (47) Monel	Beginning of podding (47) Finbel	Podding (63) Monel	Podding (63) Finbel
Control	0.05a	0.10	4.08a	4.87a
DAP	0.07a	0.08	2.80a	5.07a
CAN	0.02a	0.07	2.33a	4.20a
Seed inoculation	0.02a	0.10	3.27a	5.07a
DAP+CAN	0.02a	0.02	2.20a	5.28a
Seed inoculation+DAP	0.02a	0.06	3.07a	5.40a
Seed inoculation +CAN	0.04a	0.09	2.93a	6.13a
Seed inoculation +DAP+ CAN	0.03a	0.05	2.60a	5.80a
S.Emean	0.02	0.03	0.56	0.59
C.V%	105.24	48.56	23.69	42.38

( ) Days after planting. Data are means of 3 blocks.
Means separation within columns by Duncan's Multiple range test, 5% level.

Table 5a shows that the influence of N-source and seed inoculation on the total dry matter production was significant at flowering (46 days after planting) in 'Monel' plants and during podding (64 days after planting) in 'Finbel' plants, in the off-season experiment only. At flowering, the use of inoculated seeds and DAP at planting resulted in 'Monel' plants accumulating significantly higher total dry matter than those from all the treatments where DAP was not included. Application of DAP at planting followed with CAN top dressing resulted in a total dry matter production that was significantly higher than from the control, 'Monel' plants from inoculated seeds fertilized with CAN, and seed inoculation alone. The same happened when inoculated seeds and DAP were used at planting and later top dressing the 'Monel' plants with CAN. Similarly, application of DAP alone at planting resulted with 'Monel' plants accumulating significantly higher total dry matter than those from the control and seed inoculation alone. In both varieties, all the plants that received DAP at planting produced more total dry matter than those that did not. Similarly, all the plants that did not receive DAP at planting were not significantly different in their total dry matter production. At podding, the use of inoculated seeds and DAP at planting resulted in 'Finbel' plants accumulating significantly higher total dry matter than those from all the other treatments except the one where DAP was applied at planting followed later with CAN top dressing. Application of DAP at planting followed with CAN top dressing resulted

Table 5: Effect of fertilizer N-source and Rhizobium Seed inoculation on the total drymatter production (g/plant) of French beans, 'Monel'and `Finbel'.

a) OFF-SEASON(August-October)

Treatment	Flowering (46) Monel	Flowering (46) Finbel	Podding (64) Monel	Podding (64) Finbel
Control	2.98 d	3.15 a	10.67 a	6.32 c
DAP	4.49 abc	4.89 a	12.45 a	9.86 bc
CAN	3.80 bcd	2.97 a	12.63 a	8.68 bc
Seed inoculation	2.67 d	2.68 a	9.92 a	7.07 c
DAP+CAN	5.08 ab	4.36 a	15.77 a	13.63 ab
Seed inoculation+DAP	5.51 a	4.23 a	13.14 a	16.10 a
Seed inoculation+CAN	3.50 cd	2.34 a	11.20 a	7.70 c
Seed inoculation+ DAP+ CAN	5.05 ab	4.88 a	15.83 a	10.85 bc
S.Emean	1.05	1.02	2.19	3.39
C.V%	18.23	36.59	28.02	26.01

b) IN-SEASON (November-January)

Treatment	Beginning of podding (47) Monel	Beginning of podding (47) Finbel	Podding (63) Monel	Podding (63) Finbel
Control	5.41 a	4.17 a	13.23 a	12.94 a
DAP	4.41 a	6.12 a	10.09 a	15.17 a
CAN	4.17 a	5.45 a	9.83 a	12.52 a
Seed inoculation	3.99 a	5.16 a	11.55 a	13.52 a
DAP+CAN	4.41 a	5.13 a	10.57 a	17.34 a
Seed inoculation+DAP	4.76 a	5.39 a	11.55 a	16.14 a
Seed inoculation +CAN	4.68 a	4.89 a	10.59 a	15.27 a
Seed inoculation+ DAP+ CAN	5.66 a	5.52 a	10.56 a	17.02 a
S.Emean	0.58	0.56	1.09	1.83
C.V%	31.40	17.12	26.38	30.97

( ) Days after planting. Data are means of 3 blocks.
Means separation within columns by Duncan's Multiple range test, 5% level.

in 'Finbel' plants accumulating significantly higher total dry matter than those from seed inoculation alone and the control. 'Finbel' plants from the treatment where inoculated seeds and DAP were used at planting produced the highest total dry matter followed by those from the treatment where DAP was applied at planting and plants later top dressed with CAN. The total drymatter production was significant mainly due to the application of DAP (Appendix 3.5). In both varieties the total dry matter production increased sharply between flowering and podding in all the treatments .

All the interactions between DAP, CAN and seed inoculation for leaf, stem, flower, pod and total dry matter accumulation were not significant in both experiments .

4.1.2 Leaf area

As shown in Table 6a, the effect of fertilizer N-source and seed inoculation on the total leaf area of the plants from both varieties was significant in the off season experiment only. At flowering (46 days after planting), application of DAP at planting followed later with CAN top dressing resulted in 'Monel' plants with significantly higher total leaf area than those from inoculated seeds fertilized later with CAN, seed inoculation alone and the control. Apart from the treatment where DAP was applied at planting, all 'Monel' plants from the other treatments had a total leaf area that was not significantly different from each other. However, in both varieties all the plants from the treatments that received DAP at planting had a higher cumulative leaf area than those in 'Finbel' plants accumulating significantly higher total dry matter than those from seed inoculation alone and the control. 'Finbel' plants from the treatment where inoculated seeds and DAP were used at planting produced the highest total dry matter followed by those from the treatment where DAP was applied at planting and plants later top dressed with CAN. The total drymatter production was significant mainly due to the application of DAP (Appendix 3.5). In both varieties the total dry matter production increased sharply between flowering and podding in all the treatments .

All the interactions between DAP, CAN and seed inoculation for leaf, stem, flower, pod and total dry matter accumulation were not significant in both experiments .

4.1.2 Leaf area

As shown in Table 6a, the effect of fertilizer N-source and seed inoculation on the total leaf area of the plants from both varieties was significant in the off season experiment only. At flowering (46 days after planting), application of DAP at planting followed later with CAN top dressing resulted in 'Monel' plants with significantly higher total leaf area than those from inoculated seeds fertilized later with CAN, seed inoculation alone and the control. Apart from the treatment where DAP was applied at planting, all 'Monel' plants from the other treatments had a total leaf area that was not significantly different from each other. However, in both varieties all the plants from the treatments that received DAP at planting had a higher cumulative leaf area than those

Table 6: Effect of fertilizer N-source and Rhizobium Seed inoculation on the leaf area(cm^2/plant) of French beans , 'Monel' and 'Finbel'.

a) OFF-SEASON (August-October)

Treatment	Flowering (46)		Podding (64)	
	Monel	Finbel	Monel	Finbel
Control	532.38^{b}	509.48^{a}	1383.99^{a}	816.31^{c}
DAP	732.41^{ab}	772.20^{a}	1405.12^{a}	1201.98^{abc}
CAN	627.94^{ab}	466.92^{a}	1516.82^{a}	1068.66^{abc}
Seed inoculation	439.83^{b}	467.43^{a}	1244.47^{a}	836.24^{c}
DAP+CAN	1093.92^{a}	846.06^{a}	1892.57^{a}	1692.32^{ab}
Seed inoculation+DAP	919.74^{ab}	707.64^{a}	1664.70^{a}	1734.76^{a}
Seed inoculation+CAN	591.40^{b}	466.92^{a}	1533.54^{a}	1002.61^{bc}
Seed inoculation+ DAP+ CAN	864.58^{ab}	749.88^{a}	1951.19^{a}	1496.17^{abc}
S.Emean	220.15	160.84	247.89	367.24
C.V%	24.28	46.90	24.18	21.19

b) IN-SEASON (November-January)

Treatment	Beginning of podding (47)		Podding (63)	
	Monel	Finbel	Monel	Finbel
Control	708.80^{a}	478.01^{a}	1191.90^{a}	1074.69^{a}
DAP	561.57^{a}	743.14^{a}	1041.10^{a}	1063.90^{a}
CAN	489.78^{a}	684.06^{a}	1004.40^{a}	1028.09^{a}
Seed inoculation	524.15^{a}	643.17^{a}	1070.57^{a}	941.72^{a}
DAP+CAN	587.47^{a}	646.84^{a}	1121.18^{a}	1591.91^{a}
Seedinoculation+DAP	560.43^{a}	674.59^{a}	1151.64^{a}	1401.67^{a}
Seed inoculation +CAN	588.61^{a}	662.61^{a}	1078.55^{a}	1172.23^{a}
Seed inoculation+ DAP+ CAN	744.88^{a}	682.16^{a}	1142.78^{a}	1479.85^{a}
S.Emean	87.76	76.76	62.48	239.31
C.V%	34.94	24.86	29.79	23.00

( ) Days after planting. Data are means of 3 blocks.
Means separation within columns by Duncan's Multiple range test, 5% level.

that did not. The cumulative leaf area increase was significant mainly due to the application of DAP (Appendix 3.6).

At podding (64 days after planting), the use of inoculated seeds and DAP at planting resulted with 'Finbel' plants with significantly higher cumulative leaf area than those from seed inoculation combined with CAN top dressing, seed inoculation alone and the control. Application of DAP at planting followed with CAN top dressing resulted in 'Finbel' plants with a significantly higher total leaf area than those from inoculated seeds alone and the control. The use of inoculated seeds and DAP at planting resulted in 'Finbel' plants which had the highest cumulative leaf area values while the control had the lowest. However, at podding 'Monel' plants from the treatment where DAP was applied at planting followed with CAN top dressing had the highest total leaf area values. The effect of seed inoculation on the total leaf area was considerably enhanced by using DAP at planting. The cumulative leaf area increase was significant mainly due to DAP application and CAN top dressing (Appendix 3.6).

All the interactions between seed inoculation, DAP and CAN for total leaf area were not significant at flowering and podding stages in both varieties.

4.2 Days to 50% flowering

In both varieties, the days to 50% flowering were not significantly influenced by the various treatments considered. However, 'Finbel' flowered a day earlier than 'Monel' in both experiments. The beans flowered late during the off-season experiment (49 days) compared to the in-season experiment (43 days).

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4.3 Pod yield

4.3.1 Number of pods per plant

As table 7a and b shows, the effect of N-source and seed inoculation on the number of pods per plant was significant in 'Monel' plants in the off-season and 'Finbel' plants in the in-season experiments. In the off-season experiment application of DAP alone at planting resulted in 'Monel' yielding significantly higher number of pods per plant than using CAN to top dress plants from inoculated seeds or using inoculated seeds alone. In addition, using inoculated seeds and DAP at planting followed later with CAN top dressing or top dressing plants from uninoculated plants with CAN resulted in 'Monel' plants producing significantly higher number of pods than using inoculated seeds alone.

In the in-season experiment, the use of inoculated seeds and DAP at planting followed with CAN top dressing resulted in 'Finbel' plants producing significantly higher number of pods per plant than those from all the other treatments except the ones from the treatment where DAP was used at planting followed later with CAN top dressing. Application of DAP at planting followed later with CAN top dressing resulted in 'Finbel' plants producing significantly higher number of pods per plant than using inoculated seeds and DAP at planting, DAP alone, CAN alone, seed inoculation alone or the control. Similarly, application of DAP alone at planting or top dressing plants from inoculated seeds with CAN resulted in 'Finbel' plants producing significantly higher number of pods per plant than the control. In both

Table 7: Effect of fertilizer N-source and Rhizobium seed inoculation on the total pod yield and number of pods per plant of French beans, 'Monel' and 'Finbel.'

a) OFF-SEASON(August-October)

Treatment	Number of pods per plant		Total pod yield (tons/ha.)	
	Monel	Finbel	Monel	Finbel
Control	21.13abc	16.33a	14.20a	8.60a
DAP	25.07a	20.07a	15.60a	14.40a
CAN	23.00ab	14.27a	18.10a	14.20a
Seed inoculation	17.13c	12.20a	14.30a	10.90a
DAP+CAN	21.33abc	22.47a	15.70a	17.60a
Seedinoculation+DAP	20.67abc	18.80a	16.60a	11.50a
Seed inoculation +CAN	19.67bc	12.13a	17.40a	12.10a
Seed inoculation +DAP+ CAN	24.27ab	23.07a	15.90a	12.20a
S.Emean	2.56	4.35	1.37	2.71
C.V%	11.88	29.71	29.35	26.91

b) IN-SEASON (November-January)

Treatment	Number of pods per plant		Total pod yield (tons/ha.)	
	Monel	Finbel	Monel	Finbel
Control	9.47a	7.73d	18.60a	14.20a
DAP	10.00a	10.27c	18.30a	16.60a
CAN	9.07a	9.40cd	19.60a	17.30a
Seed inoculation	9.00a	8.73cd	17.50a	16.10a
DAP+CAN	11.40a	12.80ab	22.60a	21.20a
Seed inoculation+DAP	12.93a	10.00c	20.60a	19.40a
Seed inoculation +CAN	12.27a	11.20bc	17.20a	18.80a
Seed inoculation +DAP+ CAN	11.53a	13.47a	20.30a	22.40a
S.Emean	1.52	1.96	1.80	2.73
C.V%	25.52	10.74	16.26	21.03

Data are means of 3 blocks.
Means separation within columns by Duncan's Multiple range test, 5% level.

varieties, seed inoculation had little effect on the number of pods per plant compared to DAP and CAN fertilization.

4.3.2 Total pod yield

The effect of fertilizer N-source and seed inoculation on the total pod yield of 'Monel' and 'Finbel' French beans was not significant (Table 7a and b). However, DAP and CAN fertilizers had a greater effect on the total pod yield compared to seed inoculation. The total pod yield was generally lower in the off-season experiment compared to the in-season experiment.

4.3.3 Marketable pod yield

The marketable pod yield is shown in Table 8a and b as the sum of the extra fine and fine pods. The effect of N-source and seed inoculation on the marketable pod yield was not significant in both varieties. The marketable pod yield was lower in the off-season experiment compared to the in-season experiment.

4.4 Pod quality

4.4.1 Pod grade yield

Table 8a and b shows that the effect of N-source and *Rhizobium* seed inoculation on pod grade yield was not significant.

4.4.2 Dry weight of the pods.

There were no significant differences in the dry weight of the pods resulting from the various treatments in both bean varieties.

Table 8: Effect of fertilizer N-source and Rhizobium seed inoculation on pod grade yield and marketable pod yield of french beans, 'Monel' and 'Finbel'.

a) OFF-SEASON(August-October)

Treatment	Pod grade yield yield (tons/ha.) Extra fine Monel	Extra fine Finbel	Fine Monel	Fine Finbel	Marketable pod yield (tons/ha.) Monel	Finbel
Control	2.30	1.70	7.90	4.40	10.20	6.10
DAP	2.60	2.50	8.30	7.30	10.90	9.80
CAN	2.90	1.90	11.40	7.90	14.30	9.80
Seed inoculation	1.70	1.70	9.30	4.80	11.00	6.50
DAP+CAN	2.90	2.60	8.50	9.40	11.40	12.00
Seed inoculation +DAP	2.50	2.20	9.70	5.60	12.20	7.80
Seed inoculation +CAN	2.10	1.50	10.90	5.40	13.00	6.90
Seed inoculation+ DAP+ CAN	2.70	1.50	9.10	5.60	11.80	7.10
S.Emean	0.41	0.43	1.24	1.73	1.31	2.07
C.V%	27.56	36.09	37.20	31.56	34.66	27.68

b) IN-SEASON (November-January)

Treatment	Pod grade yield yield (tons/ha.) Extra fine Monel	Extra fine Finbel	Fine Monel	Fine Finbel	Marketable pod yield (tons/ha.) Monel	Finbel
Control	3.20	3.30	10.40	8.20	13.60	11.50
DAP	2.70	3.60	9.20	8.40	11.90	12.00
CAN	2.70	2.70	9.90	8.60	12.60	11.30
Seed inoculation	2.40	3.50	9.20	8.80	11.60	12.30
DAP+CAN	3.20	3.80	11.70	9.80	14.90	13.60
Seedinoculation +DAP	3.40	3.00	10.90	11.20	14.30	14.20
Seedinoculation +CAN	1.70	2.70	9.60	10.60	11.30	13.30
Seed inoculation +DAP+ CAN	4.20	3.70	10.10	12.50	14.30	16.20
S.Emean	0.74	0.44	0.86	1.55	1.39	1.64
C.V%	34.56	33.95	18.39	26.66	16.10	25.14

Data are means of 3 blocks.

4.4.3 Pod length

As Table 9a and b shows, the effect of N-source and seed inoculation on the pod length of both varieties was not significant. However, 'Finbel' pods were longer than those of 'Monel' as expected.

4.4.4 Pod maximum diameter

The maximum diameter of both the extra fine and fine pods were not significantly affected by the fertilizer N-sources and seed inoculation in both varieties (Table 10a and b). However, pods from 'Monel' were thicker than those of 'Finbel' as expected.

4.4.5 Crude fibre content

The proportions of the pods that snapped without protruding fibres did not differ significantly with the variation of the fertilizer N-sources and *Rhizobium* seed inoculation in both varieties. Similarly, the crude fibre content from the proximate analysis of the pods was not significantly influenced by fertilizer N-source and seed inoculation. However, the crude fibre contents ranged between 17% and 22% in both seasons.

Table 9: Effect of fertilizer N-source and Rhizobium seed inoculation on pod length of French beans, 'Monel' and 'Finbel.'

a) OFF-SEASON(August-October)

	Pod length (cm)			
	Extra fine		Fine	
Treatment	Monel	Finbel	Monel	Finbel
Control	12.40	13.00	15.70	18.43
DAP	12.27	13.60	15.50	19.10
CAN	11.93	12.93	15.73	19.03
Seed inoculation	11.67	13.17	15.10	17.13
DAP+CAN	11.87	13.83	15.73	19.17
Seed inoculation+DAP	12.00	14.10	15.23	19.73
Seed inoculation+CAN	12.17	13.20	16.17	18.57
Seed inoculation+ DAP+ CAN	12.83	14.00	15.87	17.47
S.Emean	0.36	0.46	0.34	0.89
C.V%	3.86	4.86	3.79	6.66

b) IN-SEASON (November-January)

	Pod length (cm)			
	Extra fine		Fine	
Treatment	Monel	Finbel	Monel	Finbel
Control	13.53	15.53	15.83	18.80
DAP	13.13	14.57	15.47	20.80
CAN	13.10	14.87	15.63	19.13
Seed inoculation	13.33	15.20	15.97	19.20
DAP+CAN	13.00	16.30	15.20	20.50
Seed inoculation+DAP	12.97	15.97	16.00	20.63
Seed inoculation+CAN	13.47	15.47	15.47	19.47
Seed inoculation+ DAP+ CAN	13.37	16.33	15.50	19.63
S.Emean	0.22	0.64	0.28	0.77
C.V%	5.50	5.39	4.48	5.81

Data are means of 3 blocks.

Table 10: Effect of fertilizer N-source and Rhizobium seed inoculation on maximum diameter of French beans pods, 'Monel' and 'Finbel'.

a) OFF-SEASON(August-October)

	Pod maximum diameter (mm)			
	Extra fine		Fine	
Treatment	Monel	Finbel	Monel	Finbel
Control	5.00	4.51	7.31	7.12
DAP	5.20	4.71	7.43	7.15
CAN	5.00	4.76	7.46	7.27
Seed inoculation	5.17	4.71	7.48	7.10
DAP+CAN	4.96	4.78	7.25	7.00
Seed inoculation+DAP	5.02	4.74	7.16	7.38
Seed inoculation+CAN	5.16	4.94	7.66	7.09
Seed inoculation+ DAP+ CAN	5.16	4.80	7.30	7.05
S.Emean	0.10	0.12	0.16	0.12
C.V%	3.93	4.57	3.00	3.19

b) IN-SEASON (November-January)

	Pod maximum diameter (mm)			
	Extra fine		Fine	
Treatment	Monel	Finbel	Monel	Finbel
Control	5.38	5.12	7.74	7.15
DAP	5.31	5.14	7.34	7.51
CAN	5.31	4.85	7.52	7.37
Seed inoculation	5.47	4.95	7.83	7.49
DAP+CAN	5.37	5.30	7.46	7.46
Seed inoculation+DAP	5.32	5.26	7.86	7.53
Seedinoculation+CAN	5.48	5.08	7.70	7.50
Seed inoculation+ DAP+ CAN	5.18	5.18	7.45	7.53
S.Emean	0.10	0.15	0.20	0.13
C.V%	4.38	3.71	4.36	3.96

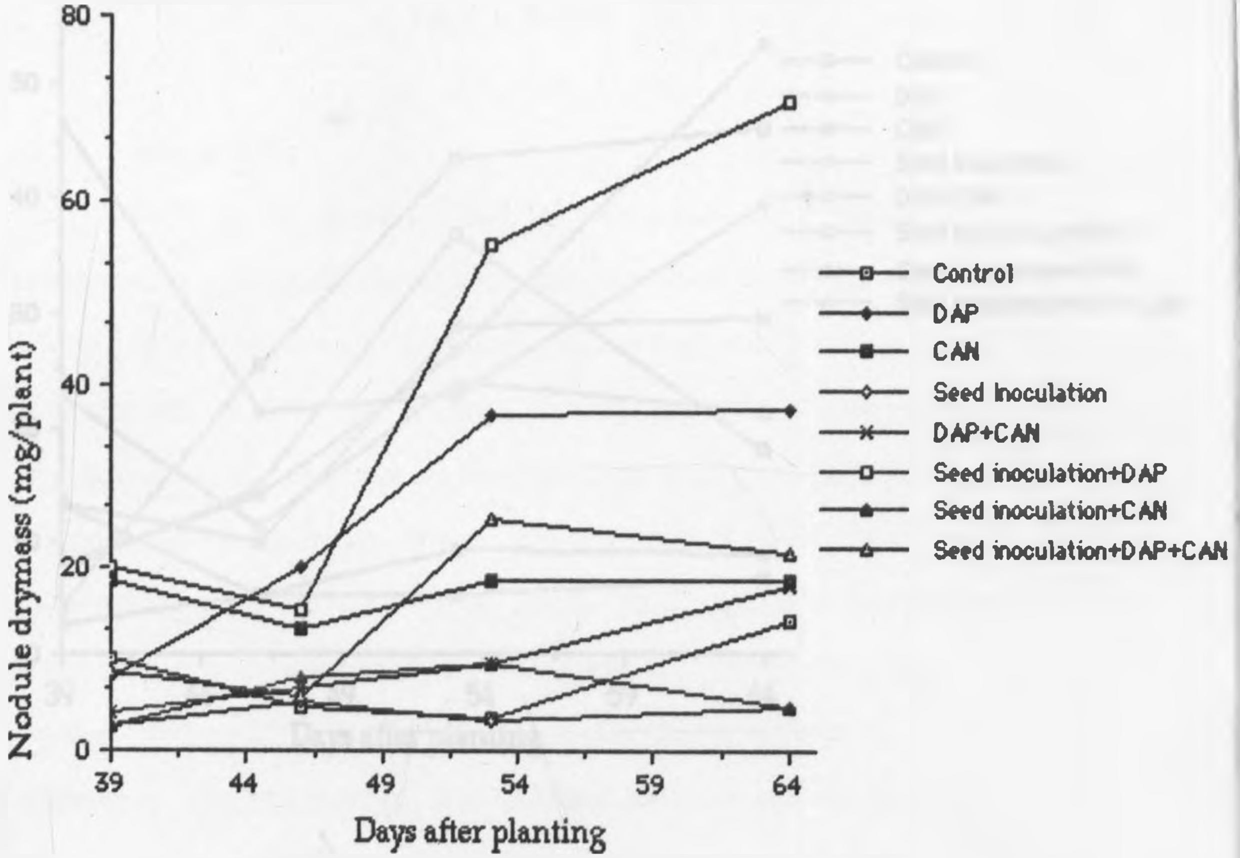
Data are means of 3 blocks.

4.5 Nodulation

The effect of N-source and seed inoculation on nodulation was significant in 'Monel' plants during podding (56 days after planting) in the in-season experiment. Apart from the control, application of DAP alone at planting resulted in 'Monel' plants that nodulated significantly better than those from the other treatments (Figure 2a). Inoculation of the seeds with *Rhizobium* and application of DAP at planting tended to favour nodulation in both varieties. However, top dressing the French beans with CAN depressed nodulation. The use of inoculated seeds and DAP at planting resulted in the highest nodule dry mass during podding in 'Monel' in the off-season experiment and in both varieties in the in-season experiment (Figures 1a, 1b and 2b). The rate of nodulation was rapid from flowering to podding in those plants that received DAP at planting (Figures 1a and 1b). In both varieties, nodulation was better in the off-season compared to the in-season experiment (Figures 1 and 2).

There was alot of variaticn in nodulation. The plants which were sampled, were either having no nodules, very few nodules or very many nodules. All the interactions between DAP, CAN and seed inoculation for nodulation were not significant.

(a) Off-season experiment.



(b) In-Season experiment.

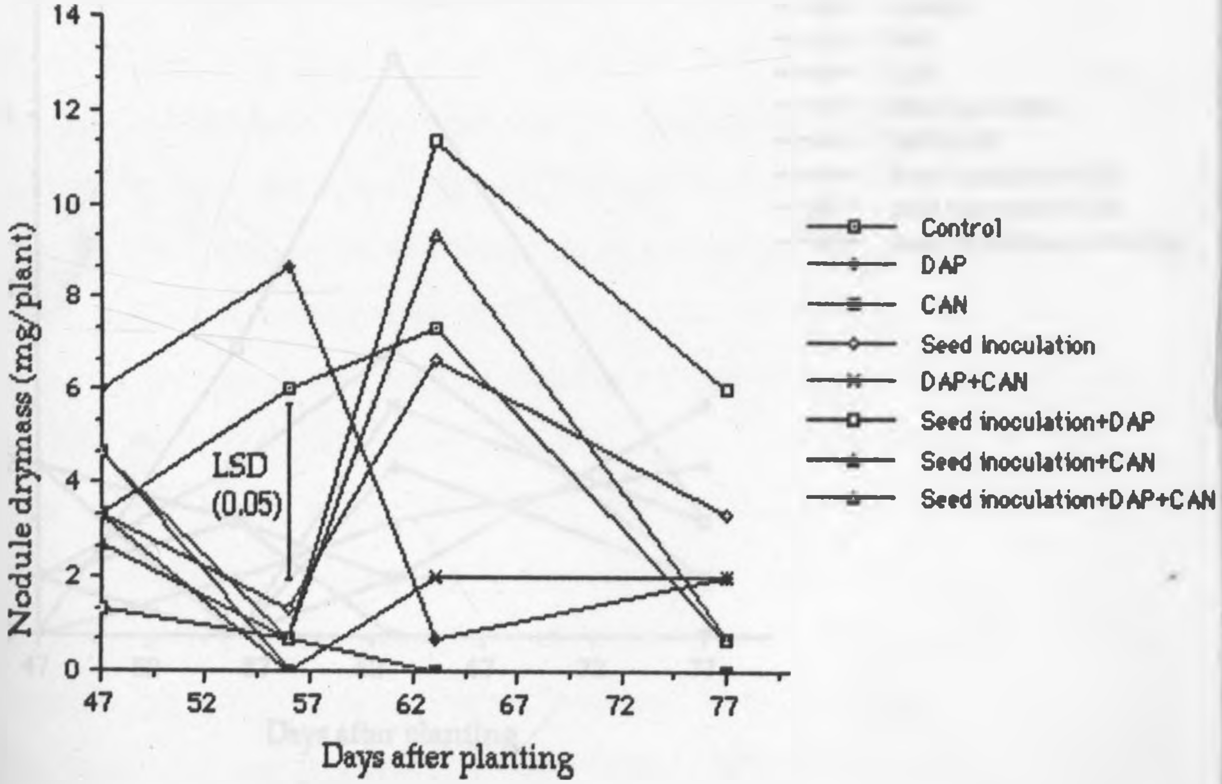
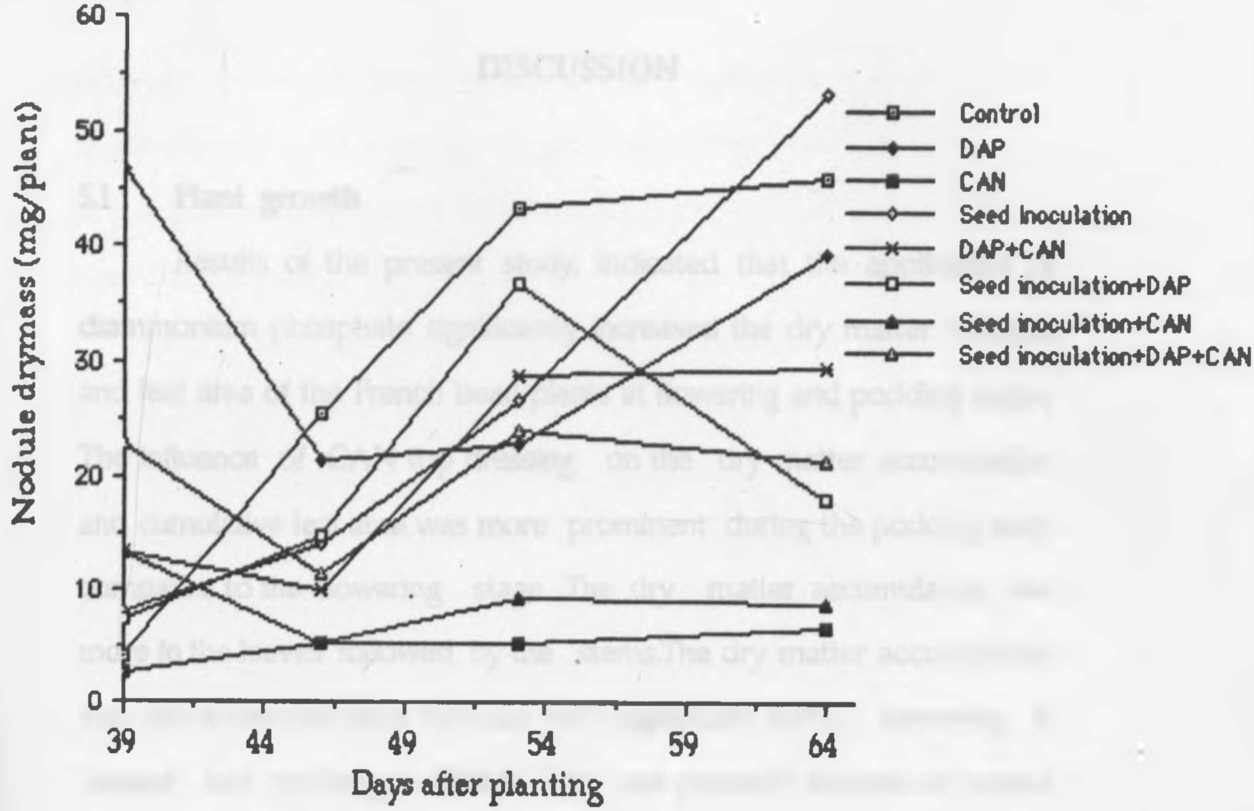


Fig. 1: The effect of fertilizer N-source and Rhizobium seed inoculation on nodulation of 'Monel' variety of French beans.

(a) Off-season experiment



(b) In-Season experiment.

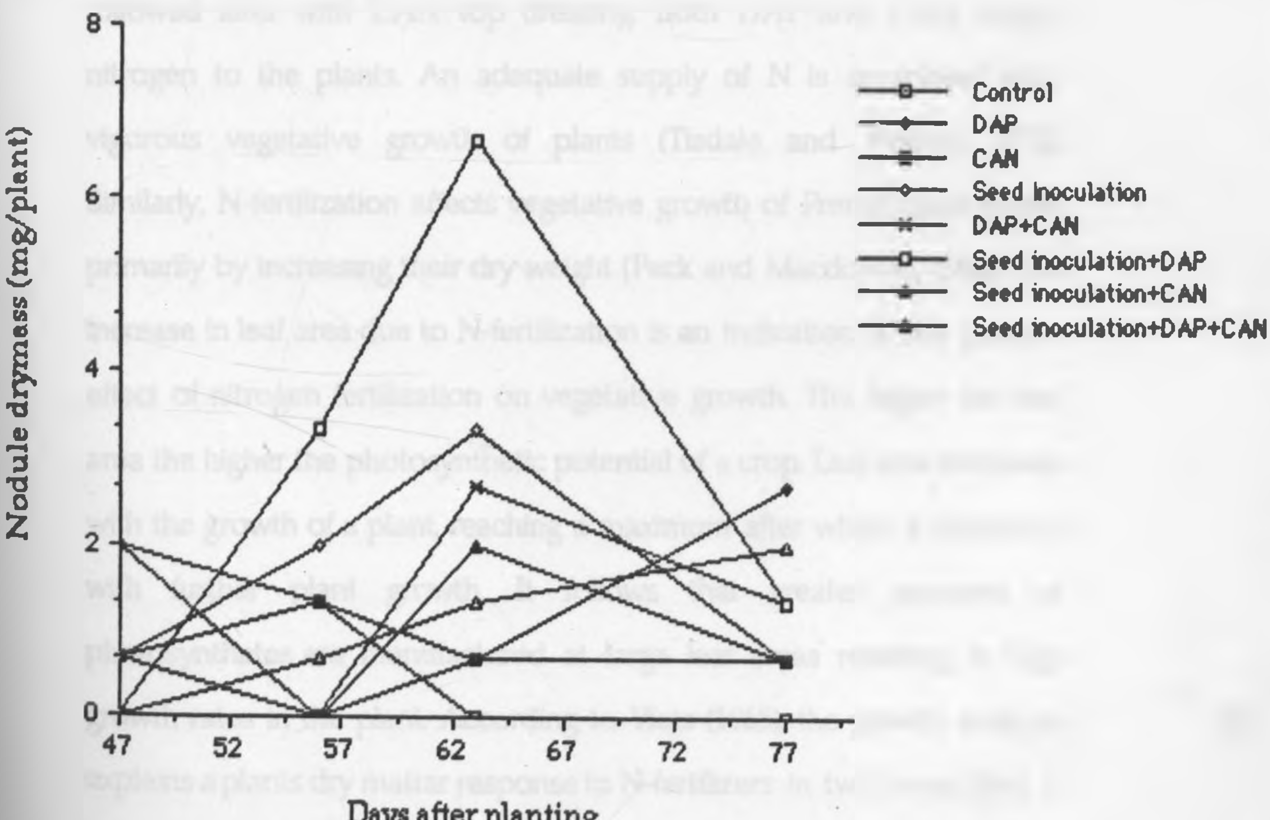


Fig. 2: Effect of fertilizer N-source and Rhizobium seed inoculation on nodulation of 'Monel' variety of French beans.

DISCUSSION

5.1 Plant growth

Results of the present study, indicated that the application of diammonium phosphate significantly increased the dry matter contents and leaf area of the French bean plants at flowering and podding stages. The influence of CAN top dressing on the dry matter accumulation and cumulative leaf area was more prominent during the podding stage compared to the flowering stage .The dry matter accumulation was more in the leaves followed by the stems.The dry matter accumulation and cumulative leaf area increase were significant during flowering in 'Monel' and podding in 'Finbel' .This was probably because of varietal differences. The dry matter accumulation and cumulative leaf area increase were significantly higher when DAP was applied at planting followed later with CAN top dressing. Both DAP and CAN supply nitrogen to the plants. An adequate supply of N is associated with vigorous vegetative growth of plants (Tisdale and Nelson, 1975). Similarly, N-fertilization affects vegetative growth of French bean plants, primarily by increasing their dry weight (Peck and Macdonald, 1984). The increase in leaf area due to N-fertilization is an indication of the positive effect of nitrogen fertilization on vegetative growth. The higher the leaf area the higher the photosynthetic potential of a crop. Leaf area increases with the growth of a plant, reaching a maximum after which it decreases with further plant growth. It follows that greater amounts of photosynthates are manufactured at large leaf areas resulting in high growth rates in the plant. According to Viets (1965), the growth analysis explains a plants dry matter response to N-fertilizers in two ways. First is the greater leaf area and secondly the increased net assimilation rate

(NAR) per unit leaf surface until self shading reduces the assimilation rate of lower leaves. In addition, Watson (1956) concluded that leaf area and yield are closely related and increasing the former results in an increase in the latter.

Seed inoculation did not significantly increase the dry matter and leaf area of French bean plants. However, when inoculated seeds and DAP were used at planting the dry matter production and leaf area of the plants were significantly increased. Chemical analysis showed that the soils of both experimental sites were low in phosphorus (Appendix 2) although they had a high inherent fertility. The soils of both experimental sites are nitosols. Nitosols have been reported to be widespread in the medium to high potential ecological zones of Kenya where most of the beans are grown. The soils have high phosphorus sorption capacity (Hinga, 1973) and hence low in available phosphorus. The soils were moderately acidic (pH range 4.8-5.2 in KCL). The pH range within which phosphorus occurs in forms available to plants is 6.0-6.5. At low pH values phosphorus forms insoluble compounds with aluminium and Iron making it unavailable (Tisdale and Nelson, 1975). In legumes, phosphorus is said to stimulate root growth and initiation of nodules, affect the extent of nodulation in terms of numbers and mass, and to influence the duration and general efficiency of *Rhizobium* - legume symbiotic system (Andrew, 1976, 1978, Franco, 1977; Freire, 1977). The low levels of available phosphorus in the soils was probably the reason why diammonium phosphate influenced the vegetative growth more than CAN and *Rhizobium* seed inoculation as it supplied phosphorus required for root development and nodulation, and also acted as a starter dose of nitrogen. Peck *et al*, (1964) showed that fertilizer phosphorus applied in a band at planting increased seedling and vegetative growth of French beans. Phosphorus increased dry matter contents, nitrogen concentration and phosphorus uptake in field beans (Ssali and Keya, 1986) and also increased N uptake by lucerne (Rao, 1971).

The poor response to the application of CAN compared to DAP was probably due to the high levels of nitrogen in the soil so that the nitrogen requirements of the beans was already satisfied. This may also have been due to the low levels of phosphorus in the soils (Appendix 2).However, CAN was top dressed 15 days after planting at the 2-3 true leaf stage and at the beginning of flowering (39 days after planting). Therefore its effect probably showed up during podding. Moreover, Smith (1977) reported that French bean plants under field conditions required relatively low levels of N, P fertilizers to give significant responses.

The increase in dry matter accumulation and leaf area in French bean plants were highest when DAP was used at planting followed with CAN top dressing at the 2-3 true leaf stage (15 days after planting) and when seeds were inoculated and DAP applied at planting or when all the three N sources were used. This may have been due to the supply of phosphorus (92 kgP_2O_5/ha) by DAP as it was low in the soil (Appendix 2). Nitrogen has been observed to influence the vegetative growth of French beans more when combined with phosphorus (Palaniyandi and Smith, 1979; El-bakry *et al*, 1980). However, the greater influence on the vegetative growth by these fertilization plans may also have been due to the fact that, a continuous adequate supply of nitrogen to the French bean plants was ensured, owing to the difference in the time of application or the availability of the symbiotically fixed nitrogen. Olson and Kurtz

(1982) observed that soil and fertilizer management must be designed to furnish a continuous supply of available N. Similarly, Vencatasamy and Peerally (1981) observed that in French beans, N-fixing activity increased until flowering and continued upto pod filling and then decreased. It is therefore, necessary to apply N-fertilizer after germination and prior to pod filling due to the short N fixing cycle. This supports the use of CAN by the farmers, as a top dress at the 2-3 true leaf stage and at the beginning of flowering. In addition, Paterson *et al.* (1966) reported that nitrogen fertilization has a positive effect on pod set and development and it may be the reason why the French beans are top dressed with CAN at the beginning of flowering. Results also indicate that the increase in dry matter production in the French bean plants was rapid from flowering to the podding stage. Peck and Macdonald (1984) also observed that dry weight accumulation in the French bean plants was slow from planting to the seedling stage, more rapid from seedling to the bloom stage and reached a more rapid rate from bloom to the pod stage. The rate of accumulation of dry matter may, therefore, depend on the growth stage. The increase in dry matter content and leaf area of French bean plants probably rises with an increase in nitrogen. This is because the dry matter content and leaf area were more when DAP was combined with CAN and/or seed inoculation. N-fertilization has also been reported to increase the dry weight of field beans (Edje *et al.*, 1975; Sundstrom *et al.*, 1982; Chui, 1985) and the increase rose with the amount of N-fertilizer added (Habish and Ishag, 1974; Koinov and Petkov, 1975; Molina, 1979; Leidi and Gomez, 1980).

Seed inoculation had no significant effect on the vegetative growth of the French bean plants. However, the effect of seed inoculation was noticeable when it was combined with DAP. Both DAP and seed inoculation were observed to positively influence nodulation of the French bean plants (Figures 1 and 2). The supply of both phosphorus and nitrogen by DAP and *Rhizobium* bacteria by seed inoculation promote early root development, favours nodulation and hence N-fixation. Therefore, the two N-sources are probably complementary and ensures an adequate supply of available N during the plant growth. Gibson (1976) observed that a relatively low amount of available N during initial plant development generally enhanced plant growth. In addition, a nitrogen dose may be needed for early growth before the onset of symbiotic N-fixation and during the entire growing season when symbiotic N-fixation is inhibited (Gibson, 1981; Van Rensburg and Strijdom, 1981). In this study the plants started to show improved nodulation when seeds were inoculated and DAP used at planting, 64 days after planting and 63 days after planting, in the off-season and in-season experiments, respectively. Habish and Ishag (1974) working with haricot beans observed that inoculated plants showed increased rate of growth about five weeks after sowing and that older plants had a greater increase in the rate of growth. Similarly, field beans benefit from *Rhizobium* inoculation as dry matter production in inoculated plants is often as good as or sometimes superior to those receiving N-fertilizer (Abdel-Ghaffer *et al*, 1982; Ruschel and Ruschel, 1975). The generally poor response to seed inoculation may probably have been caused by high soil N. Failure of legumes to respond to inoculation has often been attributed to high soil N or a large indigenous rhizobia population (Sparrow and Ham, 1983).

The two varieties used in the study differed significantly in their dry matter accumulation and cumulative leaf area (appendices 3.5 and

3.6). 'Monel' had higher dry matter content and leaf area than 'Finbel' in the off-season experiment but not in the in-season experiment. The first experiment was conducted in the off season after the long rains when it was cold while the second experiment was done during the short rains and the temperatures were higher (Appendix 1). There seemed to have been a seasonal influence which might have caused this inconsistency. Differential varietal responses to N-fertilization (Ssali and Keya, 1980, 1986) and seed inoculation (Chui and Nadar, 1984) have been observed in field beans.

5.2 Pod yield

The results indicated that N-fertilization increased the pod yield of French beans although not significantly. Seed inoculation had little effect on the total pod yield. The marketable pod yield and pod dry weight were also not significantly affected by the fertilizer N-sources. Asif (1970) showed that application of N generally increased the pod yield of French beans. Similarly, Paterson *et al* (1966) reported that N-fertilization had a significant effect on pod set and development and also increased the French bean pod yield. The total pod yield was generally higher when DAP was used at planting followed with CAN top dressing .However,the use of inoculated seeds and DAP at planting or all the three N sources combined also gave high pod yields. Generally, the pod yield was higher when CAN was used than using either DAP or seed inoculation. This shows that CAN had a greater influence at podding compared to DAP and *Rhizobium* seed inoculation. Therefore, the availability of N at the time of podding is very important, and could, therefore, determine the time of N application. In addition, a continuous adequate nitrogen supply is ensured when DAP is used at planting followed with CAN top dressing at 2-3 true leaf stage and at the beginning of flowering. Asif and Greig (1972), Doss *et al*, (1977), Mullins *et al*, (1980, 1981) and Ishimura *et al*, (1985) showed that increased N application resulted in increased French bean pod yield. Also, Smittle (1976) reported that French bean yield was increased by additional N applied as a top dress.

The results also showed that French bean pod yield was increased more when nitrogen is combined with phosphorus, probably due to the favourable effect of phosphorus on early root development and nitrogen on vegetative growth which ensures vigorous growth of a high yielding plant. Smith (1970, 1977) working with French beans, and Stolberg-Wernigerode and Grafzu (1977) with bush beans showed that yields were increased when nitrogen is used in combination with phosphorus. According to Smith (1977) this increase in yield was contributed by both nitrogen and phosphorus. In this study results indicated that DAP had influence on dry matter yield, leaf area and pod yield while CAN had more influence on pod yield. This was probably due to the fact that DAP contains both nitrogen (36 kgN/ha) and phosphorus (92 kgP_2O_5/ha) and the soils were deficient in phosphorus. In addition, phosphorus has been reported to increase the uptake of N in field beans (Ssali and Keya, 1986) and in luceme (Rao, 1971). Top dressing with CAN at the 2-3 true leaf stage and beginning of flowering ensures a continuous supply of N during podding and hence it may have a greater influence on pod yield than DAP and *Rhizobium* seed inoculation. The yield of French beans may also depend on the source of nitrogen. Thimmegowda and Krishnamurthy (1975) while working with ammonium sulphate, urea, CAN, and ammonium sulphate nitrate as sources of nitrogen in lima beans showed that CAN gave the highest yield and that the difference between the other treatments were slight. This was probably because CAN supplies calcium in addition to nitrogen and calcium is an important essential element especially in acidic soils. Reis *et al* (1972) reported that DAP increased the yield of dry beans.

Seed inoculation had no significant effect on the pod yield of French beans but its effect was noticeable after the application of DAP. There are no reports available in literature on the effect of seed inoculation on the pod yield although the same have been shown to increase the yield of dry beans. The favourable effect of DAP on seed inoculation was probably due to the phosphorus in DAP which has been found to positively affect nodulation and hence N-fixation (Ssali and Keya, 1986). Some yield responses to inoculation have been obtained in areas where beans have not been grown before (Desouza, 1969; Macartney and Watson, 1966). In Kenya, results by Keya *et al* (1981) in a survey of 68 bean producing regions, showed appreciable grain yield responses by Canadian wonder to inoculation in Embu (increase of 16%) and at Kabete (increase of 17%). However, Vencatasamy and Peerally (1981) reported that N-fixing activity in French bean plants was high between flowering and podfilling periods only. This indicated that symbiotically fixed N could be useful to the beans only during flowering and podfilling and probably not at podset which can be a disadvantage to French beans. In addition, Paterson *et al* (1966) reported that nitrogen has a positive influence on podset and development.

Results also indicated that N-fertilization increased the number of pods per plant but had no effect on the pod dry weight. Ishimura et al. (1985) showed that N-fertilizer increased the number of French bean pods but the average pod weight remained constant. In field beans, the increase in seed yield as a result of N-fertilization has been found to be either due to an increase in the number of pods per plant (Castro and Perera, 1975; Chui, 1985) or the number of pods per unit area (Scarisbric *et al*, 1982).

Seed inoculation had no effect on the number of pods per plant compared to DAP and CAN in both experiments. This was probably because the soil N may not have been limiting (Appendix 2). In soils where N is not limiting field bean yield responses to seed inoculation range from decreases (Pessanha *et al*,1970) to substantial increases where N is limiting (Habish and Ishag, 1974; Keya *et al*, 1981) and the yields are related to the number of pods per plant (Castro and Perera, 1975; Chui, 1985).

There were significant varietal differences in pod yield (Appendix 3.8). 'Monel' had significantly higher total and marketable pod yield and number of pods per plant than 'Finbel' in the off-season experiment. This was probably due to the fact that having been grown in Kenya for a long time 'Monel' may be more adapted to Kenyan environmental conditions than 'Finbel' which had been imported in 1986. The seeds of 'Monel' that were used had been multiplied in the farmers' fields and certified by the National Seed Quality Control service (NSQCS). 'Finbel' had also been noticed to have poor seedling emergence and field establishment compared to 'Monel'. This could have led to the poor performance of 'Finbel'. Cultivar differences were similarly reported by Ssali and Keya (1980, 1986).

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5.3 Pod quality

Although both DAP and CAN increased pod yield, none of them had a significant influence on pod quality.However, the yield of the extra fine pods was generally higher when DAP was used at planting followed with CAN top dressing at the 2-3 true leaf stage and at the beginning of flowering. The results, therefore, indicated that both nitrogen and phosphorus may be necessary in order to produce high quality French bean pods.

Seed inoculation had no positive effect on the yield of extra fine pods compared to DAP and CAN. In fact, it seemed to depress the extra fine pod yield when compared to the control. There was no significant difference between the application of DAP at planting followed with CAN top dressing and planting inoculated seeds with DAP. This shows that seed inoculation can probably be used in French bean production provided phosphorus is used at planting. This is because the effect of *Rhizobium* seed inoculation was noticeable after DAP application . Peck and Macdonald (1984) observed that N-fertilizer decreased the yield of large (fine grade) pods and the percentage of seeds in the pods of French beans, hence enhancing French bean pod quality. Application of DAP at planting followed with CAN top dressing enhanced pod quality by increasing the yield of the extra fine pod grade. Seed inoculation seemed to depress the yield of the extra fine pods relative to DAP and CAN fertilization. This probably indicated that seed inoculation alone without the application of DAP or a source of phosphorus may produce low quality pods. However, no other study has been reported in literature indicating the effect of seed inoculation on the physical quality characteristics of French beans.

All other quality characteristics including the proportion of pods that snapped without protruding fibres were not affected by N-sources and *Rhizobium* seed inoculation in both experiments.This may probably happen if the pods are harvested at the right time. There are no reports available in literature on the effect of N-sources and seed inoculation on the pod quality characteristics that were evaluated in the present study.

Nearly all the French bean pod quality determining characteristics were significantly influenced by the variety (Appendices 3.9a and 3.9b). 'Monel' significantly produced more extra fine and fine pods than 'Finbel'. However, when the extra fine: fine pods ratio was considered 'Finbel' had a lower ratio than 'Monel'. 'Finbel' had a ratio of 1:3 while 'Monel''s ratio was 1:4. 'Monel' also had significantly shorter and thicker pods than 'Finbel'. The proportion of the pods that snapped without protruding fibres was significantly higher in 'Monel' compared to 'Finbel' in the first experiment (Appendix 3.9b). The results, therefore, suggest that 'Monel' can produce pods of higher quality than 'Finbel'. There are no reports available in literature on the effect of variety on the pod quality characteristics of French beans.

5.4 Nodulation

Results indicated that N-fertilizer source and seed inoculation may have an effect on the nodulation of French bean plants. Nodulation was increased by seed inoculation and the application of DAP at planting. Top dressing with CAN had little influence on nodulation compared to *Rhizobium* seed inoculation and DAP application.

The positive influence of DAP on nodulation was probably due to phosphorus (92 kgP_2O_5/ha.) in it. In legumes, phosphorus is said to stimulate root growth and initiation of nodulation, affect the extent of nodulation in terms of numbers and mass, and to influence the duration and the efficiency of *Rhizobium* - legume symbiotic system (Andrew, 1976, 1978; Franco, 1977; Freire, 1977). No reports are available in literature on the effect of phosphorus on nodulation and N fixation by French beans. However, several studies using field beans have shown that application of phosphorus can improve nodulation and N-fixation (Fontes, 1972; Almeida *et al*, 1973; Anderson, 1973; Dombovari, 1977; Keya, 1977; Graham and Rosas, 1977; Keya and Mukunya, 1979). Also, Ssali and Keya (1983, 1986) showed that application of phosphorus increased nodulation and N - fixation in field beans. In addition., the chemical analysis of the soils in the experimental sites showed that the soils were low in available phosphorus (Appendix 2). This could have contributed to the positive influence of DAP on the nodulation of French beans.

Application of CAN depressed nodulation and was characterised by an initial decline in nodulation. Results of Peck and Macdonald (1984) showed that French bean plants grown without N-fertilizer had many nodules on their roots. They also observed that N-fertilizer reduced the number of nodules on the roots. A high dose of N-fertilizer decreased nodulation and N-fixation (Abdel-Ghaffer *et al*, 1982; Ssali and Keya , 1980, 1982, 1986). Sistachs (1970) working with black beans also reported that nodulation was completely suppressed by applied N. In addition, Chui (1985) observed that the application of N-fertilizer caused a significantly high nodule number degeneration relative to the uninoculated control. Considering that soil N may not have been limiting (Appendix 2), the application of CAN probably raised the nitrogen in the soil to levels which caused nodule degeneration.

Seed inoculation helps to introduce the *Rhizobium* bacteria into the soil near the bean roots, on which nodules are formed. Therefore, unless the soil N is high or a high dose of N-fertilizer is applied, inoculated seeds are supposed to produce well nodulated plants. Sparrow and Ham (1983) attributed the failure of legumes to respond to inoculation to high soil N. Infact, seed inoculation only supplements nodulation due to indigenous *Rhizobium* bacteria in the soil.

Results indicated that 'Monel' significantly produced more nodule dry mass than 'Finbel' in the in-season experiment (Appendix 3.7). 'Finbel' had higher nodule dry mass than 'Monel' in the off-season experiment (Appendix 3.7) but the nodulation did not differ significantly. Graham (1982) reported that symbiotic nitrogen fixation in legumes is the culmination of a complex interaction between host, *Rhizobium* and the environment. Each of these factors will contribute to the nodulating ability of the plant. In addition, Macferson *et al* (1982) reported that considerable variability exists among common bean genotypes for N-fixation. Keya (1977) also reported that nodulation and nitrogen fixation is limited by lack of well adapted local legume cultivars and appropriate inoculants suited to acid conditions.

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Nitrogen fertilization had greater positive effect on growth and pod yield of French beans than *Rhizobium* seed inoculation. Diammonium phosphate influenced growth and quality while CAN had a greater influence on pod yield. The best fertilization plan for French beans was the application of DAP at planting followed later with CAN top dressing at the 2-3 true leaf stage and beginning of flowering. However, the effect of seed inoculation was noticeable when DAP was applied at planting. The effect of applying DAP at planting and then topdressing the plants with CAN at the 2-3 true leaf stage and beginning of flowering on growth, yield and quality of French beans was not significantly different from the effect of using inoculated seeds and DAP at planting on the same. Therefore, both fertilization plans can be used without significantly affecting the growth, yield and quality of French beans. Infact, the use of inoculated seeds and DAP at planting may be more economically beneficial than using DAP at planting followed with CAN topdressing. Diammonium phosphate and seed inoculation promotes nodulation while CAN depresses it.

Diammonium phosphate plus CAN was the best fertilization plan probably because it ensured the availability of N throughout the growing season. Diammonium phosphate supplies N and the much needed phosphorus to the plant during the early plant growth stages while CAN ensures the availability of N throughout the growing season and especially during podding.

Monel was better than Finbel as it yielded more total and marketable pods. The quality of French beans was more influenced by genotype than N-source or *Rhizobium* seed inoculation. This is because most of the pod quality determining characteristics were not influenced by the N fertilizer source and *Rhizobium* seed inoculation but differed between the varieties.

6.2 Recommendations

In order to realise high yields of French bean pods, nitrogen must be supplied to the plants throughout the growing cycle. The N must be combined with phosphorus. Therefore, the use of DAP at planting and CAN as a topdress at the 2-3 true leaf stage and at the beginning of flowering is recommended. However, the use of inoculated seeds and DAP at planting may be more economically beneficial when individual current prices of the three N-sources and pods are considered. Monel out yields Finbel and seems to be more adapted to the conditions prevailing at Kabete.

The following are recommendations for further research;

1.) The effect of N, P fertilizer and seed inoculation on the nutritional quality of French bean pods.

2.) The direct contribution of N-fixation to the N requirement of French beans using the isotope (N^{15}) dilution technique, acetylene reduction method or other methods which estimate the amount of N contributed by the symbiotic relationship.

3.) The effect of N-fertilization and *Rhizobium* seed inoculation on the growth, yield and quality of French beans grown in different soils and agro-ecological zones of Kenya.

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APPENDICES

Appendix 1: Mean temperature and monthly rainfall received between July, 1987 and February, 1988.

Month	Monthly rainfall (mm)	Mean temperature (^{O}C)
July, 1987	9.4	16.0
August, 1987	93.9	16.5
September, 1987	17.4	18.4
October,1987	5.7	19.5
November, 1987	182.1	18.9
December,1987	15.3	19.0
January, 1988	96.2	19.5
February, 1988	72.0	20.2

Source: Agrometeorology Station, Kabete.

Appendix 2: Chemical composition of soils sampled from the experimental sites.

	First Experiment		Second Experiment	
Depth	0-15 cm	15-30 cm	0-15 cm	15-30 cm
pH in water and KCL, respectively	5.6, 4.8	5.7, 4.5	5.8, 4.8	6.3, 5.2
Total N (%)	0.37	0.27	0.34	0.26
Phosphorus, ppm	4.70	2.40	7.50	3.17
C.E.C	24.60	20.30	23.60	19.20
Exchangeable Potassium me./100g Soil	1.20	1.08	3.80	0.60
Exchangeable Calcium me/100g soil	15.05	14.30	14.9	14.00
Exchangeable Magnesium me/100g soil	2.40	2.20	2.55	3.15
Exchangeable Sodium me/100g soil	0.60	0.60	0.80	0.40
Organic matter (%)	3.74	2.10	3.50	1.90

Soil analysis procedures are as explained by Black, C.A. (1965).

The soil chemical analysis indicated a moderately acid reaction and adequate supply of other nutrient elements except phosphorus which was low. In Olsen method (used in the first experiment), phosphorus is classified as follows:

< 5 ppm, low; 5-10 ppm, fair; 10-15 ppm, adequate, 15-20 ppm, good and >20 ppm, high. In double acid method (used in second experiment), phosphorus is classified as follows: < 20 ppm, low; 20-80 ppm, adequate and > 80 ppm, high (Chege, 1982).

Appendix 3: ANOVA TABLES

3.1: Anova on the dry matter content of the leaves of French beans.

Mean sum of squares

		OFF-SEASON EXPERIMENT Days after planting		IN-SEASON EXPERIMENT Days after planting	
Source of variation	df	46	64	47	63
Total	47				
Blocks	2	31.36**	55.67ns	115.65**	535.79**
Varieties	1	25.82*	227.07*	87.35**	597.56**
Treatments	7	39.91**	159.83**	4.64ns	31.59ns
DAP	1	260.40**	784.73**	-	-
CAN	1	5.88ns	169.88*	-	-
Seed inoculation	1	9.72ns	1.59ns	-	-
DAPxCAN	1	0.52ns	1.09ns	-	-
DAPxSeed inoculation	1	1.54ns	9.61ns	-	-
CAN xSeed inoculation	1	1.20ns	131.67ns	-	-
DAPxCANxSeed inoculation	1	0.10ns	20.23ns	-	-
Error	37	7.52	33.46	11.68	47.51

* - Significantly different at the probability level of 5%.
** - Significantly different at the probability level of 1%.
ns - Not Significant.

3.2: Anova on the dry matter content of the stems of French beans.

		Mean sum of squares			
		OFF-SEASON EXPERIMENT Days after planting		IN-SEASON EXPERIMENT Days after planting	
Source of variation	df	46	64	47	63
Total	47				
Blocks	2	18.30^{ns}	41.81^{ns}	71.81**	299.40**
Varieties	1	9.81^{ns}	1002.84**	0.45^{ns}	44.09^{ns}
Treatments	7	30.23**	227.46**	7.84^{ns}	37.42^{ns}
DAP	1	190.01**	1331.41**	-	-
CAN	1	0.01^{ns}	102.67^{ns}	-	-
Seed inoculation	1	0.54^{ns}	21.33^{ns}	-	-
DAPxCAN	1	0.50^{ns}	0.02^{ns}	-	-
DAPxSeed inoculation	1	20.15^{ns}	24.08^{ns}	-	-
CAN xSeed inoculation	1	0.42^{ns}	81.64^{ns}	-	-
DAPx CANxSeed inoculation	1	0.02^{ns}	31.04^{ns}	-	-
Error	37	5.86	52.55	8.04	29.49

* - Significantly different at the probability level of 5%.
** - Significantly different at the probability level of 1%.
ns - Not Significant.

3.2: Anova on the dry matter content of the stems of French beans.

		Mean sum of squares			
		OFF-SEASON EXPERIMENT Days after planting		IN-SEASON EXPERIMENT Days after planting	
Source of variation	df	46	64	47	63
Total	47				
Blocks	2	18.30ns	41.81ns	71.81**	299.40**
Varieties	1	9.81ns	1002.84**	0.45ns	44.09ns
Treatments	7	30.23**	227.46**	7.84ns	37.42ns
DAP	1	190.01**	1331.41**	-	-
CAN	1	0.01ns	102.67ns	-	-
Seed inoculation	1	0.54ns	21.33ns	-	-
DAPxCAN	1	0.50ns	0.02ns	-	-
DAPxSeed inoculation	1	20.15ns	24.08ns	-	-
CAN xSeed inoculation	1	0.42ns	81.64ns	-	-
DAPx CANxSeed inoculation	1	0.02ns	31.04ns	-	-
Error	37	5.86	52.55	8.04	29.49

* - Significantly different at the probability level of 5%.
** - Significantly different at the probability level of 1%.
ns - Not Significant.

3.3: Anova on the dry matter content of the flowers of French beans.

		Mean sum of squares			
		OFF-SEASON EXPERIMENT Days after planting		IN-SEASON EXPERIMENT Days after planting	
Source of variation	df	46	64	47	63
Total	47				
Blocks	2	0.030^{ns}	0.270^{ns}	0.290*	0.060*
Varieties	1	0.000^{ns}	0.600*	0.090^{ns}	0.009^{ns}
Treatments	7	0.110^{ns}	0.360**	0.040^{ns}	0.030^{ns}
DAP	1	-	1.350**	-	-
CAN	1	-	0.860**	-	-
Seed inoculation	1	-	0.080^{ns}	-	-
DAP x CAN	1	-	0.040^{ns}	-	-
DAP xSeed inoculation	1	-	0.190^{ns}	-	-
CAN xSeed inoculation	1	-	0.010^{ns}	-	-
DAP xCAN xSeed inoculation	1	-	0.000^{ns}	-	-
Error	37	0.060	0.090	0.080	0.016

* - Significantly different at the probability level of 5%.
** - Significantly different at the probability level of 1%.
ns - Not Significant.

3.4: Anova on the dry matter content of the pods of French beans.

		Mean sum of squares			
		OFF-SEASONEXPERIMENT Days after planting		IN-SEASON EXPERIMENT Days after planting	
Source of variation	df	46	64	47	63
Total	47				
Blocks	2	-	83.78*	0.02^{ns}	138.68^{ns}
Varieties	1	-	1.43^{ns}	0.44**	1443.87**
Treatments	7	-	34.03^{ns}	0.05^{ns}	13.16^{ns}
Error	37	-	16.26	0.03	62.69

* - Significantly different at the probability level of 5%.
** - Significantly different at the probability level of 1%.
ns - Not Significant.

3.5: Anova on the total dry matter production of French beans.

Mean sum of squares

		OFF-SEASON EXPERIMENT Days after planting		IN-SEASON EXPERIMENT Days after planting	
Source of variation	df	46	64	47	63
Total	47				
Blocks	2	91.67*	525.64ns	393.66**	2654.02**
Varieties	1	60.39ns	2088.27**	87.86ns	4720.65**
Treatments	7	145.61**	991.79**	16.52ns	127.42ns
DAP	1	972.18**	5235.03**	-	-
CAN	1	8.81ns	543.92ns	-	-
Seed inoculation	1	3.56ns	15.01ns	-	-
DAP x CAN	1	3.58ns	13.42ns	-	-
DAP x Seed inoculation	1	30.75ns	207.17ns	-	-
CAN x Seed inoculation	1	0.00ns	681.47ns	-	-
DAP x CAN x Seed inoculation	1	0.36ns	246.52ns	-	-
Error	37	26.10	229.86	34.31	344.54

* - Significantly different at the probability level of 5%.
** - Significantly different at the probability level of 1%.
ns - Not Significant.

3.6: Anova on the cumulative leaf area of French beans.

		Mean sum of squares			
		OFF-SEASON EXPERIMENT		IN-SEASON EXPERIMENT	
		Days after planting		Days after planting	
Source of variation	df	46	64	47	63
Total	47				
Blocks	2	6316683.00**	12747993.00**	6704443.00**	36638800.00**
Varieties	1	3770000.00ns	35200000.00**	940000.00ns	4300000.00ns
Treatments	7	5426189.30**	12987264.00**	275320.71ns	2849365.10ns
DAP	1	33298859.00**	61977188.00**	-	-
CAN	1	1394066.30ns	16326766.00*	-	-
Seed inoculation	1	970728.30ns	1106764.80ns	-	-
DAPxCAN	1	420692.70ns	160532.61ns	-	-
DAP x Seed inoculation	1	11503.19ns	3180697.00ns	-	-
CAN xSeed inoculation	1	872368.99ns	3463871.00ns	-	-
DAPxCAN xSeed inoculation	1	1014400.60ns	4688931.40ns	-	-
Error	37	1180657.70	2352490.90	813825.83	2079103.80

* - Significantly different at the probability level of 5%.
** - Significantly different at the probability level of 1%.
ns - Not Significant.

3.7: Anova on the nodule dry mass.

		Mean sum of squares			
		OFF-SEASON EXPERIMENT			
		Days after planting			
Source of variation	df	39	46	53	64
Total	47				
Blocks	2	0.005ns	0.014*	0.015ns	0.013ns
Varieties	1	6.67×10^{-6}ns	0.004ns	0.006ns	0.056ns
Treatment	7	0.002ns	0.004ns	0.020ns	0.023ns
Error	37	0.003	0.004	0.020	0.020

* - Significantly different at the probability level of 5%.
** - Significantly different at the probability level of 1%.
ns - Not Significant.

IN-SEASON EXPERIMENT			
Days after planting			
47	56	63	77
1.10×10^{-3}**	6.50×10^{-4}*	1.00×10^{-3}ns	1.70×10^{-3}**
1.60×10^{-3}**	2.10×10^{-4}ns	3.00×10^{-3}*	7.00×10^{-5}ns
5.00×10^{-5}ns	3.43×10^{-4}ns	4.00×10^{-4}ns	2.00×10^{-4}ns
1.30×10^{-4}	1.57×10^{-4}	7.00×10^{-4}	9.00×10^{-5}

3.8(a): Anova on the days to 50% flowering, pod yield, yield components and pod grades of French beans (Off-season Experiment).

		Mean sum of squares						
Source of variation	df	A	B	C	D	E	F	G
Total	47							
Blocks	2	0.77^{ns}	8243114.00^{**}	4782983.60^{**}	1.19^{ns}	199.72^{**}	72114.57^{*}	3704567.40^{**}
Varieties	1	2.52^{ns}	4200000^{**}	4960000^{**}	1.51^{ns}	146.30^{**}	100944.36^{*}	11244946.00^{**}
Treatments	7	1.31^{ns}	579588.33^{ns}	350658.93^{ns}	1.87^{ns}	61.28^{**}	-	232310.77^{ns}
DAP	1	-	-	-	-	227.94^{**}	-	-
CAN	1	-	-	-	-	35.71^{ns}	-	-
Seed inoculation	1	-	-	-	-	80.60^{*}	-	-
DAP×CAN	1	-	-	-	-	0.10^{ns}	-	-
DAP×Seed inoculation	1	-	-	-	-	50.84^{ns}	-	-
CAN×Seed inoculation	1	-	-	-	-	8.84^{ns}	-	-
DAP×CAN×Seed inoculation	1	-	-	-	-	24.94^{ns}	-	-
Error	37	1.45	498169.31	324248.44	0.98	15.84	13658.80	241024.72

A - Days to 50% flowering.
B - Total pod yield.
C - Marketable pod yield.
D - pod dry weight.
E - Number of pods per plant.
F - Extra fine grade.
G - Fine grade

* - Significantly different at the probability level of 5%
** - Significantly different at the probability level of 1%.
ns - Not Significant.

3.8(b): Anova on the days to 50% flowering , pod yield,yield components and pod grades of French beans (In-Season Experiment).

		Mean sum of squares						
Source of variation	df	A	B	C	D	E	F	G
Total	47							
Blocks	2	6.84**	1335498.30*	263116.50^{ns}	10.56^{ns}	71.58**	114706.16^{ns}	154696.95^{ns}
Varieties	1	3.00^{ns}	420000^{ns}	0.00^{ns}	0.15^{ns}	0.80^{ns}	40484.94^{ns}	50000.00^{ns}
Treatments	7	2.19^{ns}	833065.36^{ns}	338003.89^{ns}	13.22^{ns}	14.56**	51622.94^{ns}	191033.97^{ns}
DAP	1	-	-	-	-	45.24**	-	-
CAN	1	-	-	-	-	31.69*	-	-
Seed inoculation	1	-	-	-	-	15.19^{ns}	-	-
DAP x CAN	1	-	-	-	-	0.80^{ns}	-	-
DAP x Seed inoculation	1	-	-	-		0.19^{ns}	-	-
CAN x Seed inoculation	1	-	-	-	-	1.27^{ns}	-	-
DAP x CAN x Seed inoculation	1	-	-	-	-	7.52^{ns}	-	-
Error	37	1.02	367371.73	216940.69	8.35	5.42	41260.99	147079.41

A - Days to 50% flowering
B - Total pod yield
C - Marketable pod yield
D - pod dry weight
E - Number of pods per plant
F - Extra fine grade
G - Fine grade

* - Significantly different at the probability level of 5%
** - Significantly different at the probability level of 1%.
ns - Not Significant

Appendix 3.9(a): Anova on the French beans pod quality characteristics (Off-season experiment).

Mean sum of squares

Sources of variation	df	A	B	C	D	E	F	G
Total	47							
Blocks	2	0.73^{ns}	0.82^{ns}	0.003^{ns}	0.45**	104.47^{ns}	10.74*	3.10^{ns}
Varieties	1	21.46**	104.43**	1.50**	0.68**	55.90^{ns}	0.001^{ns}	0.01^{ns}
Treatments	7	0.66^{ns}	1.39^{ns}	0.05^{ns}	0.05^{ns}	52.47^{ns}	1.28^{ns}	0.30^{ns}
Error	37	0.34	0.96	0.04	0.06	85.72	2.48	1.08

A - Pod length of extra fine pods.
B - Pod length of fine pods.
C_1 - Pod maximum diameter of extra fine pods.
D_1 - Pod maximum diameter of fine pods.
E - Number of pods that snapped without protruding fibres.
F - Crude fibre content at 74 days after planting.
G - Crude fibre content at 78 days after planting.
* - Significantly different at the probability level of 5%.
** - Significantly different at the probability level of 1%.
ns - Not significant.

Appendix 3.9(b): Anova on the French beans pod quality characteristics (In-season experiment).

Mean sum of squares

Sources of variation	df	A	B	C	D	E	F	G
Total	47							
Blocks	2	0.60^{ns}	2.35^{ns}	0.15	0.06^{ns}	13.80^{ns}	1.96^{ns}	1.37^{ns}
Varieties	1	63.02^{**}	205.43^{**}	0.71^{**}	0.35^{ns}	122.24^{*}	0.09^{ns}	0.79^{ns}
Treatments	7	0.67^{ns}	0.79^{ns}	0.04	0.07^{ns}	24.77^{ns}	7.98^{ns}	7.25^{ns}
Error	37	0.61	0.98	0.05	0.10	20.27	4.33	4.79

A - Pod length of extra fine pods.

B - Pod length of fine pods.

C - Pod maximum diameter of extra fine pods.

D - Pod maximum diameter of fine pods.

E - Number of pods that snapped without protruding fibres.

F - Crude fibre content at 68 days after planting.

G - Crude fibre content at 72 days after planting.

* - Significantly different at the probability level of 5%.

** - Significantly different at the probability level of 1%.

ns - Not significant

Appendix 4: Linear contrasts (independent)

Linear contrasts	Treatments and coefficients (λ)								Group comparisons						
	I	C	D	R	C+D	C+R	D+R	C+D+R							
C	-	+	-	-	+	+	-	+	C	C+D	C+R	C+D+R vs I	D	R	D+R
D	-	-	+	-	+	-	+	+	D	C+D	D+R	C+D+R vs I	C	R	C+R
R	-	-	-	+	-	+	+	+	R	C+R	D+R	C+D+R vs I	C	D	C+D
CxD	+	-	-	+	+	-	-	+	I	R	C+D	C+D+R vs C	D	C+R	D+R
CxR	+	-	+	-	-	+	-	+	I	D	C+R	C+D+R vs C	R	C+D	D+R
DxR	+	+	-	-	-	-	+	+	I	C	D+R	C+D+R vs D	R	C+D	C+R
CxDxR	-	+	+	+	-	-	-	+	C	D	R	C+D+R vs I	C+D	C+R	D+R

C - Calcium ammonium nitrate.
D - Diammonium phosphate.
R - Seed inoculation.
I - Control.

Appendix 5: **Coefficients of Variation**

The high coefficients of variation (CVS over 15%) obtained in this study could have arisen because large quantities of French bean material were handled during each sampling and harvesting time. Errors could also have arisen because of working with different people each time. However,the CVS are within the range of those obtained from similar studies on beans for example that of the grain legume project (Anon., 1974) and at Kabete (Mbugua, 1983). Beans are also prone to many external factors such as water stress, vermins, pests and diseases, the effects of which are reflected in the high CVS.

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