UNIVERSITY OF MANITOBA

THE EFFECT OF FERTILIZER NITROGEN ON YIELD, CRUDE PROTEIN CONTENT, AND SYMBIOTIC FIXATION IN *VICIA FABA* L. VAR. *MINOR*

by

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ABSTRACT

The effect of placement, rates of application, time of application, and split application of nitrogen fertilizer upon growth, yield, crude protein content, and symbiotic nitrogen fixation in fababeans were studied in field and growth chamber experiments. Tracer ^{15}N was used in some experiments to determine the amount of nitrogen fertilizer taken up by fababeans.

Regardless of rate of nitrogen application (up to 300 kg N/ha), method of application (drilled in with the seed or surface broadcast), or time of application, yield and quality of nodulated fababeans were generally unaffected. Yields and protein content of unnodulated fababeans and/or barley were increased by nitrogen fertilization on all but one site which was very high in available nitrogen.

Evidence indicates fababeans were as adept as barley in recovering applied nitrogen fertilizer, and in adsorbing soil nitrogen. Late season fertilizer nitrogen additions were more efficiently recovered by effectively nodulated fababeans than fertilizer nitrogen applied at seeding. Accumulated evidence indicate fababeans preferentially feed from soil and/or fertilizer nitrogen sources.

Fababeans were shown to be capable of symbiotically fixing substantial quantities of nitrogen. Nodulated fababeans grown in control treatments in field trials symbiotically fixed 54% of their above-ground nitrogen content. Values in individual trials ranged from 0 to 71%,

however five out of seven plots had values in the range of 63 to 71%. Fababeans grown in the control treatment in a growth chamber experiment symbiotically fixed 87.1% of their plant nitrogen, or 708.3 mg N/Plant. In a growth chamber experiment fababeans were found to have symbiotically fixed at least 28% of their nitrogen from early pod-fill to senescence. Fertilizer nitrogen applications were found to decrease the amount of nitrogen symbiotically fixed by fababeans. Evidence indicates the decrease was inversely proportional to the quantity of soil and fertilizer nitrogen taken up into the fababean.

Results indicate that effectively nodulated fababeans were efficient symbiotic nitrogen fixers, and that fertilizer nitrogen additions tended to decrease symbiotic nitrogen fixation while having no effect upon grain yield and protein content. Therefore, in Manitoba, nitrogen fertilization of effectively nodulated fababeans is not recommended.

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I INTRODUCTION

In 1973 the Faculty of Agriculture at the University of Manitoba commenced a three year multi-disciplinary project in which the production, utilization, and marketing of Vicia faba L. var. minor was studied. This project represents part of the contribution made by the Department of Soil Science.

Fababeans (Vicia faba L. var. minor) have a potentially high seed yield and protein content, and under favorable conditions can produce as much protein per hectare as soybeans. Protein contained in fababean seed is similar to soybean seed protein and hence replacement of U. S. grown soybean seed meal by Canadian grown fababean meal is feasible. Fababeans are a member of the Leguminosae family and are capable of establishing a symbiotic relationship with bacteria of the genus Rhizobia, a relationship in which elemental nitrogen is transformed into plant available nitrogen. As a result of this relationship supplemental fertilizer nitrogen additions have been considered unnecessary for attainment of maximum seed yield and protein content. In 1972 fababean field trials conducted by the Manitoba Department of Agriculture, found that fababeans which were grown in non-fallow land responded to supplemental fertilizer nitrogen additions, indicating that fababean symbiotic nitrogen production was not sufficient for plant needs (Rogalsky, 1972).

In order to elucidate fababean nitrogen requirements, the effects of various rates, methods of application, and times of nitrogen fertilizer addition upon yield, percent protein content, and symbiotic nitrogen fixation in fababeans were studied.

II LITERATURE REVIEW

Fababeans (Vicia faba L. var. minor) were introduced into Manitoba in 1970 in an attempt to alleviate local crude protein shortages and to diversify Manitoba agriculture. Fababeans are tall, upright, annual grain legumes capable of achieving grain protein contents ranging from 23 to 32 % (protein contents were based on oven dry moisture basis, Percent protein = 6.25 x %N), (Evans et al., 1972). Fababeans possess the potential to form a symbiotic relationship with bacteria of the genus rhizobia, in which elemental nitrogen is reduced to NH_3 which is readily incorporated into plant protein. This is termed symbiotic nitrogen fixation, and occurs in nodules initiated and inhabited by rhizobia. The nodules are located in some of the legume's roots.

Since most legumes have high protein contents, the plant exerts a large demand upon available sources of nitrogen. The production of a 4820 kg/ha grain yield of fababeans required 229 kg N/ha (McEwen, 1970). A 3362 kg/ha crop of soybeans (Glycine Max L. var. merrill) required 314 kg N/ha of which one-third to one-half of the plant nitrogen was derived from symbiotic nitrogen fixation (Ohlrogge, 1963). Weber (1966) calculated that a 2750 kg/ha crop of soybeans removed 215 kg N/ha of which 40% was symbiotically fixed.

Lathwell and Evans (1951) reported that approximately

50% of nitrogen in mature soybeans was in the pods. DeMooy et al., (1973) stated that 80% of soybeans' total symbiotically fixed nitrogen was fixed during the floral initiation to senescence stages, with the greatest requirement for nutrients occurring during the full bloom to full pod stages (Saltanov et al. 1974). Thus in soybeans the majority of the total seasonal nitrogen uptake occurs during a relatively short time, and in some cases the demand for nitrogen exceeds the supply, resulting in nitrogen deficient plants.

Nitrogen is an intrinsic component of yield and protein content of legumes. Since symbiotically fixed nitrogen is the major source of legume nitrogen, adverse environmental factors which affect legume nodulation and/or subsequent nodule functioning may also affect the probability of legume responses to nitrogen fertilization.

Soil pH has been reported to have multifold affects upon legume nodulation. Soil acidity has been shown to be one of the factors most limiting rhizobia viability in the rhizosphere. Provided Ca is adequate failure of legumes growing in acid soils to nodulate has been found to be due mainly to poor survival and/or proliferation of the rhizobia in the rhizosphere (Vincent, 1965). Lucerne and red clover have been reported to grow well in soil of pH 6 or higher, though some white clovers and subterranean clovers have been shown to be capable of fixing nitrogen in soils of pH 4.2 to 4.5 (Russell, 1973). The optimum pH for soybean growth based on multiple regression equations involving yield and soil pH observations was calculated to be 6.2 (de Mooy et al., 1973). In Alberta, Penny (1974) reported fababean symbiotic nitrogen fixation was reduced when fababeans were grown in a soil with a pH of 5.7, however yield of fababeans was not increased by nitrogen fertilization, suggesting that other environmental factors were limiting yield. Adverse soil reaction also affects the availability of nutrients important to the fixation process. Low soil pH renders molybdenum unavailable, thus legumes grown in acid soils have been occasionally found to be nitrogen deficient. Soil pH also affects the availability of phosphorus to legumes thus indirectly affecting legume nodulation. Thus it appears that the main effects of adverse soil pH upon symbiotic nitrogen fixation are upon rhizobia survival and upon nutrient availability.

Soil temperature has been found to be a controlling factor in symbiotic nitrogen fixation. In trifolium species the optimum soil temperature was shown to be 20°C. Increasing soil temperature resulted in increased nodulation but in reduced symbiotic nitrogen fixation. This was attributed to high soil temperature disturbing the proper functioning of the nitrogen enzyme system (Stewart, 1966). Nitrogen fixation, plant dry weight, and net photosynthesis in three week old soybeans were increased when soil temperature was raised to 27° from 15.6°C, however soil temperatures higher than the optimum of 27°C resulted in decreased symbiotic nitrogen fixation (Kuo and Boersma, 1971). Soil temperatures of 4 to 5°C have been reported to delay nodulation and nitrogen fixation in *Vicia faba* L. by 12 to 52 days (Korvin *et al.*, 1966), however *V. faba* symbiotically fixed some nitrogen at all temperatures in which it could grow. Korvin's study indicated that *V. faba* plants grown in low soil temperature environments were not nitrogen deficient, thus the probability of obtaining a response to applied nitrogen fertilizers due to reduced symbiotic nitrogen fixation resulting from adverse soil temperature is low.

Soil moisture was reported to have a major influence upon fababean production in Manitoba (Keatinge, 1975). Kuo and Boersma (1971) decreased the rate of nitrogen fixation in three week old soybeans by 41.5% by increasing soil moisture tension from 0.35 bars to 2.5 bars. They also recorded a corresponding 56% decrease in dry matter production. Lyons and Early (1952) increased yield of field grown soybeans during a hot, dry summer by adding nitrogen fertilizers, though nitrogen applied to soybeans grown during a summer with normal precipitation patterns had no affect upon grain yield. Soil moisture stress appeared to have affected symbiotic nitrogen fixation before affecting potential plant growth. Many investigators reported that nitrogen fertilizers increased yield and protein content of soybeans grown during the dry summer of

1967 in U.S.A. (deMooy *et al.*, 1973). Thus legumes grown in semi-arid areas may occasionally require supplemental nitrogen fertilization.

Soil salinity affects nodulation and nitrogen fixation in legumes. Bernstein and Ogata (1966) studied the effects of various levels of salinity upon nodulation, nitrogen fixation, and growth of *Medicago sativa* cv Common and *Glycine max* cv Lee. They found that salinity specifically inhibited nodulation of these cultivars, even when root growth approximated a normal level. Nodule weight of soybeans was depressed to 23% of control, while nodule weight of alfalfa was depressed to 80% of control. When NO_3 was applied to soybeans the relative decrease in aerial yield due to increased salinity levels was less than for control soybeans which had received no supplemental nitrogen. Thus yield of soybeans grown in saline soils were increased by nitrogen fertilization.

High symbiotic nitrogen fixation occurs only when the legume is adequately supplied with all the essential nutrients, however rhizobia bacteria have a specific demand for some nutrients which exceeds plant demand. Calcium was found to be an important factor in controlling legume nodulation. The concentration needed for adequate nodulation was shown to be higher than the concentration needed for maximum rhizobia and plant growth (Vincent, 1965). Legumes require large quantities of Mo, most of which is used by the nodules to produce leghaemoglobin. Soil deficiencies of molybdenum initially affect nodule functioning by causing a lack of leghaemoglobin, hence reducing nitrogen fixation (Vincent, 1965). Severe molybdenum deficiencies result in physiological deficiency symptoms being observed on the plant. Thus superficially the molybdenum deficient legume appears to be nitrogen deficient and in fact Parker and Harris (1970, from deMooy et al., 1973) found that molybdenum deficiencies in soybeans grown in an acid soil (pH of 5.3) were equally corrected by 70 g/ha of sodium molybdate or 134 kg N/ha. Boron deficiencies interfere with nodule functioning by limiting the development of the vascular tissue between the nodule and root hence interrupting the transfer of fixed nitrogen into the plant (Russell, 1973). Legumes require large quantities of phosphorus for adequate nodule development. Soybean nodule number and weight have been increased by a factor of 2 to 22, with the nitrogen fixing activity of the nodules being increased by 2.5 fold at the end of flowering when phosphorus was applied at seeding (deMooy and Pesek, 1966). Deficiencies of many nutrients adversely affect nodulation and/or nodule functioning before affecting plant growth per se, hence legumes express nitrogen deficiency as a direct result of the unavailability of some nutrient needed in the formation and/or functioning of the legume's nodules. In these cases deficiency can be corrected by nitrogen fertilization or by the addition of the deficient nutrient.

Inorganic soil nitrogen can affect legume nodulation. Low concentrations of inorganic soil nitrogen have been shown to stimulate legume nodulation (Beard and Hoover, 1971; Richardson et al., 1957). Medium concentrations of inorganic soil nitrogen have had no consistent effect upon nodulation, though high concentrations of inorganic soil nitrogen have been reported to have deleterious effects upon legume nodulation.

High concentrations of inorganic nitrogen have been reported to initially reduce size and weight of legume nodules, with further additions causing a reduction in nodule number (Weber 1966; Ham et al., 1975). Thus Weber (1966) reported that the application of 56, 112, 168 kg N/ha at seeding caused a progressive reduction in nodule tissue formed in field grown soybeans. When 4370 kg/ha of ground corn cobs (*Zea Mays* L.) were added to the soil in an attempt to immobilize some of the soil inorganic nitrogen, 672kg N/ha fertilizer had to be added in order to give the same degree of inhibition 168 kg N/ha had previously given when no corn cobs were mixed into the soil.

Inorganic nitrogen additions have reduced nodulation of fababeans grown in growth chamber experiments (Moukova et al., 1968; Kralova et al., 1974). Application of 336 kg N/ha surface broadcast at seeding decreased nodulation in field grown fababeans by 50% (McEwen,1970).

Application of nitrogen at seeding significantly reduced numbers, size and distribution of nodules in soybeans, lespezda and sweet clover grown in pots. Midseason nitrogen applications however had no affect upon nodule mass, but did significantly increase aerial soybean yield, indicating that soybeans could not fix all their nitrogen requirements during the later stages of growth (Thornton, 1946). Allos and Bartholomew,(1959) observed that the size and number of nodules were not decreased by combined nitrogen until the combined nitrogen additions approached the amount of nitrogen needed by the plant for maximum growth.

Beard and Hoover (1971) reported that 112 kg N/ha broadcast at flowering onto soybeans had no effect upon nodulation, while the application of 56 kg N/ha at seeding decreased nodule number. Therefore literature indicates that only high concentrations of inorganic nitrogen present in the nodulating zone during nodule initiation stages are deleterious to nodule mass, therefore midseason nitrogen applications have had no consistent effect upon nodule mass. An inverse linear relationship significantly at 1% probability level between number of nodules formed and the rate of nitrogen application was found to exist in soybeans (Beard and Hoover, 1971). A similar relationship was observed in Phaselous vulgaris L. where nodule number was inversely correlated to levels of soluble and inorganic nitrogen compounds in the plant tissue

(Cartwright, 1967).

Quantities of nitrogen symbiotically fixed by soybeans were found to be closely correlated (r=0.9) to nodule mass (Weber, 1966). Since the number of nodules formed in soybeans were shown to be inversely proportional to the quantity of inorganic soil nitrogen present (Beard and Hoover, 1971), it can be postulated that the quantity of inorganic nitrogen symbiotically fixed by soybeans is inversely proportional to the quantity of nitrogen present in the rhizosphere, and indeed this was reported to occur in soybeans (Allos et al., 1955). Thus after the legume's nitrogen requirements were satisfied addition of inorganic nitrogen only resulted in decreased symbiotic nitrogen fixation.

Methods of nitrogen fertilizer placement affect nodulation to different degrees. The method of placement which results in the highest inorganic nitrogen concentration in the nodulation zone appears to cause the greatest degree of inhibition of nodulation. McEwen (1970) showed that sidebanded nitrogen fertilizers were more deleterious to field grown fababean nodulation than surface broadcast fertilizer nitrogen, indicating that the sidebanded nitrogen application resulted in an initially higher inorganic nitrogen concentration in the nodulation zone than did surface broadcast nitrogen method of placement. Harper and Cooper (1971) showed that deep placed nitrogen fertilizer was less deleterious to nodulation of soybeans than nitrogen which had been mixed uniformly throughout the nodulation zone, thus indicating that the deep placed nitrogen was effectively below the nodulation zone.

The form of the nitrogen fertilizer used has also been shown to influence nodulation of legumes. Nitrate or nitrite forms of nitrogen have been shown to have a more inhibitory effect upon nodulation than ammonium (Dialtoff, 1968; Richardson et al., 1957). Dialtoff (1968) reported that 168 ppm of NO_3 inhibited nodulation of excised soybean roots, while 224 ppm NH_4 caused only partial inhibition. KNO_3 was reported to have inhibited fababean nodulation to a greater extent than did $(NH_4)_2SO_4$ (Mouchova, et al., 1974).

The mode of inhibition is uncertain. In the past carbohydrate to nitrogen ratios were regarded as the most important factor governing inhibition of nodulation. The theory postulated that the attraction of rhizobia to plant roots was caused by excretion of carbohydrates from the host plant's roots into the rhizosphere. Failure of host legumes to nodulate when grown in environments containing high quantities of inorganic nitrogen was attributed to large quantities of nitrogen being assimilated by the plant which tied up plant carbohydrates by forming proteins, thus preventing carbohydrate excretion from the roots. Recently, it has been considered that nodule inhibition is caused by external localized factors, and not by internal factors such as carbohydrate to nitrogen ratios.

Raggio, Raggio and Torry (1957) observed that when NO_3 was added to a bathing medium containing excised roots reduced nodulation occurred. However when nitrogen was introduced directly into the root via the base no decrease in nodulation occurred, indicating that the carbohydrate to nitrogen ratio theory was invalid. Tanner and Anderson (1963) advanced a theory which attributed the decrease in nodulation to specific localized effects. They considered that NO_2 which had been reduced from NO_3 by the rhizobia led to the destruction or reduction in the formation of indole acetic acid, an auxin which is thought to play a prominent role in the invasion of the legume's lateral roots by the rhizobia.

Rapid initial growth of legumes is partially dependent upon the presence of sufficient available nitrogen in the growth media (Hatfield et al., 1974, Russell, 1973). Low rates of nitrogen application have increased growth rate and nodulation of legumes grown in nitrogen deficient media (Hatfield et al., 1974; Richardson et al., 1957). In growth chamber experiments fast growing legumes, such as pisum and vicia spp., grown in soils containing less than 20 to 25 mg N/kg soil had their initial growth increased by the addition of small quantities of nitrogen at seeding (Trepachev et al., 1973). Low nitrogen application rates had no effect upon the growth rate of deep rooted, slow growing legumes such as lupin and clover, indicating that the nitrogen fertilizers were used to supply the fast growing legume with nitrogen before symbiotic nitrogen fixation was occurring rapidly.

Low rates of nitrogen fertilizers applied to legumes at seeding have been reported to increase total plant nitrogen by more than the quantity of nitrogen applied. Allos and Bartholomew (1959) reported that the addition of 80 mg nitrogen at seeding increased the nitrogen content in soybeans by 121 mg N, in alfalfa by 98 mg N, and in ladino clover by 109 mg N. Presumably this starter effect was caused by the inorganic nitrogen fertilizer delaying legume nodulation during the early stages of legume growth. While nodulation was delayed the legume root grew in an environment containing adequate nitrogen, thus when nodulation occurred there were more potential sites for bacterial invasion to occur (Vincent, 1965). Recently, Hatfield et al, (1974) reported that soybeans which had to rely entirely on seed and nodule nitrogen exhibited lower dry weight, and nitrogen uptake than did soybeans which had received low amounts of combined nitrogen at seeding. Low rates of nitrogen fertilization have increased nodulation and total nitrogen in fababeans grown in sand cultures (Nowtony et al., 1972), in six-week old alfalfa (Richardson et al, 1957), and have been useful in the amelioration of retarded symbiosis in Glycine weightii, a small seeded legume, grown in nitrogen deficient media (Dialtoff, 1974). Thus nitrogen applications at seeding have increased the initial growth, nodulation and hence symbiotic fixation in legumes. The increase appears to be more pronounced in smaller seeded legumes which contain only limited quantities of seed nitrogen. Data indicate the degree of response is partially correlated to the quantity of nitrogen initially available to the nodulating legume. Therefore faster growing, deeper rooting legumes, and/or legumes possessing small seeds and/or legumes in which nodulation occurs slowly appear to profit from nitrogen fertilization.

Yield and grain protein content of field grown soybeans were increased by small quantities of nitrogen applied at seeding in Minnesota (Ham *et al.*, 1975). In Western Nigeria 30 kg N/ha applied at seeding to field grown soybeans were required for attainment of maximum yield (Kang, 1975). However in Illinois nitrogen fertilizers applied at different rates at seeding and at other times during the growing season, and by different methods of application significantly increased soybeans' grain yield in only 3 out of 133 instances (Welsh *et al.*, 1973). Seed yield of *Pisum sativa* L. in Manitoba was not affected by nitrogen fertilizers applied at seeding though application of fertilizers significantly decreased plant population (Racz, 1970). Thus low quantities of nitrogen applied at seeding have had variable effects upon legume grain yield. When nitrogen fertilization of annual grain legumes was not beneficial it was considered that soil nitrogen was ample enough to meet the grain legume demand for supplemental nitrogen (Ham *et al.*, 1975).

Effectively nodulated legumes can not symbiotically fix their total nitrogen demand. Norman and Krampitz (1946) reported that soybeans did not achieve maximum yield when relying predominantly upon symbiotic nitrogen fixation to supply their nitrogen demands. Ham *et al.*, (1975) considered that seed yield and/or protein contents of higher yielding soybean varieties may be increased by nitrogen fertilization. Trepachev *et al.*, (1973) reported that annual legumes grown in a nitrogen deficient soil but in an otherwise normal environment symbiotically fixed 90 to 95% of their total nitrogen demand. In smaller seeded legumes such as alfalfa and *Glycine weightii* the greatest demand for supplemental nitrogen has been found to occur during the initial stages of growth, while in larger seeded legumes such as soybeans this demand occurred during the floral initiation stages (Thornton, 1946).

Legumes appear to preferentially feed from combined nitrogen sources. That is, nitrogen which is associated with another element or compound. The proportion of plant nitrogen derived from symbiotic nitrogen fixation has been shown to decrease as soil nitrogen increases, the decrease being inversely proportional to the amount of inorganic soil nitrogen present (Allos and Bartholomew, 1955, 1959). When corn cobs were added to Iowa soils in an attempt to decrease soil inorganic nitrogen soybean symbiotic nitrogen fixation was increased from 159 kg N/ha to 179 kg N/ha (Weber, 1966). Sears and Lynch (1951) reported that soybeans fixed 20% of their total nitrogen requirements when grown in soils containing high concentrations of available nitrogen. Upon the addition of ground oat straw (*Avena sativa* L.) the proportion of soybean nitrogen derived from symbiotic nitrogen fixation was increased to 66%.

Large variances in the estimation of the quantity of nitrogen symbiotically fixed by annual grain legumes exist due to differences in patterns of soil nitrogen release, and differences in the microenvironments of the experiments. In temperate climates field grown soybeans have been consistently reported to fix approximately 50% of their nitrogen requirements. Weber (1966) reported that soybeans grown in soil of normal inorganic nitrogen contents in Iowa symbiotically fixed 40% of their nitrogen requirements on the average. Values from individual plot sites ranged from 1 to 70%, with the variation in symbiotic nitrogen contribution to total plant nitrogen being dependent upon quantity and availability of soil nitrogen and water. Norman (1944), and Norman and Krampitz (1946) using ^{15}N determined that soybeans grown in a prairie soil of average fertility in Iowa (about 112 kg N/ha is nitrified in a growing season) derived 25 to 35% of their nitrogen requirements from symbiotic fixation. Differences in Iowa soybean yields, they reasoned, were due to changes in the available nitrogen content of the soil, and in the patterns of nitrogen release.

Lyon (1936), in a classic field experiment reported that soybeans, fababeans, and peas grown for grain symbiotically fixed between 123 to 246 kg N/ha, which was approximately the amount of nitrogen removed in the grain. Lyon observed that all grain legumes depleted soil nitrogen reserves to the same extent cereal crops did. McEwen (1970) stated that the nitrogen in fababean grain was equal to the amount of nitrogen symbiotically fixed, which was 146 to 212 kg N/ha in his experiments.

The amount of nitrogen which can be symbiotically fixed by a legume crop is highly dependent upon the longevity of its nodules. Since nitrogen availability during later growth stages has been found to increase pod set and hence grain yield in soybeans (Lathwell and Evans, 1951, Stamp, 1972, Sinclair and deWit, 1976), and in Phaseolus vulgaris L. (Asif, 1972) determination of the time of nodule senescence, and subsequently factors which prolong nodule functioning are of great agronomic interest.

Symbiotic nitrogen fixation in a number of grain legumes ceases during flowering and early pod-filling stages (Russel, 1973). This is accompanied by leaf drop and a corresponding decrease in plant carbohydrates (Lathwell and Evans, 1951, Pate and Dart, 1961). Presumably the developing pods become the major available nitrogen and photosynthate sink, thus resulting in nodule senescence (Thibodeau, et al., 1975). This results in breakdown of foliar proteins causing a metabolic slow down which decreases uptake and translocation of essential nutrients from soil to developing pods, thereby resulting in reduced yield and/or protein content at time of crop maturity. Recently, Sinclair and deWit (1976) postulating that soybean seed yield was limited by the translocation of available nitrogen from vegetative tissues to the developing seeds, developed a dynamic simulation model which accounted for the availability of nitrogen and photosynthate within soybeans during the pod-filling stage. The simulation model showed that duration of seed fill was limited by intra-soybean nitrogen translocations, and that increased levels of available nitrogen within the soybean plant during pod-filling stages were required for increased soybean yields.

Annual grain legumes have been shown to have their greatest requirement for nutrients during the bloom to full pod stages (Saltanov and Kuzin, 1975; Hanway and Weber, 1971). In soybeans 50% of the total plant nitrogen was located in the pods at maturity (Lathwell and Evans, 1951). When supplemental nitrogen was not applied during pod formation large quantities of nitrogen were drained from the leaves and stems to the pods, resulting in reduced yield. In other attempts to increase the longevity of nodules in field grown soybeans large quantities of nitrogen were applied at mid-pod stage, however translocation of nitrogen from leaves and stems to the developing pods occurred. The translocation of nitrogen within the soybean plant during pod formation was observed to occur even when soybeans were grown in soils containing large quantities of available nitrogen (Hanway and Weber, 1971). Recently, split foliar fertilization of soybeans with a N,P,K,S mixture during pod set stages has been found to decrease leaf drop, and increase yields of seed (J.J. Hanway, pers. comm., 1976[1]; Garcia and Hanway, 1976) with the increased grain yield being mainly attributed to increased nodule longevity.

The situation as to the time of nodule senescence in fababeans remains confused. Candlish and Clark (1975), employing acetylene-ethylene reduction techniques determined that fababeans had the potential to fix nitrogen after pod formation. Cojeneau et al., (1968) found a significant reduction in fababean nodule numbers occurring during the flowering and beginning of pod formation stages.

A few investigators have reported fababeans not to be particularly efficient in fixing nitrogen. Rogalsky (1972) in Manitoba and Sadler (1975) in Saskatchewan reported that fertilizer nitrogen surface broadcast at seeding significantly increased fababean seed yield. Kralova and Mouchova (1974) reported that maximum aerial yield of fababeans harvested at flowering occurred when 105 to 210 mg N/kg soil were added. They also observed that fababeans grown in higher nitrogen application treatments had less nodules than fababeans grown in control treatments.

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Most reports, however, suggest that fababeans are efficient symbiotic nitrogen fixers. McEwen (1970) reported that 112 and 224 kg N/ha surface broadcast at seeding had no effect upon fababean seed yield and crude protein content. High rates of nitrogen fertilizer 336 kg N/ha), in excess of that which could be symbiotically fixed by fababeans, resulted in seed yield increases of less than 10%, and had no effect upon crude protein content. Single large (112, 224 and 336 kg N/ha) late season fertilizer nitrogen applications, and split applications of fertilizer nitrogen had no effect upon fababean seed yield and crude protein content. McEwen concluded that in the environmental conditions encountered during the course of the experiment, symbiotic nitrogen fixation in fababeans was not limiting seed yield and crude protein content. Bailey (pers.comm., 1976)[1] in Manitoba, Penney (1974) in Alberta, and Bishop _et al._ (1976) in Nova Scotia reported that no rate of nitrogen fertilizer applied at seeding had an effect upon yield and protein content of field grown fabsbeans.

Moukova (1968) reported that increasing increments of nitrogen applied at seeding to fababeans grown in pots had no effect upon aerial yield at flowering. In field and growth chamber experiments neither nitrogen applied at seeding, in split applications, or in large applications at

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flowering or at pod formation had beneficial effects upon yield and protein content of fababean seed (Rinno *et al*., 1973). However, in identical experiments conducted with *Pisum sativum* L. and *Pisum arvense* L. aerial yields were significantly increased by single large applications of fertilizer nitrogen at flowering and pod formation stages. It was concluded that fababeans were more efficient symbiotic fixers than other legume species, and appeared to fix nitrogen throughout their growth cycle.

III METHODS AND MATERIALS

A. FIELD TRIALS

Field experiments where the effects of placement, rates of application, split applications and time of nitrogen application on yield, protein content and symbiotic nitrogen fixation in fababeans were conducted during the summers of 1973, 1974 and 1975. A nine-row, double disk, Allis Chalmers press drill with an eighteen centimeter row spacing was used to seed fababeans. Fababeans were seeded at a rate of two hundred kilograms of inoculated seed per hectare and were seeded to a depth of seven to ten centimeters. In order to insure adequate nodulation Nitrogin Corporation Q culture[1] inoculum was applied in a slurry at the recommended rate of 418 grams per 100 kg fababean seed prior to seeding. All 1973 experimental sites and the Altona site in 1974 were seeded to Ackerperle variety fababeans. Diana variety fababeans were sown at the remaining 1974 sites and at all sites in 1975. Phosphorus was drilled in with the seed. In 1973 phosphorus as monoammonium phosphate was drilled in with the seed at 10 kg P/ha. In 1974 and 1975 phosphorus as triple super phosphate was drilled in with the seed at a rate of 15 kg P/ha and 20 kg P/ha respectively. In 1975 potassium as KCl was surface broadcast at a rate of 100 kg K/ha at experimental sites where soils contained less

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[1] Supplier: Nitrogin Co., Milwaukee, Wisconsin, 53209, U.S.A.

than 100 ppm NaOAc exchangeable potassium. Sulfur as $CaSO_4 \cdot 2H_2O$ was surface broadcast after seeding at a rate of 30 kg S/ha at the Teulon site in 1975 as initial soil testing data indicated that the soil at Teulon was low in SO_4-S.

Field trials were of a randomized complete block design consisting of five replicates. Blocks were separated by a 1.5 meter roadway. In the 1973 and 1974 field trials individual plots were nine rows (1.62m) wide and six meters long. In 1975 individual plots were nine rows (1.62m) wide and nine meters long, enabling frequent sampling of individual plots throughout the growing season.

Soils at experimental sites were sampled at seeding in order to determine soil chemical characteristics. Soils were sampled at the four corners of the experimental plot and in several random locations within the experimental plot in the following depth increments: 0-15 cm, 15-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm. Soils were placed in plastic bags, and several drops of toluene were added to each sample to arrest nitrification. Soils were later subdivided, with one subsection being air dried, and the other subsection being oven dried at 105° C. When oven space was not immediately available soils were frozen. Oven dried soil samples were used for nitrate-nitrogen and moisture determination, and air dried samples were used to determine other soil chemical properties. Description of methods used in soil analysis are presented in the

Analytic Procedures subsection.

FIELD TRIALS - 1973

In 1973 three field experiments were sown to Ackerperle fababeans in early May. The objectives of the field experiments were:

1. To determine yield and protein content of fababeans at various rates and placements of nitrogen, phosphorus, potassium, and sulfur fertilizers.
2. To study the effects of carbonated and non-carbonated soils upon yield response of fababeans to nitrogen, phosphorus, potassium, and sulfur fertilizers.
3. To determine nutrient uptake by fababeans.
4. To study the effect of drilled compared to broadcast potassium on fababean germination and yield.

In order to achieve the desired objectives three field experiments, two located on non-carbonated soils and one located on a carbonated soil were sown. However due to severe wild mustard (*Brassica nigra* L.) one of the experiments on a non-carbonated soil was abandoned. The experiment consisted of fifteen fertilizer treatments, containing various combinations of nitrogen, phosphorus, potassium and sulfur fertilizer (Table 1). Since only the effect of nitrogen fertilizers upon fababean growth performance was of immediate concern

TABLE 1

Fababean Fertility Treatments used in 1973 Field Trials.

Treatment number	Nutrient Applied (kg/ha)			
	nitrogen	phosphorus	potassium	sulfur
1	0	0	0	0
2	0	10D[1]	84D	20B[2]
3	34B	10D	84D	20B
4	67B	10D	84D	20B
5	202B	10D	84D	20B
6	34D	10D	84D	20B
7	67D	10D	84D	20B
8	34B	0	84D	20B
9	34B	20D	84D	20B
10	34B	10D	84D	0
11	34B	10D	0	20B
12	34B	10D	14D	20B
13	34B	10D	28D	20B
14	34B	10D	28B	20B
15	34B	10D	56B	20B

1: D designates fertilizer drilled in with the seed

2: B designates fertilizer surface broadcast after seeding to this study the results of only six treatments are discussed. The treatments considered were numbers 2, 3, 4, 5, 6, 7. Nitrogen fertilizers, as NH_4NO_3, were either surface broadcast at seeding at 34, 67 and 202 kg N/ha or were drilled in with fababean seed at rates of 34 and 67 kg N/ha. Since a control treatment (#2) was also included in the experimental paragin, the effect of rates and placement of nitrogen fertilizers on fababean seed yield, protein content, and total nutrient uptake were determined from data obtained from two experimental sites.

FIELD TRIALS - 1974

The objectives of the 1974 field program were:

1. To determine yield and protein contents of fababeans at various rates of nitrogen fertilizer.
2. To determine seasonal nutrient uptake patterns and dry matter accumulation by fababeans, and to study the effect of fertilizer nitrogen upon these characteristics.
3. To determine efficiency of fertilizer nitrogen uptake by fababeans.
4. To determine the effect of nitrogen fertilizer upon yield and protein contents of uninoculated fababeans, and to compare seasonal nitrogen uptake by uninoculated fababeans to that of barley grown in similar fertility treatments.
5. To determine the quantities of nitrogen symbio-

tically fixed by fababeans, and elucidate the effect of nitrogen fertilizer upon fababean nitrogen fixation.

In order to achieve the desired objectives three field trials located at Altona, Pilot Mound and Seven Sisters were sown to fababeans on May 27 at Altona, June 1 at Pilot Mound, and June 10 at Seven Sisters, dates later than recommended. The late seeding was caused by an unfavorably wet spring, and the need to share seeding equipment.

Rates of nitrogen, as NH_4NO_3, surface broadcast at seeding were used to determine the effect of various levels of nitrogen on fababean yield and protein content. The rates used are presented in Table 2a. These treatments were located at all three experimental sites. In order to study the effect of rates of nitrogen on fababean nutrient uptake and dry matter accumulation, these treatments were sampled forty (40) and seventy (70) days after seeding and at maturity. Fababeans harvested forty days after seeding were in the floral initiation to pre-bloom growth stages, and fababeans harvested seventy days after seeding were in the post-bloom to early pod-filling stages. These harvest times were selected on basis of soybean data which indicate these stages are "nitrogen critical stages", stages in which growth and nitrogen uptake are at a maximum.

In order to determine the effect of nitrogen fertil-

TABLE 2a

General Fababean Fertility Treatments Used in 1974 Field Trials.

Treatment Number	Nitrogen Applied (kg N/ha)
1	0
2	30*
3	60
4	90*
5	150
6	300

* indicates nitrogen fertilizer enriched with ^{15}N at Altona.

TABLE 2b

Continuous Sampling Treatments Included in Experimental Paragin in Altona and Seven Sisters Field Trials 1974.

Treatment Number	Nitrogen Applied (kg N/ha)	Harvest Time (days after seeding)	
		Seven Sisters	Altona
7	0	25	27
8	0	38	41
9	0	52	55
10	0	71	69
11	0	78	75
12	0	109	97
13	90	25	27
14	90*	38	41
15	90*	52	55
16	90	71	69
17	90*	78	75
18	90	109	97

* indicates nitrogen fertilizer enriched with ^{15}N at Altona

TABLE 2c

Non-nod Fababean Fertility Experiment in Altona and Seven Sisters Field Trials 1974.

Treatment Number	Nitrogen Applied (kg N/ha)
19	0
20	90
21	300

ization on fababean dry matter accumulation and nitrogen uptake five additional 0 and 90 kg N/ha treatments were inserted into the experimental paragin at Altona and Seven Sisters (Table 2b). Commencing three weeks after seeding and continuing bi-weekly throughout the growing season these treatments were sampled for dry matter accumulation and nutrient uptake data. Times of harvest are presented in Table 2b.

In order to determine percent nitrogen fertilizer utilization by fababeans ^{15}N-labelled fertilizers were used in the 30 and 90 kg N/ha application rates in the general study (Table 2a) and in three of the 90 kg N/ha continuous sampling treatments (Table 2b) at Altona. Percent fertilizer nitrogen recovery into fababean aerial portions was determined by ^{15}N in fababean forage harvested 41, 55 and 75 days after seeding and in fababeans harvested at maturity. Enrichments used, methods of application and plant sampling techniques are discussed in the ^{15}N subsection, pages 37 and 38.

Uninoculated fababeans were sown at Altona, and Seven Sisters in order to determine the quantity of soil nitrogen taken up into fababean above-ground plant parts. In order to minimize the possibility of accidental inoculation of fababeans this experiment was seeded as a separate entity, and was separated from other fababean experiments by nine inoculated fababean guard rows (1.6m) and twenty-seven uninoculated fababean guard rows (4.9m). On the other side of the uninoculated fababean experiment barley was sown. Barley and uninoculated fababeans were separated by 18 uninoculated fababean guard rows (3.24 m) and 18 barley guard rows (3.24 m). The uninoculated fababean experiment consisted of nitrogen surface broadcast at seeding at rates of 0, 90, 300 kg N/ha (Table 2c), the highest rate was applied in an attempt to fully supply fababean's potential nitrogen uptake by inorganic nitrogen sources.

Barley (Hordeum vulgare var Conquest) was sown at all three experimental sites at a rate of 100 kg/ha and a depth of 3 to 5 cm. Barley was sown in order to compare aerial nitrogen uptake of a cereal to aerial nitrogen of uninoculated fababeans. The experiment consisted of six fertility treatments (Table 3) composed of various combinations of nitrogen and phosphorus fertilizers. The results only of treatments 24 and 25 (Table 3) which were 0 and 90 kg N/ha surface broadcast at seeding in conjunction with 15 kg P/ha drilled in with the seed will be used in this report.

TABLE 3

BARLEY FERTILITY TREATMENTS USED IN 1974 FIELD TRIALS

Treatment Number	nutrient applied (kg/ha)	
	Nitrogen	Phosphorus
22	0	0
23	90B[1]	0
24	0	15D[2]
25	90B	15D
26	0	30D
27	90B	30D

1: B designates fertilizer surface broadcast at seeding

2: D designates fertilizer drilled in with the seed

FIELD TRIALS - 1975

The objectives of the 1975 field program were:

1. To study the effect of rates of nitrogen fertilizer applied at seeding on fababean yield and protein content.
2. To study the effect of single large quantities of nitrogen applied during later growth stages on fababean growth performance.
3. To study the effect of split applications of nitrogen fertilizer on fababean growth performance.
4. To further elucidate fababean nitrogen uptake patterns.
5. To determine quantities of nitrogen symbiotically fixed by fababeans.

In order to achieve the desired objectives four field experiments located at Teulon, Carman, Zhoda, and St. Claude were sown to fababeans (variety Diana) on May 11 and 12 at Carman, May 14 at St. Claude, May 23 at Zhoda, and May 31 at Teulon. The experiments consisted of a general rate study which investigated the effect of rates of nitrogen fertilizer surface broadcast at seeding upon fababean growth performance. The rates of nitrogen fertilizer employed were 0, 30, 90 and 150 kg N/ha (Table 4a). Single dressings of 90 kg N/ha were surface broadcast at full bloom and early pod-fill stages on to plots which previously had received no nitrogen.

In order to further elucidate fababean nutrient and dry matter accumulation five additional 0 and 90 kg N/ha treatments were inserted into each replicate in the Carman field trial (Table 4b). Commencing three weeks after seeding and continuing bi-weekly throughout the course of the experiments, fababeans from these treatments were sampled for yield and nutrient uptake data. In addition, soils from these treatments were sampled to 120 cm for NO_3-N and soil moisture data. Times of harvests are presented in Table 4b. Two of the 90 kg N/ha fababean continuous sampling treatments had square meter areas in which NH_4NO_3 was enriched with ^{15}N. These treatments were harvested 49 and 77 days after seeding (Table 4b). General harvests of the 0, 30, 90 and 150 kg N/ha fababean treatments and the 0 and 90 kg N/ha barley treatments were conducted 50 and 80 days after seeding and at maturity at all experimental sites.

TABLE 4a

GENERAL FERTILITY TREATMENTS USED IN FABABEAN FERTILITY FIELD EXPERIMENTS 1975.

Treatment Number	Nitrogen applied (kg N/ha)
1	0
2	30
3	90 S*
4	150 S
5	90 F
6	90 P

S designates nitrogen fertilizer surface broadcast at seeding
F designates nitrogen fertilizer surface broadcast at full bloom
P designates nitrogen fertilizer surface broadcast at early to mid-pod-filling stage
* designates nitrogen fertilizer enriched with ^{15}N at Carman

TABLE 4b

CONTINUOUS SAMPLING TREATMENTS INCLUDED IN EXPERIMENTAL PARAGIN IN CARMAN FIELD TRIAL 1975

Treatment number	Nitrogen applied (kg N/ha)	harvest time days after seeding
8	0	21
9	90	21
10	0	35
11	90	35
12	0	49
13	90*	49
14	0	63
15	90	63
16	0	77
17	90*	77

* indicates nitrogen fertilizer enriched with ^{15}N

In order to study the effect of split applications of nitrogen fertilizer on fababean yield, protein content and fertilizer recovery a ^{15}N-labelled single fertility treatment as described by Fried et al. (1975) was incorporated into the experimental paragin at Carman. Nitrogen fertilizer applied in three split applications of 30 kg N/ha at seeding, full bloom and early pod-fill stage. In order to determine fertilizer uptake into fababean aerial portions from each application time three treatments existed. These treatments differed only in the time of ^{15}N-labelled fertilizer addition (Table 4c), at seeding in 7a, at full bloom in 7b and at early pod-fill in 7c. Physiologically these treatments were identical but isotopically these treatments differed and hence quantitative determination of the recovery of nitrogen fertilizer applied at various growth stages was accomplished.

TABLE 4c

ILLUSTRATION OF ^{15}N-LABELLED SINGLE FERTILITY TREATMENT AT CARMAN FIELD TRIAL 1975.

	Nitrogen applied (kg N/ha)		
	Time of nitrogen application		
Treatment number	Seeding	Full Bloom	early to Mid-pod filling
7a	30*	30	30
7b	30	30*	30
7c	30	30	30*

* designates nitrogen fertilizer enriched with ^{15}N

Barley was sown at all field trials in conjunction with fababeans enabling estimation of available soil nitrogen without a non-nodulating fababean isoline. Barley treatments consisted of 0 and 90 kg N/ha surface broadcast at seeding. Nitrogen carrier used was NH_4NO_3. Phosphorus, as triple super phosphate was drilled in with the seed at 20 kg P/ha. Seeding rates and other agronomic practices were similar to those used in 1974 field trials.

PLANT PREPARATION

In 1973 a three meter by two row strip of individual plots was sampled at maturity. In 1974 a 1.5m by four row strip of all treatments at all sites was sampled at floral initiation to pre-bloom (40 days after seeding), at post-bloom to early pod fill (70 days after seeding) and at maturity. In addition commencing three weeks after seeding and continuing bi-weekly throughout the growing season the extra 0 and 90 kg N/ha treatments located at

Altona and Seven Sisters were sampled for plant aerial yield and nutrient uptake data. Owing to the extreme variability of germination and in size of fababeans in the seedling state, the sampling area was three meters by four rows during the first sampling. Thereafter the sampling area used was 3 meters by two rows.

In 1975 all spring application treatments at all sites were harvested at full bloom (50 days after seeding), at early to mid pod-fill (80 days after seeding) and at maturity. Fababeans fertilized with 90 kg N/ha at full bloom and at early pod-fill, and fababeans grown in the split application treatment were sampled at maturity. Sampling area was 3 meters by two rows. At Carman the 0 and 90 kg N/ha continuous sampling treatments of fababeans were sampled for bi-weekly plant yield and nutrient uptake in the same manner described previously for 1974 continuous sampling treatments.

Plant samples were air-dried at 30°C for several days and then oven dried at 70°C for 24 hours, weighed, ground with a Wiley mill so as to pass through a 2 mm sieve. Mature fababean and barley samples were air dried, weighed threshed, grain weight recorded, and ground so as to pass through a 2 mm sieve. Percent moisture content of grain and straw samples was determined thus enabling calculation of oven dry yield. All yields are reported on an oven dry moisture basis. Total nitrogen (Kjeldahl N) was then determined using the procedure outlined in the Analytical

Methods Subsection. Percent protein was then calculated on an oven dry moisture basis. The factor used to convert percent nitrogen into percent crude protein was 5.7, that is: % Protein = 5.7 x %N.

^{15}N FIELD METHODOLOGY

Selected treatments in 1974 and 1975 had ^{15}N enriched NH_4NO_3 fertilizer[1] applied (Tables 2a, 2b, 4a, 4b, 4c). The material used was doubly labelled NH_4NO_3 having enrichments of 1.5 and 2.82 atom percent excess ^{15}N at the 90 kg N/ha and 30 kg N/ha rates, respectively. The enrichments of the labelled fertilizer nitrogen applied to fababeans were twice as high as the enrichments which would have been used for cereals. Enrichments were selected on basis of 1973 fababean nitrogen uptake data which indicated fababeans had a potential nitrogen uptake of more than double that of cereal crops. Due to the high cost of ^{15}N material only one meter squares located in the center of individual plots were fertilized with $^{15}NH_4{}^{15}NO_3$. The $^{15}NH_4{}^{15}NO_3$ was surface broadcast at seeding or in the case of the ^{15}N-labelled single fertility treatments experiment at full bloom and at early pod-fill (Table 4c). Simultaneously the remaining area of individual plots was fertilized with $^{14}NH_4{}^{14}NO_3$. In order to avoid border effects, ^{15}N plant samples were taken from several plants which had grown in the center of the ^{15}N ferti-

[1]Supplier: Azote et Produits Chemiques, Division Produits Industriels. Telex: Agroprochem - Paris

lized square meter. Yield and protein determinations were conducted upon plants harvested in the remaining area of the plots.

B GROWTH CHAMBER EXPERIMENTS

In 1974 the effect of rates of nitrogen at seeding, single large doses of nitrogen applied at critical stages of growth, and the effect of split applications of nitrogen on fababean aerial yield, percent nitrogen content, aerial nitrogen content and symbiotic fixation were studied in two growth chamber experiments. The soil used was an Ap horizon of a Stockton SiL (Ehrlich et al., 1957). The soil was neutral in pH, low in soluble salts and available NO_3-N. Other pertinent soil characteristics are discussed in Results and Discussion.

Fertility treatments used in the two growth chamber experiments were identical. Fababeans (var.Diana) grown in experiment one were inoculated with "Legumaid" Rhizobia[1]. These Rhizobia were found to be ineffective and caused great variability in experiment one data. Hence the experiment had to be repeated with an effective Rhizobia. Fababeans grown in experiment two were inoculated with "Nitrogin Corp." Rhizobia. Growth chamber experiments consisted of thirteen fababean fertility treatments, and two barley treatments. Each treatment had three replications. Individual pots contained 3000 grams of soil which

[1]Supplier: Ag. Labs. Inc., 1445 Chesapeak Ave., Columbus, Ohio, 43212, U.S.A.

had been previously ground to pass through a 2 mm sieve. In order to assure an adequate supply of macro-nutrients 50 ppm of P as KH_2PO_4, 50 ppm of S as K_2SO_4 and 185 ppm of K as KH_2PO_4 and K_2SO_4 were mixed throughout the soil in each pot one week before planting fababean seeds.

Growth chamber ambient temperatures were changed weekly to adjusted mean day and night temperatures recorded at Brandon, commencing on a simulated May 1 and ending on a simulated August 23 (115 day growing period). The formulas used to derive the adjusted mean day and night temperatures are:

$$T\ day = MT + 2/3\ (M_2 - MT)$$

$$T\ night = MT - 2/3\ (MT - M1)$$

$$\text{Where:}\quad MT = \frac{M1 + M2}{2}$$

T day = Adjusted mean day ambient temperature

T night = Adjusted mean night ambient temperature

M1 = Minimum ambient temperature

M2 = Maximum ambient temperature

The resulting adjusted mean temperature values are presented in Appendix I A. The adjusted mean temperature formula negated the effect of diurnal temperature fluctuation which occur in the field and which could not be simulated in the growth cabinets. Thus average seasonal heat units in the growth chamber were identical to average seasonal heat units received in Brandon during the selected growing season. The photoperiod used during the course of the experiment was sixteen hours of day light and eight hours of night.

Eight inoculated fababeans were sown at a depth of three centimeters into each pot. After seeding the soils were watered to field capacity, which had been previously determined to be 24.5% moisture content based on oven dry soil weight. Thereafter soil moisture content was maintained between 15% moisture and 24.5% moisture (F.C.) based on oven dry soil weight. At the time of 50% plant emergence fababeans were thinned to two plants per pot, and seeds of all other fababeans were removed, deleting a potential source of nitrogen from the growth media.

FERTILITY TREATMENTS

One week after seeding, nitrogen fertilizer in the form of NH_4NO_3 was applied to appropriate treatments with the irrigation water. Nitrogen fertilizer was applied at this time rather than at seeding in an attempt to minimize antagonistic effects between NH_4^+ and the K^+ fertilizer ions which had been added one week prior to seeding. Fertility treatments used are presented in Table 5. Experiments consisted of four parts, a general rate study, a time of nitrogen application study, a split N application study, and a barley study. All nitrogen fertilization treatments were tagged with ^{15}N. Fertilizer nitrogen was applied at rates of 0, 75, 150, 300, 600 and 900 mg N/Pot at seeding. An attempt was made to determine if fababeans could effectively use more nitrogen than they could symbiotically fix. The stimulatory effect which small amounts of nitrogen have been reported to have upon symbiotic fixation in legumes was studied by the 75 mg N/Pot treatment. The 900 mg N/Pot treatment was used to determine the maximum quantity of nitrogen which potentially could have been assimilated by fababeans. The use of ^{15}N fertilizer permitted quantitative determination of the proportion of plant nitrogen derived from fertilizer nitrogen and from symbiotic and soil nitrogen. Thus the effect of increasing increments of nitrogen fertilizer upon fababean symbiotic nitrogen fixation was quantitatively determined.

The effect of split applications of nitrogen fertilizer upon yield, symbiotic performance and fertilizer utilization was studied by four 75 mg N/Pot applications of nitrogen applied at seeding, 6 weeks after seeding, full bloom and early pod stages. The times of nitrogen applications were selected in response to U.S. soybean literature which had indicated that nitrogen applied at these "physiologically critical nitrogen stages" could be effective in inducing yield responses. In order to quantitatively determine nitrogen fertilizer uptake for each nitrogen application period a ^{15}N-labelled single treatment fertility experiment as described by Fried <u>et al.</u> (1975) was used. The plan is shown in Table 5. Thus at seeding subtreatment 7a received ^{15}N labelled

TABLE 5

NITROGEN FERTILITY TREATMENTS USED IN GROWTH CHAMBER EXPERIMENTS ONE AND TWO.

		Nitrogen applied (mg N/Pot) time nitrogen applied				
Crop	Treat.	seeding	6 weeks after seeding	bloom	early pod-fill	atom % ^{15}N excess in fertilizer
Faba-bean	1	0	0	0	0	0
"	2	75*	0	0	0	8.14
"	3	150*	0	0	0	3.64
"	4	300*	0	0	0	2.12
"	5	600*	0	0	0	2.12
"	6	900*	0	0	0	0.81
"	7a	75*	75	75	75	8.14
"	7b	75	75*	75	75	8.14
"	7c	75	75	75*	75	8.14
"	7c	75	75	75	75*	8.14
"	8	0	300*	0	0	2.12
"	9	0	0	300*	0	2.12
"	10	0	0	0	300*	2.12
Barley	11	0	0	0	0	0
"	12	300*	0	0	0	2.12

* indicates fertilizer labelled with ^{15}N.

subtreatments b, c, d received unlabelled fertilizer. At the 6 week application time only 7b received ^{15}N-labelled fertilizer, full bloom only 7c received ^{15}N-labelled fertilizer and at early pod only 7d received ^{15}N-labelled fertilizer. The four subtreatments were physiologically identical, though each subtreatment had ^{15}N applied at a different time. Thus quantitative determination of nitrogen fertilizer efficiency for each application time could be determined.

The effect of adding single large applications of nitrogen on fababean performance was studied by adding 300 mg N at the same growth stages split N applications were added (Table 5). The fertilizer used was labelled with ^{15}N, thus it was possible to compare the effect of time of nitrogen application upon nitrogen uptake from split and single applications.

Barley (Hordeum vulgare var. Conquest) was also grown at two levels of nitrogen, 0 and 300 mg N/Pot applied at seeding. Barley was used to measure the quantity of soil nitrogen that was available to fababeans during the experiment.

Fababeans were harvested 115 days after seeding and barley 90 days after seeding. In addition fababean leaves which abscised during the course of the experiment were collected and added to the harvested plant material at harvest time. Plants were oven dried (70°C for 24 hours), weighed, and ground to pass through a

2 mm sieve. Both total nitrogen and ^{15}N were determined in the plant material.

C: ANALYTIC PROCEDURES

SOILS

The following analytic methods were used to determine characteristics of the experimental site soils. The majority of the methods employed were those currently used by the Manitoba Provincial Soil Testing laboratory.

a) NO_3-N determination:

Soil NO_3-N concentrations were determined by hydrazine reduction using a modification of the automated colorimeteric procedure of Kamphake *et al.* (1967), the method currently used by the Provincial Soil Testing laboratory. Bulk density data were used to convert ppm NO_3-N into kg NO_3-N/ha.

b) Phosphorus

$NaHCO_3$ extractable soil phosphorus was colorimetrically determined by a modified Olson *et al.* (1954) method using asorbic acid as the reductant for the phosphomolybdate complex. Results are expressed in ppm phosphorus.

c) Potassium

NH_4OAc extractable potassium concentrations were determined by flame photometry using lithium as an internal standard. Results are presented in ppm potassium.

d) Sulfate - Sulfur

Water soluble sulfate-sulfur was determined by the turbidmetric method described by Bardsley and Lancaster (1960). Bulk density data were used to convert ppm SO_4 into kg SO_4-S/ha.

e) Soil pH

The electrometric method of measuring pH of a soil-water suspension described by Peech (1965) was used. pH was measured with a Fisher Combination Electrode on a Radiometer pH meter.

f) Soil conductivity

The same soil-water suspension used for the soil pH determination was used for soil electrical conductivity analysis. Electrical conductivity was measured using a Fisher Combination electrode on a Radiometer conductivity meter. Results are expressed in mmhos/cm.

g) Soil Organic Matter Content

Walkley and Black's dichromate oxidation method described by Allison (1965) was used to determine soil organic matter. Results are expressed in percent organic matter.

1) Field Capacity

Field capacity of the soil used in growth chamber experiments one and two was determined using plastic cylinders into which air dried soil had been placed. The top portion of soil in the cylinder was saturated with water. After twenty-four hours the water percentage of the wet portion of the soil was determined on an oven dry basis. Hence results are expressed as percent moisture in oven dry soil.

PLANT MATERIAL ANALYSIS

a) Total nitrogen content

Total plant nitrogen was determined by the modified Kjeldahl - Gunning method described by Jackson (1958). The digestion accelerator used was a Kelpak[1] No. 2, which contained 0.3 g $CuSO_4$ and 10.0 g K_2SO_4.

b) Excess atom % ^{15}N

Abundance of tracer ^{15}N in a plant sample was determined by mass spectrometric analysis of enriched plant material using a modification of the method described by Bremner (1965). Ammonium released from plant material during a Kjeldahl determination was distilled into 25 to 50 ml of 0.1N H_2SO_4 containing methyl red indicator, ammonium content was determined by back titration with standardized 0.1N NaOH. The distillate was then acidified with a drop of concentrated H_2SO_4, and then evaporated on a hot plate, or in an oven, until the solution volume was reduced to five milliliters. If all liquid in the distillate evaporated several ml of distilled water were added, and the NH_4SO_4 was redissolved. The sample was placed in a numbered test tube, capped with a

[1]Supplier: Canadian Lab. Supplier, Ltd.
80 Jutland Road, Toronto, Ontario.

rubber stopper and stored in a refrigerator set at 4 to 5° C prior to further analysis.

Nitrogen gas was manufactured by sodium hypobromite oxidation of the ammonium solution. The apparatus used was similar to that used by Pang (1969) Fehr (1969) and McGill (1972), and the method used to prepare elemental nitrogen gas was a modification of the method described by Bremner (1965). The modifications consisted of discarding the use of liquid nitrogen around the Rittenberg reaction vessel after mixing of the enriched ^{15}N solution and sodium hypobromite solution and prior to releasing the nitrogen gas into the evacuated collection vessel. The use of liquid nitrogen lowers partial pressure of water and thus prevents gaseous water from entering into the mass spectrometer. Since the use of liquid nitrogen was cumbersome and time consuming, a new method of removing H_2O vapor from the gas sample was suggested by C.M. Cho[1]. The method consisted of adding several KOH crystals to the gas collection tube. Since KOH is a strong desiccant water vapor was removed from the gas sample inside the gas collection tube, therefore greatly expediting gas preparation.

A MAT GD 1500 mass spectrometer was used. Since only ion intensities of mass 28 and 29 were measured the formula used to convert ratios of

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[1] C.M. Cho. Professor. Department of Soil Science, University of Manitoba. Winnipeg, Manitoba. R3T 2N2

mass 28 and 29 to atom % ^{15}N was the formula described by Bremner (1965);

$$\text{Where: Atom \% } {}^{15}N = \frac{100}{\frac{2\,({}^{14}N{}^{14}N)}{({}^{14}N{}^{15}N)} + 1}$$

This equation is only valid when the system $^{14}N_2 + {}^{15}N_2 = 2\,{}^{14}N{}^{15}N$ is in equilibrium:

$$\text{ie} \quad \frac{({}^{14}N{}^{15}N)^2}{({}^{14}N_2)({}^{15}N_2)} = K = 4$$

The equilibrium value of four has been verified on the apparatus used in previous works (Pang 1969, Fehr 1969).

ANALYSIS OF ^{15}N STANDARDS

Samples of ^{15}N fertilizers used in all experiments underwent mass spectrometric analysis for ^{15}N enrichment. Since NH_4NO_3 was the nitrogen carrier used in all experiments it was necessary to reduce the NO_3 to NH_4 before gas preparation. NH_4NO_3 fertilizers were dissolved into water and sufficient quantity of solution which contained 80 mg N was drawn off and placed in a 700 ml Kjeldahl flask, 270 ml distilled H_2O and 1.0 to 1.5 grams of Devarda's alloy (45% Al, 50% Cu, 5% Zn) a reducing agent were added. The resulting mixture was distilled into 40 ml of 0.1N H_2SO_4 until approximately 180 ml solution was distilled. Percent nitrogen was then determined by titration with 0.1 N NaOH. Samples were then treated in same manner as described for plant material ^{15}N determinations.

^{15}N CALCULATIONS

^{15}N and ^{14}N, by virtue of the tracer theory are assumed to be chemically and physically indistinguishable in the soil. Therefore, only simple dilution calculations were required to convert determined plant ^{15}N concentrations into total fertilizer nitrogen concentrations in the plant. Natural abundance was assumed to be 0.375 atom % ^{15}N. Atom % excess ^{15}N in plant material was calculated by subtracting percent natural abundance from percent ^{15}N in plant material considered. The formula used to convert atom % excess ^{15}N into ^{15}N uptake was:

$$1)\quad {}^{15}N \text{ Uptake} = \frac{\%\ {}^{15}N \text{ excess in plant tissue} \times \text{yield} \times \%\ N}{10^4}$$

From this calculation percent recovery of applied fertilizer was calculated by:

$$2)\quad \%\ \text{nitrogen fertilizer recovery} = \frac{\text{Total } {}^{15}N \text{ uptake (from equation one)}}{\text{atom } \%\ {}^{15}N \text{ excess in fertilizer} \times 10^{-4} \times \text{fertilizer rate}}$$

CALCULATION OF QUANTITY OF NITROGEN SYMBIOTICALLY FIXED BY THE FABABEAN

Quantity of nitrogen symbiotically fixed by fababeans was determined by subtracting quantity of aerial nitrogen derived from soil and fertilizer sources from total above ground fababean nitrogen. That is:

$$V.Sf.N. = T.V.N. - S.N. - F.N.$$

Where: V.Sf.N. = quantity of fababean aerial nitrogen derived from symbiotic nitrogen fixation

T.V.N. = nitrogen uptake into fababean aerial portions

S.N. = quantity of fababean aerial nitrogen derived from soil nitrogen

F.N. = quantity of fababean aerial nitrogen derived from nitrogen fertilizers

Nitrogen uptake into fababean aerial portions was calculated by multiplying oven dry aerial yield by oven dry percent nitrogen content. Quantity of fababean aerial nitrogen derived from soil nitrogen was determined by non nodulating fababeans and/or barley aerial nitrogen uptake. Quantity of fababean aerial nitrogen derived from nitrogen fertilizers was determined directly by ^{15}N techniques, and indirectly by non nodulating fababean and/or barley fertilizer nitrogen uptake.

STATISTICAL METHODS

Since all field experiments were of a random block design analysis of variance was conducted by computerized methods. Two way analysis of variance, measuring treatment variance and replicate variance was conducted in the manner described by Steel and Torrie (1960). Intratreatment significance was determined by Duncan's New Multiple Range test using a 95% probability level as the significance level.

Growth chamber experiments were of a completely randomized design, and hence analysis of variance was calculated in the manner described by Steel and Torrie for randomized experiments. Intratreatment significance was calculated and illustrated by Duncan's multiple range test using the 95% significance level.

IV RESULTS AND DISCUSSION

FIELD TRIALS - 1973

Work conducted in Manitoba showed that yields of fababeans grown on non-fallowed land were significantly increased by the addition of nitrogen fertilizers at rates up to 67 kg N/ha surface broadcast at seeding, and that yield of fababeans grown on fallow land was unaffected by all rates of nitrogen fertilizers surface broadcast at seeding (Rogalsky, 1972). Experimental data suggest that these fababeans were incapable of symbiotically fixing sufficient nitrogen for optimum growth, and hence were incapable of achieving potential seed yield when relying predominately upon symbiotic nitrogen fixation. Rogalsky (1972) also noted that nitrogen fertilizers placed with fababean seed had no adverse effect upon fababean germination and subsequent seed yield.

In order to elucidate fababean fertilizer, and total nitrogen requirements more fully three field trials were conducted during the summer of 1973. However, due to infestation of wild mustard (Brassica nigra L.) one of the trials was discarded. Field trials were located at Carman and Carberry. The legal description of the Carman site was SW 9-7-4W, and the legal description of the Carberry trial was NE 8-12-15W. The objectives of the field trials were:

1. To determine yield and protein content of fababeans at various rates and placements of nitrogen,

phosphorus, potassium and sulfur fertilizers.

2. To study the effects of carbonated and non-carbonated soils upon yield response of fababeans to nitrogen, phosphorus, potassium and sulfur fertilizers.

3. To determine nutrient uptake by fababeans.

4. To study the effect of drilled compared to broadcast nitrogen on fababean germination and yield. Methods used to achieve these objectives are described in the Methods and Materials section.

SOILS

The soil at the Carman experimental site was a gleyed Rego Black developed on coarse textured lacustrine deposits and was mapped as an Almasippi very fine sandy loam (Ellis et al., 1943). The soil at Carberry was an Orthic Black developed on sandy outwash and was mapped as a Stockton fine sandy loam (Ehrlich et al., 1957). Soils at both experimental sites had been cropped the previous year. At seeding, NO_3 content of the Stockton FSL was low according to Provincial Soil Testing Laboratory guidelines, while the Almasippi VFSL contained medium quantities of NO_3. Other pertinent soil characteristics are presented in Table 6.

RESULTS

Seed and straw yields were high with little variation occurring among treatments at both experimental sites. Data indicate that application of nitrogen fertilizer

TABLE 6

Some Characteristics of Soils in 1973 Field Trials

Site	Soil Name	Texture	pH	conductivity mmhos/cm	Nitrate-Nitrogen Content (kg/ha) 0-60cm	Nitrate-Nitrogen Content (kg/ha) 0-120cm	$NaHCO_3$ extractable P(ppm)	Exchangeable K(ppm)
Carman	Almasippi (Gleyed Rego Black)	VFSL	7.8	0.7	43	53	8.0	474
Carberry	Stockton (Orthic Black)	FSL	7.6	0.5	19	25	4.7	484

surface broadcast at seeding at rates up to 202 kg N/ha, and nitrogen placed with the seed at rates up to 67 kg N/ha had no significant affect upon fababean seed and straw yields (Table 7). Percent protein content of fababean seed and straw (Table 8) and nitrogen uptake into above ground fababean plant material (Table 9) appeared to have been unaffected by nitrogen fertilization, but due to sampling procedures used, analysis of variance of these data could not be conducted and therefore statistical verification of these observations was not possible. These data are in agreement with European reports (Moukova et al., 1968, McEwen, 1970, and Rinno et al, 1973) which state that yield and percent protein content of fababeans were not affected by rates of nitrogen fertilizers surface broadcast at seeding. These data however are not in full agreement with Rogalsky's work (1972) which indicated maximum seed yield of fababeans grown on non-fallowed soil in Manitoba was not obtained without supplemental nitrogen additions. The reason for this discrepancy is not apparent but could be due to poor nodulation in Rogalsky's fababeans.

Grain yield to straw yield ratios were unaffected by nitrogen applications, and were calculated to be 0.95:1 at Carberry, and 1.04:1 at Carman. These ratios are similar to grain : straw ratios obtained in cereals grown in Manitoba (Racz, 1976 per. com.)[1].

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TABLE 7

EFFECT OF NITROGEN FERTILIZER ON GRAIN AND STRAW YIELDS OF FABABEANS IN FIELD TRIALS 1973

Nitrogen applied (kg N/ha)	Yield (kg /ha) — Field Trial Location: Carberry		Carman	
	Grain	Straw	Grain	Straw
0	3476a	3432a	2871a	2771a
34B	3645a	3687a	2719a	2402a
67B	3274a	3374a	2971a	2783a
202B	3339a	3735a	2910a	2837a
34D	3011a	3500a	2593a	2615a
67D	3443a	3517a	2456a	2458a

B = nitrogen surface broadcast after seeding
D = nitrogen drilled in with seed.

(numbers followed by same letters in columns are not significantly different at $P = 0.05$ by Duncan's Multiple Range.)

TABLE 8

EFFECT OF NITROGEN FERTILIZATION ON PERCENT PROTEIN CONTENT IN SEED AND STRAW OF FABABEANS IN FIELD TRIALS 1973.

	Percent Protein[1] Content			
	Field Trial Location			
	Carberry		Carman	
Nitrogen applied (kg N/ha)	Grain	Straw	Grain	Straw
0	31.8	6.0	30.9	7.1
34B	30.8	5.6	29.8	7.1
67B	30.4	5.7	29.6	7.5
202B	31.7	6.7	28.6	7.5
34D	30.7	6.0	30.1	8.0
67D	30.7	5.7	28.9	8.1

B=nitrogen surface broadcast after seeding
D=nitrogen drilled in with the seed.

1: Protein content of grain based on oven dry moisture content, Protein content of straw based on air dry moisture content. Protein factor = 5.7 x %N

TABLE 9

EFFECT OF NITROGEN FERTILIZATION ON NITROGEN UPTAKE INTO FABABEAN SEED AND STRAW IN FIELD TRIALS 1973.

Nitrogen applied (kg N/ha)	Nitrogen Uptake (kg N/ha) into Fababean Seed and Straw					
	Field Trial Location					
	Carberry			Carman		
	Grain	Straw	Total	Grain	Straw	Total
0	178	36.0	214.0	150	34.4	184.4
34B	181	36.1	217.1	131	30.0	161.0
67B	161	34.1	195.1	141	36.5	177.5
202B	172	43.7	215.7	134	37.2	171.2
34D	149	36.8	185.8	126	36.6	162.6
67D	170	35.5	205.5	114	35.1	149.1

B = nitrogen fertilizer surface broadcast at seeding
D = nitrogen fertilizer drilled in with seed.

Percent crude protein in fababean seed was high according to levels mentioned by Evans et al. (1972). Nitrogen uptake (Table 9) into above ground fababean portions was high, ranging from 149 to 187 kg N/ha in Carman fababeans, and from 185 to 217 kg N/ha in Carberry fababeans. The distribution of nitrogen in fababean aerial plant portions was calculated. At Carberry 80.5% of fababean aerial nitrogen was located in the seed and 19.5% in other plant parts. At Carman 82% of the fababean aerial nitrogen was located in the seed and 18% in other plant parts. These figures do not take into account nitrogen contained in abscised leaves which could not be determined, and hence the ratios are somewhat biased in favor of seed production at the expense of leaf production.

Results showed that nitrogen fertilizer had no effect upon yield, and protein content of fababeans grown in soils which contained low and medium contents of available NO_3 at seeding. Data indicate fababeans which were grown in these field trials were not nitrogen deficient, suggesting that they symbiotically fixed sufficient nitrogen for attainment of maximum yield and protein contents possible when grown in environmental conditions which prevailed during the course of the experiment. Thus yield and protein content of fababeans were independent of content of available inorganic soil nitrogen. The Almasippi VFSL at Carman contained 2.1 times more NO_3 to 120 cm than did the Stockton FSL at Carberry (Table 6), however the average fababean seed yield at Carberry was 23% higher than at Carman. These data suggest that fababeans fixed adequate nitrogen, in agreement with McEwen (1970) who reported that seed yield of fababeans was not limited by low contents of available inorganic soil nitrogen.

FIELD TRIALS - 1974

Fababeans grown in 1973 field trials did not respond to nitrogen fertilizer applied in various rates and placements when grown in soils containing low and medium NO_3 contents at seeding. Lack of response was attributed to sufficient symbiotic nitrogen fixation for plant needs. These data did not agree with Rogalsky's (1972) report which indicated fababeans required supplemental nitrogen additions in order to achieve potential seed yield when grown in non-fallow Manitoba soils. In order to resolve this discrepancy three field trials were conducted during the summer of 1974. The objectives of the field program were:

1. To determine the effect of rates of nitrogen applied at seeding on nodulated fababean yield, percent protein content and nitrogen uptake.

2. To determine the effect of nitrogen fertilizer applied at seeding on non-nod fababean yield, percent protein content, and nitrogen uptake.

3. To determine the effect of nitrogen fertilizer on fababean dry matter accumulation and aerial nitrogen uptake.

4. To determine the quantity of fababean aerial nitrogen derived from symbiotic nitrogen fixation. Experimental designs and methods are discussed in the Methods and Materials section.

SOILS

In 1974 field trials were conducted at three sites; Altona, Pilot Mound, and Seven Sisters. The soil at the experimental site at Altona was an Orthic Black developed on sandy lacustrine and deltaic deposits and was mapped as an Altona FSL (Ehrlich et al, 1953). The soil at Pilot Mound was an Orthic Black developed on mixed till and water deposits and was mapped as a Snowflake CL (Ellis et al, 1943). The soil at Seven Sisters was a Gleyed Dark Grey developed on lacustrine clay over strongly calcareous silty deltaic deposits and was mapped as a Framnes CL (Smith et al, 1967).

Soil sampling at seeding showed that all soils were base saturated and had low soluble salt concentrations (Table 10). Available phosphate ($NaHCO_3$ extractable) concentrations rated by Provincial Soil Testing Laboratory guidelines were very low in the Snowflake CL and Framnes CL and low in the Altona FSL. Potassium (NaOAc exchangeable) concentrations were high in all experimental sites. Water soluble sulfate contents in the 0 to 60 cm depth increment were adequate at all sites except Seven Sisters where sulfur fertilizers would have been recommended for rapeseed production. All sites had medium contents of NO_3 in the 0 to 60 cm depth increment according to Provincial

TABLE 10

Some Characteristics of Soils in 1974 Field Trials

Location	Soil Name	Texture	pH	Conductivity mmhos/cm	Nitrate Nitrogen content (kg/ha) 0-60cm	Nitrate Nitrogen content (kg/ha) 0-120cm	$NaHCO_3$ Ext. P(ppm)	Exchangeable K(ppm)	Sulfate Sulfur content (kg/ha) 0-60 cm	Sulfate Sulfur content (kg/ha) 0-120cm
Altona	Altona (Orthic Black)	FSL	8.0	0.4	31	44	7.2	265	31	184
Pilot Mound	Snowflake (Orthic Black)	CL	6.9	0.3	35	53	4.8	356	140	381
Seven Sisters	Framnes (Gleyed Dark Grey)	CL	7.0	0.3	28	64	1.8	154	17	26

Soil Testing Laboratory guidelines (Fehr, 1974).

EFFECT OF NITROGEN ON YIELDS OF NODULATED FABABEANS

Climatic conditions in 1974 were unfavorable for good fababean growth. A wet spring delayed seeding and thus the seeding dates were May 29 at Altona, June 1 at Pilot Mound, and June 10 at Seven Sisters. Hot dry weather encountered in July resulted in lower than average pod set and premature senescence of the plants at the Altona site. Fababeans grown at Seven Sisters and Pilot Mound were killed by frost in late August, resulting in reduced grain yields due to the presence of a large quantity of unfilled seeds.

Yield of fababeans harvested during floral initiation to pre-bloom stages (40 days after seeding) and during post bloom to early pod-fill stages (70 days after seeding) was generally unaffected by rates of nitrogen fertilizer applied at seeding (Table 11). Exceptions occurred at Pilot Mound where the 60 kg N/ha treatment significantly increased yield of pre-bloom fababean forage, and at Altona where the 300 kg N/ha treatment significantly increased yield of fababeans harvested during early pod-filling stages. Yield of fababeans harvested biweekly throughout the growing season was unaffected by the application of 90 kg N/ha at seeding, substantiating general harvest data. The period of maximum dry matter accumulation was found to occur during early to mid pod-filling stages of fababean

TABLE 11

EFFECT OF NITROGEN FERTILIZER ON AERIAL YIELD OF NODULATED FABABEAN FORAGE HARVESTED 40 AND 70 DAYS AFTER SEEDING IN FIELD TRIALS 1974.

Nitrogen applied (kg N/ha)	Yield of Forage (kg /ha) — Field Trial Location: Pilot Mound		Seven Sisters		Altona	
	40 d	70 d	40 d	70 d	40 d	70 d
0	824a	3521a	896ab	3810a	791a	2201ab
30	992ab	2975a	802ab	4226a	915a	2488ab
60	1179b	2982a	762a	4828a	921a	2350ab
90	913ab	2934a	830ab	3923a	1020a	1925a
150	1129ab	3886a	841ab	4543a	1048a	2122ab
300	1040ab	3399a	1021b	4300a	987a	2798b

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

growth. During this growth period rate of dry matter accumulation tended to be greater, though not significantly greater in fababeans fertilized with 90 kg N/ha than in control fababeans. Thus at Seven Sisters maximum dry matter production was 259 and 321 kg dry matter/ha/day by unfertilized and fertilized fababeans respectively. At Altona unfertilized fababeans produced 92 kg dry matter/ha/day, and fertilized fababeans produced 143 kg dry matter/ha/day during their period of maximum growth.

Fababean seed and straw yields were low and variable in 1974 field trials. No rate of nitrogen fertilizer employed consistently increased seed and straw yields (Table 12), however significant effects occurred at Seven Sisters where the lowest nitrogen application rate employed (30 kg N/ha) significantly increased seed but not straw yields, the 60 and 90 kg N/ha significantly increased straw but not seed yields, and the 300 kg N/ha treatment significantly increased both seed and straw yields. At Altona and Pilot Mound all treatments had similar seed and straw yields. These data are in general agreement with 1973 data which indicated neither rate nor placement of nitrogen fertilizer affected fababean seed and straw yields. Seed to straw yield ratios were calculated to be 0.66:1 at Pilot Mound, 0.26:1 at Seven Sisters, and 0.41:1 at Altona. These ratios are considerably lower than those calculated from 1973 data and were due to premature senescence caused by fall frosts. It was observed that

TABLE 12

EFFECT OF NITROGEN FERTILIZATION ON INOCULATED FABABEAN SEED AND STRAW YIELDS IN FIELD TRIALS 1974.

Nitrogen applied (kg N/ha)	Yield (kg /ha)					
	Field Trial Location					
	Pilot Mound		Seven Sisters		Altona	
	Grain	Straw	Grain	Straw	Grain	Straw
0	1669ab	2574ab	1481a	5427a	745a	1890a
30	1307a	1901a	1876b	6504ab	670a	1894a
60	1863b	2720b	1717ab	6604b	950a	2211a
90	1246a	1987a	1483a	6580b	850a	2122a
150	1562ab	2404ab	1708ab	6370ab	975a	2209a
300	1562ab	2281ab	1859b	6899b	970a	2161a

(numbers followed by same letters in columns are not significantly different at P = 0.05) fababean seeds produced in 1974 were smaller than those produced in 1973 field trials indicating fababean seeds did not have the opportunity to fill out fully in 1974. Thus it appears that low seed yields encountered in 1974 were not due to a lack of available nitrogen, but to environmental factors.

EFFECT OF NITROGEN FERTILIZERS UPON PERCENT CRUDE PROTEIN IN NODULATED FABABEANS:

Percent crude protein contents of fababean forage were generally unaffected by nitrogen fertilization (Table 13). However, at Seven Sisters the 60 kg N/ha treatment significantly increased percent crude protein in pre-bloom fababean forage, though in subsequent harvests this effect disappeared. At Seven Sisters, percent protein content of fababeans harvested during mid-pod stages were significantly increased in 300 kg N/ha treated fababeans.

Percent fababean crude protein content decreased with advancing crop maturity (Table 13). Percent protein content of fababean forage grown in the control treatment at Seven Sisters decreased from 24.6% when harvested 25 days after seeding to 17.0% when harvested 71 days after seeding. The trend of decreasing plant protein content with advancing crop maturity has been well documented in alfalfa (Barnes and Gordon, 1972) and in soybeans (Hanway and Weber, 1971).

Percent protein content of mature fababean seed remained unaffected by all but the highest rate of nitrogen

TABLE 13

EFFECT OF NITROGEN FERTILIZATION ON PERCENT PROTEIN CONTENT OF NODULATED FABABEAN FORAGE AT 40 AND 70 DAYS AFTER SEEDING IN FIELD TRIALS 1974.

Nitrogen applied (kg N/ha.)	Percent Protein[1] in Fababean Forage					
	Field Trial Location					
	Pilot Mound		Seven Sisters		Altona	
	40 d	70 d	40 d	70 d	40 d	70 d
0	20.4ab	12.7a	21.2a	16.7ab	20.0c	12.7a
30	19.6a	11.9a	22.2ab	16.1a	19.9c	15.1b
60	21.3b	12.0a	24.1b	16.4ab	18.9bc	15.3b
90	20.6a	14.0a	22.2ab	18.0bc	17.6a	13.9ab
150	21.1b	13.3a	22.6ab	17.1b	18.7ab	14.4ab
300	19.6a	13.2a	22.3ab	20.6c	17.8ab	15.6b

(numbers followed by same letter within a column are not significantly different at P = 0.05 by Duncan's Multiple Range.)

1: Protein reported on oven dry moisture content, Protein factor = 5.7 x %N employed (Table 14). At Seven Sisters and Altona the 300 kg N/ha treatment significantly increased percent protein content of fababean seed. At Altona application of 30 kg N/ha significantly decreased percent protein of fababean seed. Percent protein contents of fababean seed grown in 1973 field trials were higher than those encountered at Seven Sisters and Pilot Mound and similar to protein contents obtained at Altona. However all seed protein contents are within the range reported for Manitoba by Evans et al.(1972).

EFFECT OF NITROGEN ON NITROGEN UPTAKE INTO FABABEANS

Aerial nitrogen uptake into fababean forage was not affected by nitrogen fertilizers. Therefore above ground nitrogen contents of all fababean treatments were generally similar (Table 15). Due to large variability in yield and percent nitrogen contents some exceptions occurred. At Pilot Mound nitrogen uptake into forty day fababeans was significantly increased in the 60 and 150 kg N/ha treatments. At Altona nitrogen uptake into seventy day fababean forage was increased in the 30 and 300 kg N/ha treatments. These data are confirmed by biweekly determination of nitrogen uptake into fababean forage which demonstrated that unfertilized and fertilized fababeans contained similar quantities of nitrogen throughout the growing season. At Altona fababeans appeared to lose nitrogen during the 55 to 67 day period. This dip in the nitrogen

TABLE 14

EFFECT OF NITROGEN FERTILIZERS ON PERCENT PROTEIN CONTENT OF SEED AND STRAW OF NODULATED FABABEANS IN FIELD TRIALS 1974.

Nitrogen applied (kg N/ha)	Percent Protein[1] Content of Fababean Seed and Straw — Field Trial Location: Pilot Mound		Seven Sisters		Altona	
	Grain	Straw	Grain	Straw	Grain	Straw
0	22.7ab	4.3	29.1a	10.6	31.8bc	11.3
30	22.1a	5.3	29.3ab	8.9	28.6a	9.9
60	21.7a	4.7	29.5ab	8.0	30.5b	10.8
90	24.3b	5.4	29.5ab	9.2	32.4c	11.5
150	23.3ab	5.2	29.6ab	9.1	32.6c	10.8
300	22.5ab	6.2	30.3b	10.5	33.1d	11.3

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

1: Protein reported on oven dry moisture content, Protein factor = 5.7 x %N

TABLE 15

EFFECT OF NITROGEN FERTILIZATION ON AERIAL NITROGEN UPTAKE INTO NODULATED FABABEAN FORAGE HARVESTED 40 AND 70 DAYS AFTER SEEDING IN FIELD TRIALS 1974.

Nitrogen applied (kg N/ha)	Nitrogen uptake (kg N/ha) into Fababean Forage — Field Trial Location: Pilot Mound 40 d	Pilot Mound 70 d	Seven Sisters 40 d	Seven Sisters 70 d	Altona 40 d	Altona 70 d
0	29.4a	77.3ab	33.1a	118.9a	28.1a	47.7a
30	34.2ab	62.4a	31.1a	119.8a	32.1a	65.9bc
60	43.7b	82.6ab	32.4a	137.8a	31.8a	63.3abc
90	30.9a	72.1ab	32.3a	128.5a	33.8a	46.2a
150	41.6b	90.7b	35.0a	131.5a	32.7a	53.0ab
300	35.7ab	76.9ab	40.7a	152.3a	30.7a	76.7c

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

uptake curve (Fig.1) was caused by large quantities of leaves being abscised due to dry, hot climatic conditions. Since leaves were not collected from the ground at the time of harvest nitrogen content of 67 day old fababeans was less than 55 day fababean nitrogen content. At Seven Sisters application of 90 kg N/ha at seeding had no effect upon nitrogen uptake into fababean aerial portions, and hence curves for nitrogen uptake into control fababeans and fababeans fertilized with 90 kg N/ha were similar (Fig.2). Due to more favorable growth conditions at Seven Sisters, nitrogen uptake into nodulated fababeans continued progressively during the course of the experiment. Maximum rate of nitrogen uptake occurred during post bloom to early pod-filling stages. These data are in agreement with soybean data (Hanway and Weber, 1971) which indicated maximum nutrient accumulation occurred between full bloom to late pod-filling stages, closely approximating rates of dry matter accumulation.

Seasonal nitrogen uptake into fababeans determined by summation of seed and straw nitrogen contents was lower in fababeans grown in 1974 field trials than in fababeans grown in 1973 field trials (Tables 8 and 16). Since nitrogen contents of straw samples were determined on a composite sample obtained at the time of threshing, analysis of variance could not be determined. However, at Seven Sisters data indicate nitrogen uptake into fababean seed

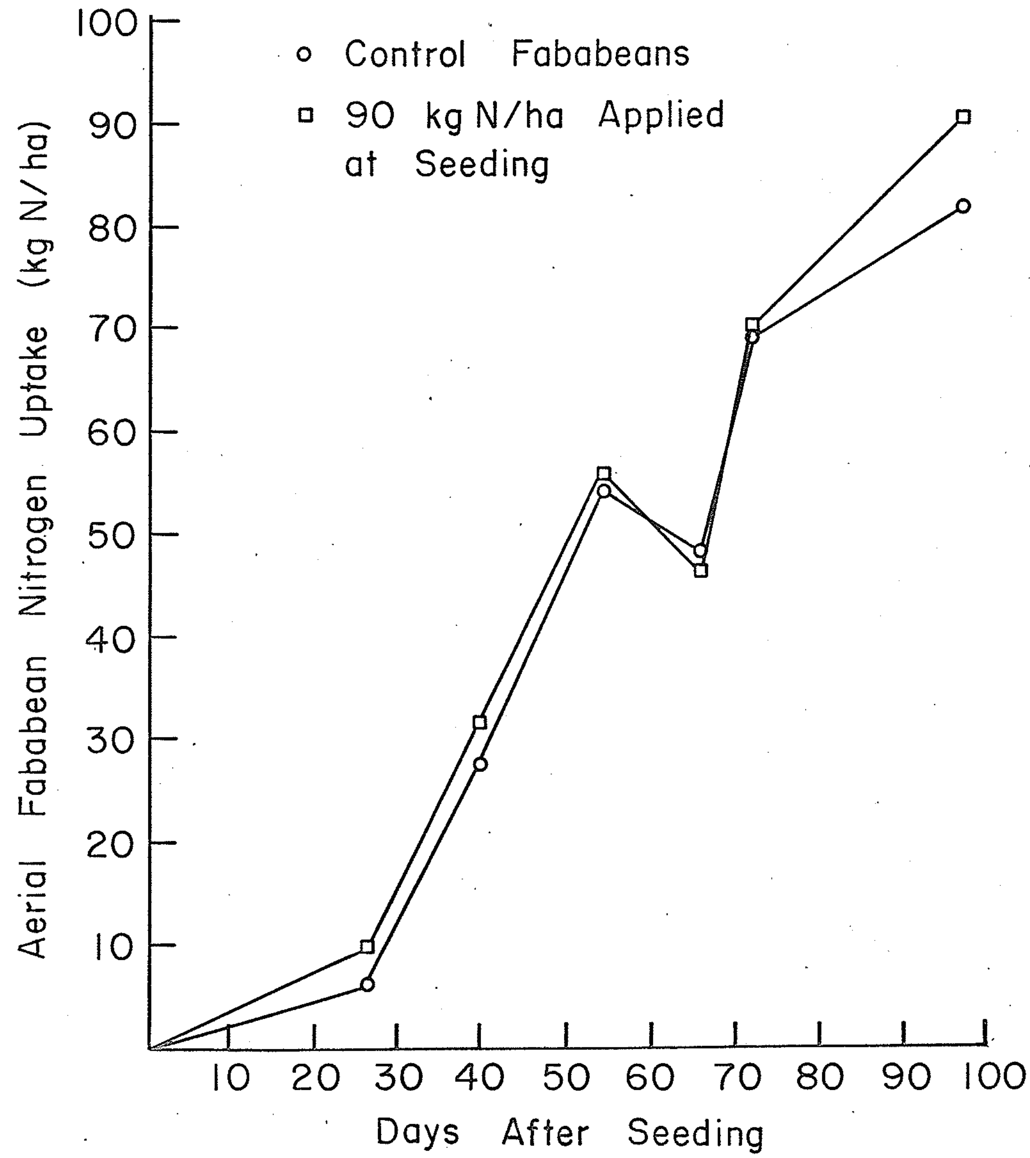

FIGURE 1: Effect of 90 kg N/ha surface broadcast at seeding on seasonal nitrogen uptake into aerial portions of fababeans in Altona field trial 1975.

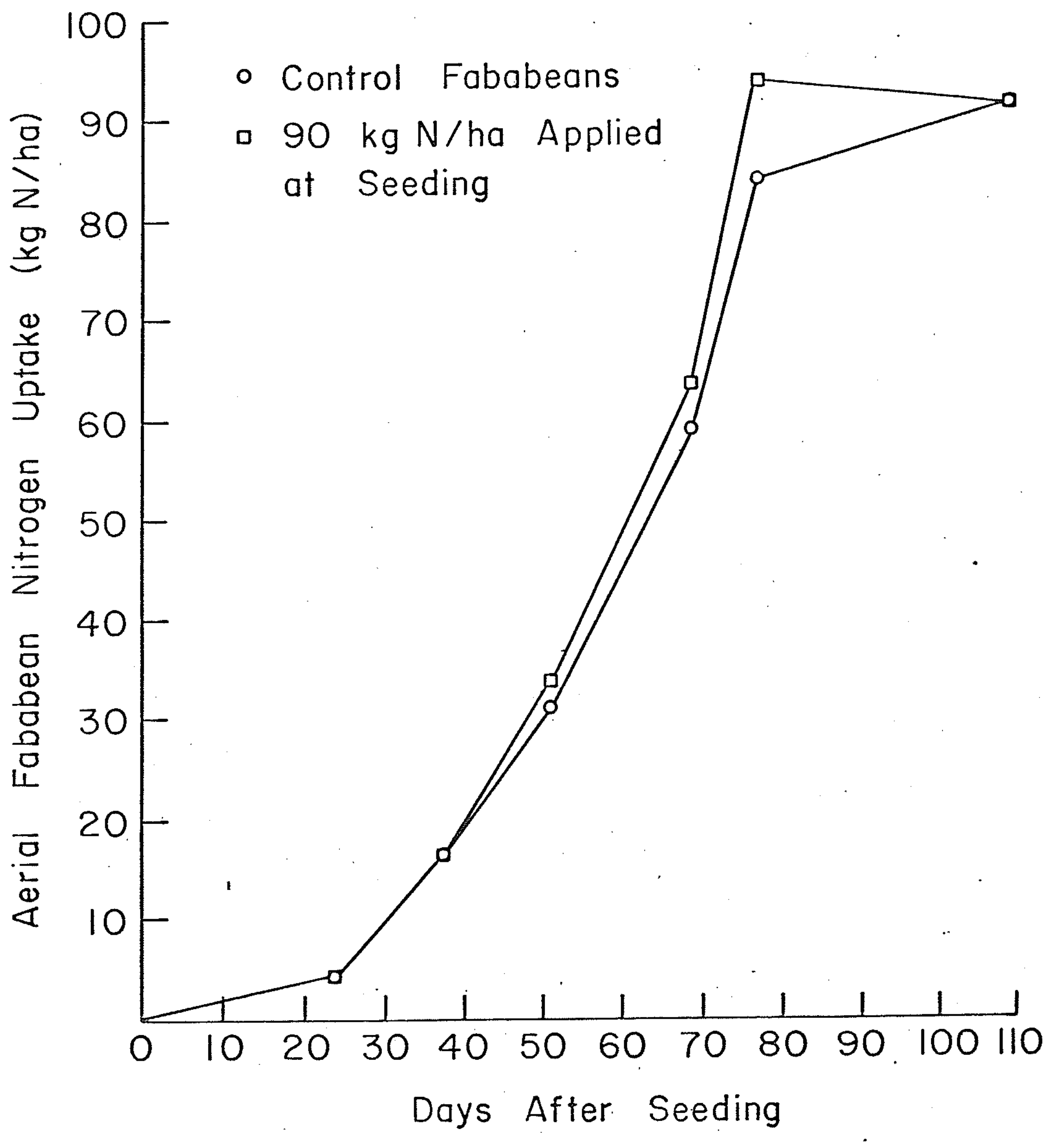

FIGURE 2: Effect of 90 kg N/ha surface broadcast at seeding on seasonal nitrogen uptake into aerial portions of fababeans grown in Seven Sisters field trial 1975.

TABLE 16

EFFECT OF NITROGEN FERTILIZATION ON NITROGEN UPTAKE INTO SEED AND STRAW OF INOCULATED FABABEANS IN FIELD TRIALS 1974.

Nitrogen applied (kg N/ha)	Nitrogen Uptake into Fababean Seed and Straw (kg N/ha)								
	Field Trial Location								
	Pilot Mound			Seven Sisters			Altona		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
0	66.4b	19.3	85.7	75.3a	101	176.3	41.2a	37.6	78.8
30	50.1a	17.7	67.8	96.6b	102	198.6	33.5a	33.0	66.5
60	70.8b	22.3	93.1	86.6ab	92.5	179.1	50.8a	42.0	92.8
90	51.5a	18.7	70.2	76.7a	107	183.7	48.1a	42.9	91.0
150	58.8ab	22.1	80.9	86.7ab	102	188.7	56.0a	42.0	98.0
300	61.8ab	24.6	86.4	98.6b	127	225.6	55.6a	42.8	98.4

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

and straw increased with increasing increments of nitrogen fertilization. Nitrogen uptake into fababean seeds was increased by all levels of nitrogen fertilization, though significant increases occurred only in 30 and 300 kg N/ha treated plots (Table 16). Total aerial nitrogen uptake into Altona and Pilot Mound fababeans was considerably lower than nitrogen uptake into fababeans grown at Seven Sisters. Nitrogen uptake into fababeans grown at Pilot Mound was similar in all treatments. At Altona total aerial nitrogen uptake appeared to have been increased by nitrogen fertilization, though seed nitrogen data suggest that these increases were not significant (Table 16).

Total aerial nitrogen contents of Seven Sisters fababeans were similar to the quantities reported for 1973 field trials. However, the distribution of nitrogen within plant parts was different. At maturity 45% of above-ground nitrogen was located in fababean seed in Seven Sisters field trials, in 1973 field trials 81.3% of the total aerial nitrogen was contained in fababean seed. These data indicate that fababeans grown at Seven Sisters suffered premature senescence which resulted in cessation of nitrogen translocation from vegetative to seed plant parts. This effect also occurred at Altona and Pilot Mound where percentage total aerial nitrogen located in fababean seed was calculated to be 54% at Altona and 74% at Pilot Mound.

Yield, percent protein content, and nitrogen uptake data indicate that fababeans grown in 1974 field trials were not nitrogen deficient at any stage of growth therefore indicating that soil inorganic nitrogen contents and symbiotically produced nitrogen were sufficient to meet fababean requirements. If fababeans had been nitrogen deficient, biweekly fababean yield and nitrogen uptake determinations would have revealed time and severity of the deficiency. Since fertilizing fababeans had no significant effect upon nitrogen uptake into aerial fababeans throughout the growing season (Fig. 1 and 2) fababeans were assumed to have had sufficient nitrogen during all growth stages.

EFFECT OF NITROGEN FERTILIZERS UPON NON NODULATED FABABEANS

Uninoculated fababeans were sown in conjunction with inoculated fababeans at Seven Sisters and Altona field trials in the manner described in Methods and Materials. It was assumed that experimental soils did not contain naturalized rhizobia species capable of nodulating fababeans, as it was imperative that no nodulation should occur. It was considered that nodules which were ineffective but present would cause erroneously low values of nitrogen uptake into above ground portions due to parasitic effects, while presence of unwanted effective nodules would have resulted in erroneously high nitrogen uptake values due to the occurrence of unwanted symbiotic nitrogen fixation. Non nodulated fababeans were used to measure soil and/or fertilizer nitrogen contributions to fababean nitrogen nutrition in the same manner non-nod soybean isolines have been used (Weber, 1966). The quantity of symbiotically fixed nitrogen contained in nodulated fababean aerial portions was estimated by subtracting the quantity of nitrogen contained in non nodulated fababean plant material from nitrogen contained in nodulated fababeans grown on similarly treated fertility plots. This method makes no allowances for differentially larger nodulated fababean root growth which could result in more soil nitrogen uptake into nodulated control treatment fababeans than into non nodulated control treatment fababeans. Non nodulating fababeans also permitted direct comparison between combined nitrogen uptake into barley and non nodulating fababeans.

Non nodulating fababeans grown in the control treatment became chlorotic within four weeks after emergence, and shortly after were observed to be shorter than fababeans in the 90 and 300 kg N/ha treatments. At time of the 40 day general harvest all treatments could be visually identified, with the 0 kg N/ha being the shortest and most chlorotic and the 300 kg N/ha treatment being the tallest and least chlorotic. At no time during the season were 300 kg N/ha non nodulated fababeans as tall as or as green as fababeans grown in the nodulated control treatment.

EFFECT OF FERTILIZER NITROGEN UPON YIELD OF NON NODULATING FABABEANS

Increasing rates of nitrogen applied to non nodulating fababeans resulted in a corresponding increase in plant health, however significant yield increases of fababean forage were obtained only in 70 day fababeans grown at Altona (Table 17), though non-significant response trends were observed in Altona 40 day fababean forage, and in 70 day Seven Sisters fababean forage. Seed yields at Seven Sisters were increased by nitrogen with increasing levels of fertilization causing further significant yield increases (Table 17). Seed yields at Altona were increased by all levels of nitrogen used, though significant yield increases were obtained only in the 300 kg N/ha treatment. Straw yields in both field trials were significantly increased by all rates of nitrogen (Table 17). Seed and straw yields of non nodulated fababeans grown at Seven Sisters fertilized with 300 kg N/ha were similar to yields of nodulated control fababeans (Tables 12, 17), while at Altona seed and straw yields of non nodulated fababeans grown in the 300 kg N/ha treatment were less than yields of nodulated control fababeans. These data indicate that the quantity of nitrogen symbiotically fixed by nodulated control fababeans was equivalent to a 300 kg/ha application of fertilizer nitrogen.

TABLE 17

EFFECT OF NITROGEN FERTILIZATION ON YIELD OF NON NODULATED FABABEANS IN FIELD TRIALS 1974.

Nitrogen applied (kg N/ha)	Yield of Non-Nod Fababeans (kg /ha) — Field Trial Location: Seven Sisters — Forage 40 d	Seven Sisters — Forage 70 d	Seven Sisters — Mature Grain	Seven Sisters — Mature Straw	Altona — Forage 40 d	Altona — Forage 70 d	Altona — Mature Grain	Altona — Mature Straw
0	912a	3085a	645a	3849a	415a	722a	73a	1002a
90	985a	3292a	1145b	5165b	698a	1257b	190a	1349b
300	963a	3528a	1592c	6030c	712a	1994c	513b	1790c

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

EFFECT OF FERTILIZER NITROGEN UPON PERCENT PROTEIN IN NON NODULATED FABABEANS

Percent protein contents of fababean forage were generally increased by nitrogen fertilization (Table 18). Percent protein contents of 40 day fababean forage at Altona and 70 day fababean forage at Seven Sisters were significantly increased by both rates of nitrogen fertilizer applied. Thus, application of 300 kg N/ha resulted in significantly higher percent protein contents than did application of 90 kg N/ha, and 90 kg N/ha applied to fababeans resulted in percent protein contents which were significantly higher than those which occurred in control treatment fababeans. Percent protein content of fababean seed grown at Seven Sisters was significantly increased by both rates of fertilization, with each increase being significantly higher than the other. At Altona percent protein of seed was significantly increased by only the 300 kg N/ha treatment. Although fababeans grown in the 90 kg N/ha treatment had higher seed protein contents than did fababeans grown in the control treatments, the difference was non-significant. At both Altona and Seven Sisters non nodulated fababeans treated with 300 kg N/ha and control nodulated fababeans had similar percent protein contents in the seed.

EFFECT OF FERTILIZER NITROGEN ON NITROGEN UPTAKE INTO NON NODULATED FABABEANS

Increasing rates of nitrogen fertilizer generally

TABLE 18

EFFECT OF NITROGEN FERTILIZATION ON PERCENT PROTEIN CONTENT OF NON-NOD FABABEANS IN ALTONA AND SEVEN SISTERS FIELD TRIALS 1974.

	Percent Protein[1] of Non-nod Fababeans							
	Field Trial Location							
Nitrogen applied	Seven Sisters				Altona			
	Forage		Mature		Forage		Mature	
(kg N/ha)	40 d	70 d	Grain	Straw	40 d	70 d	Grain	Straw
0	20.23a	9.46a	24.32a	5.5	12.03a	10.43a	28.67a	12.4
90	20.00a	14.19b	26.79b	6.0	13.68b	11.51a	28.84a	13.6
300	22.74b	20.52c	30.50c	10.1	16.13c	13.91a	31.98b	14.4

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

1 Protein reported on oven dry moisture content. % Protein = %N x 5.7

significantly increased nitrogen uptake into non nodulated fababean forage harvested 40 and 70 days after seeding, and into mature fababean seed (Table 19). However, exceptions occurred. At Seven Sisters nitrogen uptake into fababean forage harvested 40 days after seeding was significantly increased by only the 300 kg N/ha rate, and at Altona only the 300 kg N/ha rate significantly increased nitrogen uptake into fababean seed. At Seven Sisters and Altona nitrogen uptake into mature aerial fababean portions of non nodulated fababeans treated with 300 kg N/ha at seeding, and into control nodulated fababeans were similar. These data indicate that non nodulated fababeans were severely nitrogen deficient, and that application of 300 kg N/ha at seeding was required to alleviate these deficiencies. Hence data suggest that nodulated fababeans were efficient symbiotic nitrogen fixers.

BARLEY

Barley was grown at all field trials. Yield of barley was significantly increased by nitrogen fertilization at all harvests at Altona and Pilot Mound (Table 20), however at Seven Sisters yields of barley grown in control 90 kg N/ha treatments were similar. At Altona, and Pilot Mound final nitrogen uptake into barley aerial portions was significantly increased by nitrogen fertilization, however at Seven Sisters no effect occurred (Table 21). Since at Seven Sisters barley yields, and percent protein

TABLE 19

EFFECT OF NITROGEN FERTILIZERS ON NITROGEN UPTAKE INTO NON-NOD FABABEANS IN ALTONA AND SEVEN SISTERS FIELD TRIALS 1974.

Nitrogen applied (kg N/ha)	Nitrogen Uptake into Non-nod Fababean Aerial Portions (kg N/ha)									
	Field Trial Location									
	Seven Sisters					Altona				
	Forage		Mature			Forage		Mature		
	40 d	70 d	Grain	Straw	Total	40 d	70 d	Grain	Straw	Total
0	32.3a	60.5a	27.3a	37.3	64.6	8.1a	12.6a	3.7a	21.8	25.5
90	34.3ab	87.9b	53.3b	54.2	107.5	16.7b	25.4b	9.8a	32.1	41.9
300	38.2b	124.7c	86.7c	106.8	193.5	20.0c	48.1c	28.8b	45.1	73.9

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

TABLE 20

EFFECT OF NITROGEN FERTILIZATION ON FORTY-DAY FORAGE YIELD AND YIELD OF GRAIN AND STRAW OF BARLEY IN FIELD TRIALS 1974.

Nitrogen applied (kg N/ha)	Yield (kg /ha)								
	Field Trial Location								
	Pilot Mound			Seven Sisters			Altona		
	40 d	Grain	Straw	40 d	Grain	Straw	40 d	Grain	Straw
0	630	1461	1205	1064	1623	2041	300	865	952
90	1411	2443	2048	1168	1581	1581	409	1648	1648

TABLE 21

EFFECT OF NITROGEN FERTILIZERS ON NITROGEN UPTAKE INTO AERIAL BARLEY PORTIONS IN FIELD TRIALS 1974.

Nitrogen applied (kg N/ha)	Nitrogen Uptake (kg N/ha) into Barley					
	Field Trial Location					
	Pilot Mound		Seven Sisters		Altona	
	40 d	Final	40 d	Final	40 d	Final
0	11	28	37	37	13	15
90	21	44	45	39	28	32

contents were high, it must be assumed that the soil supplied sufficient quantities of nitrogen to barley.

Control non-nod fababeans and control barley plants had similar aerial nitrogen uptake values (Tables 19, 21). Due to fababeans higher potential nitrogen uptake capabilities, non-nod fababeans fertilized with nitrogen grown at Seven Sisters extracted more nitrogen than did barley grown in similarly treated plots. The lack of barley response to nitrogen fertilizers suggests barley's nitrogen requirements had been satisfied by soil nitrogen. These data also indicate that non-nod fababeans were indeed non-nodulated since any contribution of symbiotic nitrogen to plant growth would have resulted in differences between barley and non-nod fababean aerial nitrogen uptake. Therefore data indicate that eitherbarley or non-nod fababeans can be used to measure quantities of soil nitrogen and fertilizer nitrogen which would be available to nodulated fababeans.

FABABEAN FERTILIZER NITROGEN UPTAKE

Fababean fertilizer nitrogen uptake was determined directly by ^{15}N techniques at Altona and indirectly by the difference method using non-nod fababeans and/or barley at all experiment sites. Tracer ^{15}N permits quantitative determination of fertilizer nitrogen uptake by nodulated fababeans. ^{15}N subplots in 90 kg N/ha plots were sampled in forage harvests conducted 41, 55 and 75 days after seeding and at crop maturity. Data indicate (Table 22) that the efficiency of fertilizer nitrogen recovery by aerial portions of nodulated fababeans was low. At maturity above ground fababean portions grown in 90 kg N/ha treatment recovered 8.7 kg N/ha or approximately 10% of the applied fertilizer. Fababeans treated with 30 kg N/ha at seeding recovered 6.4 kg N/ha or 21% of applied fertilizer in above ground plant portions. The low efficiency of nitrogen fertilizer recovery by fababean aerial portions was attributed to the extremely dry conditions which possibly prevented proliferation of fababean roots in the fertilizer zone.

Continuous sampling ^{15}N data indicate nodulated fababeans adsorbed nitrogen fertilizer throughout their entire growth period, with 54% of their total nitrogen fertilizer uptake occurring during the 75 to 97 days after seeding time period, corresponding to the post bloom to senescence periods of plant growth. Nitrogen fertilizers adsorbed during the post bloom to senescence growth periods appear to have been used mainly by the developing seed, and hence at maturity 98% of the nitrogen fertilizer adsorbed during this time interval was located in the seed.

The efficiency of fertilizer nitrogen recovery non-nod fababeans and barley was determined by the difference method. The formula used was:

$$P.N.U. = \frac{F.N_F. - U.N_F}{F.R.} \times 100$$

TABLE 22

EFFICIENCY OF NITROGEN UPTAKE INTO NODULATED FABABEANS AT VARIOUS HARVEST TIMES AS MEASURED BY ^{15}N IN ALTONA FIELD TRIAL 1974.

Nitrogen applied (kg N/ha)	Percent fertilizer nitrogen recovered by fababean aerial portions					
	Harvest time (days after seeding)					
	Forage			Mature		
	41 d	55 d	75 d	Grain	Straw	Total
30	-	-	-	12.17	9.13	21.30
90	1.93	2.71	4.47	5.13	4.65	9.78

where: P.N.U. = percent nitrogen fertilizer recovered into aerial plant portions

$F.N_F.$ = nitrogen uptake into fertilized non-nod (or barley) aerial portions

$U.N_F.$ = nitrogen uptake into unfertilized non-nod (or barley) aerial portions

F.R. = nitrogen fertilizer application rate

The efficiencies of nitrogen fertilizer uptake into non-nod fababeans and into barley as determined by the difference method are shown in Table 23.

Efficiency of nitrogen fertilizer recovery at Seven Sisters was higher in fababeans than in barley (Table 23). This was caused by the presence of a high amount of soil nitrogen which was sufficient for barley growth, thus unfertilized and fertilized barley had similar total quantities of aerial nitrogen. Barley was therefore estimated to have recovered 0% of the applied fertilizer nitrogen, while non-nod fababeans, a species with a higher nitrogen demand, recovered 48% of the nitrogen applied in the 90 kg N/ha rate and 43% of the nitrogen applied in the 300 kg N/ha rate. These data indicate that fababeans possess a high nitrogen demand, and when grown in a soil containing high amounts of inorganic nitrogen were capable of extracting more nitrogen than could barley.

Efficiency of fertilizer nitrogen recovery by non-nod fababeans and by barley grown at Altona were low but similar. Aerial portions of barley treated with 90 kg N/ha recovered 23% of the applied fertilizer, while non-nod fababeans recovered 18% of the nitrogen applied in the

TABLE 23

EFFICIENCY OF FERTILIZER NITROGEN UPTAKE INTO NON-NOD FABABEANS AND BARLEY AT VARIOUS HARVESTS AS DETERMINED BY THE DIFFERENCE METHOD IN FIELD TRIALS 1974.

Nitrogen applied (kg N/ha)	Percent Fertilizer Nitrogen Recovered in Aerial Plant Portions							
	Field Trial Location							
	Pilot Mound		Seven Sisters			Altona		
	40 d	Mature	40 d	70 d	Mature	40 d	70 d	Mature
Barley 90	11.4	27.8	8.2	-	0	17.2	-	22.9
non-nod 90	-	-	0	31.2	47.7	9.5	14.2	18.2
beans 300	-	-	0	21.4	43.0	4.0	11.8	16.3

300 kg N/ha rate. At Pilot Mound aerial barley portions recovered 28% of the 90 kg N/ha fertilizer application. In Manitoba average percent recovery of applied nitrogen fertilizers into aerial portions of cereal crops has been reported to be 52% (Soper et al., 1971). Efficiency of nitrogen fertilizer uptake into crops grown in 1974 field trials were considered to be low as a result of the dry soil conditions predominating throughout the course of the experiments which rendered applied nitrogen fertilizers unavailable. Low efficiency of nitrogen fertilizer utilization was observed in other field trials conducted in Manitoba during the summer of 1974 (Racz, per. comm. 1976)[1]. Experimental data indicate that fababeans and barley recover similar quantities of combined nitrogen.

Comparison of the recovery of nitrogen fertilizer as calculated directly by ^{15}N techniques and indirectly by the difference method showed that the difference method consistently gave higher values than did the ^{15}N method. This phenomenea also was reported to occur in cereals grown in Manitoba soils (McGill, 1972), and in other crops throughout the world. The discrepancy has generally been

[1] Racz, G.J., Professor, Department Soil Science, University of Manitoba, Winnipeg, Manitoba. R3T 2N2

attributed to the priming effect that nitrogen fertilizers have upon nitrification of soil organic matter and/or differential growth of roots as a result of nitrogen fertilization.

QUANTITY OF NITROGEN SYMBIOTICALLY FIXED BY FABABEANS

Non-nod fababeans and/or barley were used to estimate the quantity of soil and fertilizer nitrogen which was available to nodulated fababeans. It was assumed that combined nitrogen uptake into non-nod and nodulated fababeans were similar. At Seven Sisters and Altona quantities of symbiotic nitrogen contained in above ground plant portions were calculated by subtracting nitrogen uptake into non-nod fababeans from nitrogen uptake into nodulated fababeans grown in similarly treated fertility plots. Non-nod fababeans were not seeded at Pilot Mound and thus nitrogen uptake into barley shoots was used to estimate quantities of combined nitrogen available to nodulated fababeans. The formula used in these calculations was:

$$\%\ \text{N.S.F.} = \frac{\text{T nod} - \text{T non-nod} \times 100}{\text{T nod}}$$

where: % N.S.F. = Percent fababean aerial nitrogen derived from symbiotic fixation

T nod = Total aerial nitrogen uptake into nodulated fababeans

T non-nod = Total aerial nitrogen uptake into non-nod fababeans

Mature unfertilized fababeans derived approximately two-thirds of their aerial nitrogen by symbiotic nitrogen fixation (Table 24). Variation among experimental sites was low, ranging from 63% at Seven Sisters to 68% at Altona. However, though the proportion of fababean aerial nitrogen derived from symbiotic fixation was similar among field trials, the actual quantity of nitrogen symbiotically fixed was not similar (Table 24). At Seven Sisters unfertilized fababeans symbiotically fixed 112 kg N/ha, at Pilot Mound 58 kg N/ha, and at Altona 53 kg N/ha. Thus unfertilized fababeans which exhibited the largest growth symbiotically fixed the most nitrogen, and fababeans which exhibited the smallest growth symbiotically fixed the least amount of nitrogen. Similar results for five different legume species were reported by Allos and Bartholomew (1955).

Addition of nitrogen fertilizer decreased the amount of nitrogen symbiotically fixed by fababeans. Therefore symbiotic nitrogen fixation was decreased from 63% to 41% by the application of 90 kg N/ha, and subsequently to 14% by the application of 300 kg N/ha (Table 24). At Seven Sisters symbiotic nitrogen fixation contributed 112 kg N/ha to aerial portions of control fababeans, 76 kg N/ha to aerial portions of fababeans treated with 90 kg N/ha, and 32 kg N/ha to aerial portions of fababeans treated with 300 kg N/ha. Results from Altona and Pilot Mound (Table 24)were similar. These data are consistent with results reported by Allos and Bartholomew (1955, 1959),

TABLE 24

EFFECT OF NITROGEN FERTILIZERS ON PERCENT OF TOTAL ABOVE GROUND FABABEAN NITROGEN DERIVED FROM SYMBIOTIC NITROGEN FIXATION IN FIELD TRIALS 1974.

Nitrogen applied (kg N/ha)	Percent of aerial fababean nitrogen derived from symbiosis							
	Field Trial Location							
	Pilot Mound Harvest time		Seven Sisters Harvest time			Altona Harvest time		
	40 d	Final	40 d	70 d	Final	40 d	70 d	Final
0	62	68	0	49	63	71	74	68
90	31	37	0	32	41	51	45	54
300	-	-	0	18	14	35	37	25

and Weber (1966) which indicate application of nitrogen fertilizers to soybeans results in decreased symbiotic nitrogen fixation, the decrease being inversely proportional to quantity of fertilizer nitrogen applied.

Data appear to indicate that fertilizer nitrogen had a greater effect upon fababean symbiotic nitrogen fixation than did the quantity of inorganic soil nitrogen available at seeding. Seven Sisters fababeans symbiotically fixed a larger quantity of nitrogen than did fababeans grown at Altona and Pilot Mound, yet the Framnes CL soil at Seven Sisters contained more NO_3-N to 120 cm at seeding than did the soils at other experimental sites. Addition of fertilizer nitrogen to Seven Sisters fababeans decreased symbiotic nitrogen fixation in a similar manner to the decrease observed at Pilot Mound and Altona, suggesting fertilizer nitrogen had a more inhibitory effect upon the symbiotic process than did inorganic soil nitrogen. However, this observation is not valid since it assumes that combined nitrogen concentrations were the factors which had the greatest effect upon fababean symbiotic nitrogen fixation. Keatinge (1975) reported that climatic factors were the most important parameters affecting fababean yield, and that fababeans grown at Seven Sisters outyielded fababeans grown at Altona and Pilot Mound because of the more favorable climatic conditions which prevailed at Seven Sisters. Since fababeans grown at Altona, and Pilot Mound did not respond to nitrogen fertilizers, the quantity of nitrogen symbiotically fixed in conjunction with available inorganic soil nitrogen appeared to have been sufficient for plant needs. These data indicate that low symbiotic nitrogen fixation was caused by environmental conditions which reduced fababean growth *per se*, and was not due to factors which influenced functioning of fababean nodules.

FIELD TRIALS: 1975

Fababeans grown in field trials in 1973 and 1974 on soils containing low to high quantities of NO_3 at time of seeding were unaffected by rate and placement of nitrogen fertilizers. Fababeans in 1974 field trials were found to have derived approximately two-thirds of their total nitrogen from symbiotic nitrogen fixation. The 1974 field trial results also indicated that fababeans could symbiotically fix adequate quantities of nitrogen when grown in adverse environmental conditions. However insufficient data were generated from these field trials concerning the ability of fababeans to symbiotically fix adequate nitrogen when grown in more favorable conditions. Therefore, in an attempt to further elucidate fababeans symbiotic nitrogen fixation capacity additional field trials were conducted during the summer of 1975. The methods used to conduct these experiments are described in the Methods and Materials section.

SOILS

In 1975 field experiments were conducted at Carman, St. Claude, Teulon and Zhoda. The soil at Carman was an Orthic Black developed on light to medium textured deltaic and lacustrine deposits and was mapped as an AltonaVFSL (Ellis et al., 1943). The soil at St. Claude was an Orthic Black developed on coarse textured lacustrine deposits and was mapped as an Almasippi loamy sand (Ehrlick et al., 1957). The soil at Teulon was a Gleyed Rego Black, developed on medium to moderately coarse textured deltaic deposits and was mapped as a Plum Ridge (Pratt et al., 1961). The soil at Zhoda was an Eluviated Gleysol developed on sandy textured outwash deposits on Calcareous till and was mapped as a Pine Ridge sandy loam (Ehrlick et al., 1953).

Soil sampling conducted at seeding showed that all soils were base saturated and had low soluble salt concentrations. $NaHCO_3$ extractable phosphorus concentrations were very low at Zhoda, and at Teulon, low at St. Claude and medium at Teulon based on ranges used by Provincial Soil Testing Laboratories (Fehr 1974). NaOAc exchangeable potassium contents ranged from very low at Zhoda to very high at Carman (Table 25). Water soluble SO_4 in the 0 to 60 cm depth increment was adequate at all sites except at Teulon where sulfur fertilizers would have been recommended for rapeseed production. Nitrate-nitrogen contents in the 0 to 60 cm depth increment were low at

TABLE 25

Some Characteristics of Soils in 1975 Field Trials.

Location	Soil Name	Texture	pH	Conductivity mmhos/cm	Nitrate Nitrogen content (kg/ha)		$NaHCO_3$ Ext. P(ppm)	Exchangeable K(ppm)	Sulfate Sulfur content (kg/ha)	
					0-60cm	0-120cm			0-60 cm	0-120cm
St.Claude	Almasippi (Orthic Black)	LFS	8.00	0.1	20.37	55.64	5.4	51.0	32.9	58.6
Carman	Altona (Orthic Black)	VFSL	7.98	0.3	125.2	184.9	9.7	169.0	130.7	511.6
Teulon	Plum Ridge (Orthic Black)	VFSL	7.90	0.3	15.3	24.8	3.0	64.4	19.3	53.5
Zhoda	Pine Ridge (Eluviated Gleysol)	SL	7.20	0.3	29.3	40.1	3.9	40.2	27.2	58.2

St. Claude and Teulon, and medium in the Pine Ridge soil at Zhoda. However the 0 to 120 cm depth increment at St. Claude the Almasippi LFS had higher quantities of NO_3 than did the Pine Ridge soil at Zhoda. The Altona VFSL at Carman contained very high amounts of NO_3 in both the 0 to 60 cm and 0 to 120 cm depth increments, such that cereal response to added nitrogen fertilizers were not predicted.

EFFECT OF NITROGEN FERTILIZERS UPON FABABEAN YIELD

Nitrogen fertilizer surface broadcast at seeding at rates up to 150 kg N/ha had no significant effect upon the forage yield of fababeans harvested 50 and 80 days after seeding (Table 26). Dry matter production by unfertilized and fertilized fababeans harvested biweekly throughout the season were similar (Fig.3). These data are in agreement with previous results reported for 1974 field trials though data from 1975 field trials were much more uniform than the data from 1974 field trials. Maximum rate of dry matter production occurred during the full bloom to mid pod-fill stage (63 to 76 days after seeding at Carman), the same time which maximum growth in 1974 field trials was observed. Unfertilized fababeans had a maximum growth rate of 75 kg plant material/ha/day and fertilized fababeans had a growth rate of 77 kg plant material/ha/day. These growth rates are considerably lower than those recorded in 1974 field trials, and could possibly be due to the more adverse growth conditions which occurred at the

TABLE 26

EFFECT OF NITROGEN FERTILIZATION ON TOTAL ABOVE GROUND YIELD OF FABABEAN FORAGE HARVESTED 50 AND 80 DAYS AFTER SEEDING IN FIELD TRIALS 1975.

Nitrogen applied (kg N/ha)	Yield of Forage (kg /ha)						
	Field Trial Location						
	Carman		St. Claude		Teulon		Zhoda
	50 d	80 d	50 d	80 d	50 d	80 d	50 d
0	802a	2273a	557a	2226a	925a	3341a	800a
30	859a	3322a	606a	2312a	832a	3347a	1171a
90	1003a	3259a	695a	2415a	778a	3563a	1021a
150	964a	3232a	558a	2584a	877a	3078a	857a

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

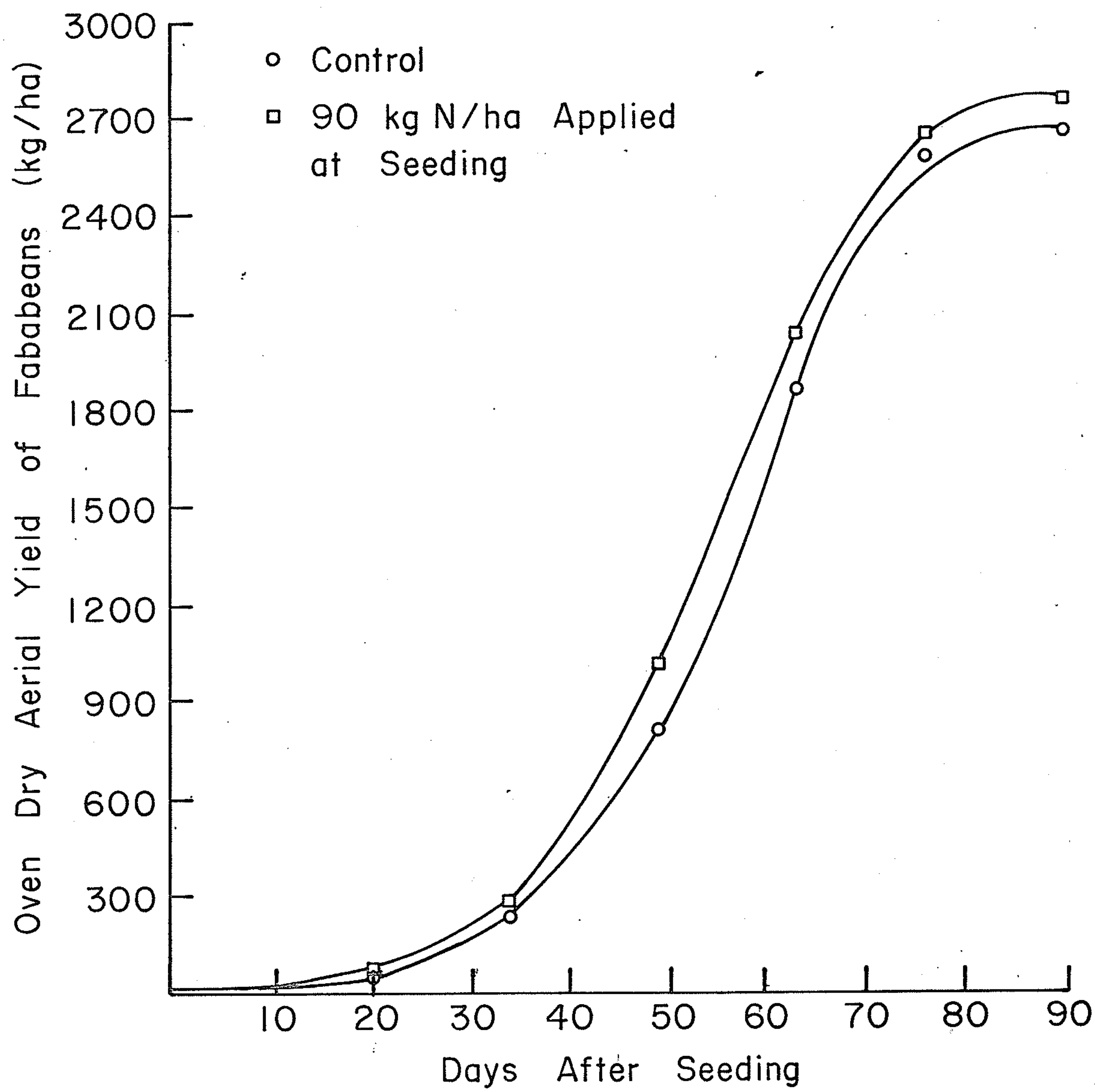

FIGURE 3: Effect of 90 kg N/ha surface broadcast at seeding on seasonal aerial dry matter accumulation in Carman field trial 1975.

Carman field trial in 1975.

Seed and straw yields in 1975 field trials were similar to values reported for 1974 field trials (Tables 12, 27, 28). Nitrogen fertilizer applied at seeding, in single large late season doses, or in split applications (Table 28) had no effect upon seed or straw yields of 1975 fababeans. These data are in agreement with previous field trial data which showed that neither rate, nor placement of nitrogen fertilizer had a significant effect upon fababean seed and straw yields. Ratios of seed to straw yields were 0.64:1 at Carman; 0.76:1 at St. Claude; 0.64:1 at Teulon and 0.44:1 at Zhoda. These ratios are similar to ratios obtained in 1974 field trials, and possibly indicate that fababean seed yields were again restricted as a result of adverse environmental conditons, as the ratios were considerably lower than ratios obtained from 1973 field trials when seed yields were high.

EFFECT OF NITROGEN FERTILIZATION UPON PERCENT PROTEIN CONTENT OF FABABEANS

Percent protein content of fababeans forage harvested during full bloom and early to mid-pod filling stages (50 and 80 days after seeding respectively) were variably affected by nitrogen fertilization (Table 29). Percent protein content of fababeans grown in one or more nitrogen fertilization treatments were significantly increased in fababean forage harvested 50 and 80 days after seeding at Carman, in fababean forage harvested 80 days

TABLE 27

EFFECT OF NITROGEN FERTILIZATION ON YIELD OF FABABEAN SEED AND STRAW IN FIELD TRIALS 1975.

Nitrogen applied (kg N/ha)	Yield (kg/ha) — Field Trial Location: St. Claude		Teulon		Zhoda	
	Grain	Straw	Grain	Straw	Grain	Straw
0	1407a	1760a	1582a	2758a	729a	1522a
30	1309a	1528a	1527a	2448a	614a	1348a
90	1298a	1731a	1587a	2650a	629a	1292a
150	1275a	1693a	1421a	2342a	601a	1847a
90[1]	1394a	1794a	1447a	2476a	731a	1758a
90[2]	1160a	1801a	1484a	2590a	670a	1478a

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

[1] fertilizer applied at full bloom stage

[2] fertilizer applied at early to mid pod fill stage

TABLE 28

EFFECT OF NITROGEN FERTILIZERS ON YIELD OF FABABEAN SEED AND STRAW IN CARMAN FIELD TRIAL 1975.

Nitrogen Applied (kgN/ha)				
Time of Nitrogen Application			Yield (kg/ha)	
Seeding	Full bloom	Early pod fill	Grain	Straw
0	-	-	1110a	1439a
30	-	-	1053a	1547a
90*	-	-	1167a	1483a
150	-	-	994a	1465a
-	90	-	1186a	1700a
-	-	90	1165a	1710a
30*	30	30	914a	1449a
30	30*	30	1048a	1571a
30	30	30*	1100a	1666a

* Nitrogen fertilizer enriched with ^{15}N

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

TABLE 29

EFFECT OF NITROGEN FERTILIZER ON PERCENT PROTEIN CONTENT OF FABABEAN FORAGE HARVESTED 50 AND 80 DAYS AFTER SEEDING IN FIELD TRIALS 1975.

Nitrogen applied (kg N/ha)	Percent Protein[1] Content of Forage — Field Trial Location: Carman 50 d	Carman 80 d	St. Claude 50 d	St. Claude 80 d	Teulon 50 d	Teulon 80 d	Zhoda 50 d
0	21.2a	15.4a	23.7a	13.0ab	24.5a	18.4a	21.0a
30	23.2ab	20.2b	23.2a	15.2bc	24.3a	18.7a	21.2a
90	24.4b	19.1ab	22.6a	9.6a	26.3b	18.3a	22.8a
150	24.6b	19.1ab	24.0a	18.6c	26.7b	18.9a	21.8a

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

[1] Protein content expressed on oven dry moisture content. Protein factor = 5.7 x %N.

after seeding at St. Claude, and in fababean forage harvested 50 days after seeding at Teulon (Table 29). These data are consistent with results from 1974 field trials which indicated that nitrogen fertilization had variable effects upon percent protein content of fababean forage. Percent protein content of fababean forage decreased with advancing crop maturity, as in 1974 field trials.

Percent protein content of fababean seed was unaffected by all rates, times and application methods of nitrogen fertilizer (Table 30). The only exception which occurred was at Teulon where the two highest spring application rates used (90, 150 kg N/ha) significantly reduced percent protein in fababean seed. These data concur with data obtained from 1973 and 1974 field trials (Tables 8 and 14). Percent protein contents of fababean seed from Carman and St. Claude were similar to values reported in previous years. However percent protein content of fababean seed grown at Teulon and Zhoda were higher than any previously obtained. Percent protein content of fababean straw appeared to have been increased by nitrogen fertilizers. However, due to method of obtaining straw samples for crude protein analysis, statistical verification of this trend was not accomplished.

EFFECT OF NITROGEN FERTILIZER ON NITROGEN UPTAKE INTO FABABEAN AERIAL PORTIONS

Total aerial nitrogen uptake into fababean forage was not affected by various rates of nitrogen surface broad-

TABLE 30

EFFECT OF NITROGEN FERTILIZER ON PERCENT PROTEIN CONTENT IN SEED AND STRAW OF FABABEANS IN FIELD TRIALS 1975.

Fertilizer applied (kg N/ha)	Percent Protein[1] Content — Field Trial Location							
	Carman		St. Claude		Teulon		Zhoda	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
0	28.9a	4.73	30.1a	7.5	33.1b	6.8	32.1a	8.3
30	29.8a	5.38	29.3a	8.2	33.2b	7.6	31.0a	8.4
90	30.0a	4.24	29.1a	7.3	31.8a	6.7	32.3a	9.4
150	31.1a	5.26	29.8a	10.7	31.6a	8.0	33.4a	9.4
90[2]	29.4a	5.00	30.0a	9.0	33.0b	8.3	32.8a	7.9
90[3]	29.5a	4.36	29.9a	7.9	33.9b	9.0	32.6a	9.1
90[4]	30.2a	4.89	-	-	-	-	-	-

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

1: Protein content expressed on oven dry moisture content % Protein = 5.7 x %N
2: Fertilizer applied at full bloom
3: Fertilizer applied at early pod-fill
4: Split application of nitrogen fertilizer at seeding, full bloom, and early pod

cast at seeding (Table 31), except in fababean forage harvested eighty days after seeding at Carman, where all fertilizer rates used substantially increased fababean aerial nitrogen uptake. Nitrogen uptake into fababean seed and straw was unaffected by all rates and times of nitrogen fertilizer application (Table 32). Quantities of nitrogen contained in above-ground fababean plant material at maturity in 1975 were similar to 1974 fababean nitrogen uptake values, (Table 16), and lower than 1973 fababean nitrogen uptake values (Table 9).

Results obtained from biweekly sampling of control and 90 kg N/ha treated fababeans grown at Carman indicate fababean above ground nitrogen content was highest in fababeans harvested at mid pod-fill stage (Fig.4). Fababeans appeared to lose nitrogen during the mid pod-fill to senescence harvests. Nitrogen uptake into fababeans treated with 90 kg N/ha at seeding appeared to be greater than into control fababeans throughout most of the growing season (Fig.4). Though in later growth stages the differences appear to be large, the differences between nitrogen uptake into control and 90 kg N/ha treated fababeans are non-significant. Other treatments at Carman also lost nitrogen during these growth periods (Tables 31, 32).

Distribution of nitrogen within mature fababean aerial portions was calculated. The percent of total aerial nitrogen contained in fababean seed with 81% at

TABLE 31

EFFECT OF NITROGEN FERTILIZATION ON NITROGEN UPTAKE INTO FABABEAN FORAGE HARVESTED 50 AND 80 DAYS AFTER SEEDING IN FIELD TRIALS 1975.

Nitrogen applied (kg N/ha)	Nitrogen Uptake (kg N/ha)						
	Field Trial Location						
	Carman		St. Claude		Teulon		Zhoda
	50 d	80 d	50 d	80 d	50 d	80 d	50 d
0	30.3a	62.3a	23.3a	51.4a	39.4a	105.7a	29.6a
30	35.3a	119.8b	24.5a	60.6ab	35.4a	109.8a	43.5a
90	42.7a	110.1b	27.7a	39.4a	35.9a	115.3a	41.4a
150	41.7a	109.5b	23.6a	83.1b	41.0a	100.1a	32.3a

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

TABLE 32

EFFECT OF NITROGEN FERTILIZATION UPON NITROGEN UPTAKE INTO SEED AND STRAW OF FABABEANS IN FIELD TRIALS 1975.

Nitrogen applied (kg N/ha)	Nitrogen Uptake (kg N/ha) — Field Trial Location: Carman			St. Claude			Teulon			Zhoda		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
0	54.6a	11.9	66.5	73.4a	23.3	96.7	91.7a	30.9	122.6	40.9a	22.2	63.1
30	55.2a	14.6	69.8	67.1a	22.1	89.2	89.2a	30.6	119.8	33.3a	20.0	53.3
90	61.4a	11.0	72.4	65.0a	22.3	87.3	88.6a	24.5	113.1	35.5a	21.3	56.8
150	54.1a	14.5	68.6	66.9a	24.7	91.6	78.8a	30.7	109.5	34.7a	30.5	65.2
90[1]	64.4a	14.9	78.8	72.8a	28.5	101.3	83.7a	33.7	117.4	41.6a	24.3	65.9
90[2]	60.5a	13.1	73.6	60.8a	24.8	85.6	87.7a	38.3	126.0	38.2a	23.6	61.8
90[3]	58.2a	13.5	71.7	-	-	-	-	-	-	-	-	-

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

1: fertilizer applied at full bloom
2: fertilizer applied at early pod-fill
3: fertilizer applied in split application of 30 kg N/ha at seeding, at full bloom and at early pod-fill stage

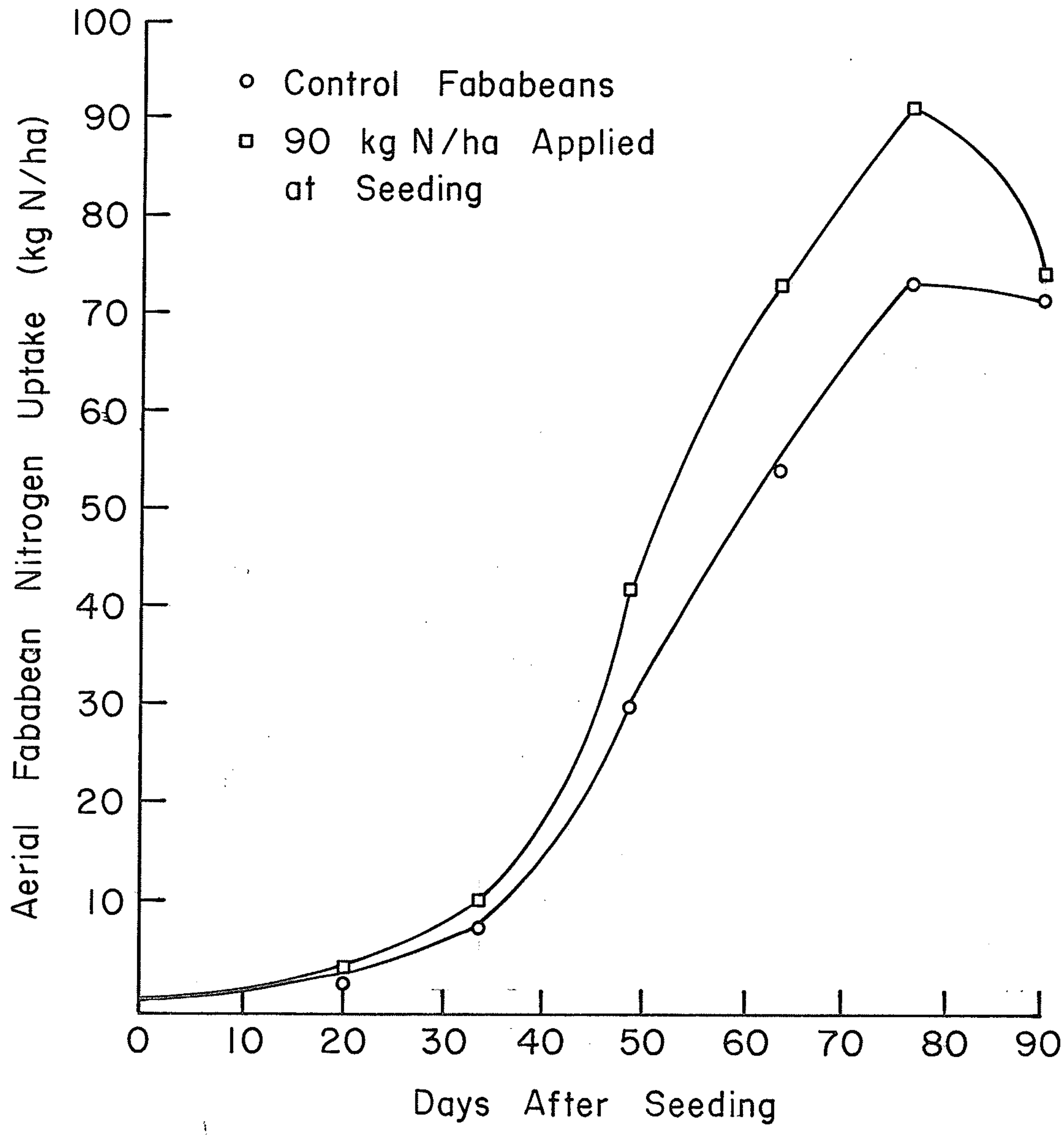

FIGURE 4: Effect of 90 kg N/ha surface broadcast at seeding upon seasonal nitrogen uptake into aerial portions of fababeans in Carman field trial 1975.

Carman, 74% at St. Claude, 73% at Teulon, and 63% at Zhoda. The remainder of plant nitrogen was located in plant leaves, stems, and pods. These values are somewhat higher than obtained in 1974 field trials, and except for Carman are lower than 1973 field trial results. Values indicate 1975 fababeans were more mature than 1974 fababeans at senescence, confirming previous observations that 1974 fababeans were killed by frost.

EFFECT OF NITROGEN FERTILIZER ON BARLEY

Nitrogen fertilizer applied to barley at seeding significantly increased forage yields, and yields of seed and straw in all 1975 field trials except Carman (Table 33). Due to a misunderstanding mature barley samples from Carman were not threshed, and hence grain and straw data are unavailable. However the final nitrogen uptake into barley was high, as were vegetative yields, indicating that the lack of barley yield response to applied nitrogen fertilizers was due to presence of sufficient quantities of available soil inorganic nitrogen. Due to the cooperator accidentally swathing the barley experiment before final yield samples were taken at Teulon, grain and straw data are unavailable. Vegetative barley samples harvested the week prior to the planned mature harvest date were used in lieu of mature samples. Generally nitrogen uptake into barley closely followed yield trends, and therefore significant nitrogen uptake increases

TABLE 33

EFFECT OF NITROGEN FERTILIZATION ON FORAGE YIELD OF BARLEY IN FIELD TRIALS 1975.

Nitrogen applied (kg N/ha)	Barley Yield (kg /ha) — Field Trial Location: Carman 50 d	Carman 80 d	St. Claude 50 d	St. Claude 80d	St. Claude Grain	St. Claude Straw	Teulon 50 d	Teulon 80 d	Zhoda 50 d	Zhoda Grain	Zhoda Straw
0	2687b	5674a	1189a	3287a	957a	1360a	1558a	2295a	1970a	1474a	1716a
90	2113a	5321a	2365b	5050b	1714b	2499b	2661b	3707b	2757b	1947b	3180b

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

TABLE 34

EFFECT OF NITROGEN FERTILIZATION ON NITROGEN UPTAKE INTO AERIAL BARLEY PORTIONS IN FIELD TRIALS 1975

Nitrogen applied (kg N/ha)	Nitrogen Uptake into Barley (kg N/ha) — Field Trial Location: Carman 50 d	Carman 80 d	St. Claude 50 d	St. Claude 80 d	St. Claude Grain	St. Claude Straw	St. Claude Total	Teulon 50 d	Teulon 80 d	Zhoda 50 d	Zhoda Grain	Zhoda Straw	Zhoda Total
0	89.4b	95.2a	22.4a	49.6a	20.8a	7.8	28.5	23.4a	30.7a	29.0a	32.1a	7.8	39.8
90	62.0a	97.4a	56.5b	83.6b	40.0b	15.5	65.5	56.3b	60.0b	60.3b	50.2b	22.0	72.8

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

into barley as a result of nitrogen fertilization occurred at all sites except Carman (Table 34). At Carman nitrogen uptake into unfertilized barley was similar to that into fertilized barley.

Experimental data obtained from 1974 field trials indicated that non-nod fababeans and barley had similar aerial nitrogen uptake values. Therefore, in 1975 field trials barley was used to measure the quantity of soil and fertilizer nitrogen which was available to nodulated fababeans.

FABABEAN NITROGEN FERTILIZER UPTAKE

Fertilizer nitrogen uptake into fababeans was measured by ^{15}N techniques at the Carman field trial. Tracer ^{15}N subplots consisted of three labelled 90 kg N/ha subplots which were harvested 50 and 80 days after seeding and at maturity. A ^{15}N-labelled single fertility treatment described by Fried *et al.* (1975) was incorporated into the experimental paragin. The treatment consisted of three applications of 30 kg N/ha applied at seeding, full bloom and mid pod-fill stages. The treatment was repeated three times in each replicate, such that one of the treatments had labelled fertilizer nitrogen applied and the other two unlabelled fertilizers in each application time. Each of the three treatments had ^{15}N fertilizers applied once, at seeding in treatment 7a, at full bloom in 7b, and at mid pod-fill in 7c (Table 4c). Since these treatments only differed in time of ^{15}N

application determination of percent fertilizer recovery by fababean aerial portions for each application was possible.

Fertilizer uptake into fababeans grown at Carman was low, as determined by ^{15}N techniques (Table 35). Aerial portions of fababeans fertilized with 90 kg N/ha surface broadcast at seeding recovered 12% of the applied fertilizer at senescence. Data indicate fababeans had completed most of their fertilizer nitrogen uptake at the time of the fifty day harvest, and all at the time of the 80 day harvest. Quantity of fababean aerial nitrogen derived from fertilizer sources appears to have decreased during the interval between mid pod-fill and maturity (Table 35). These data agree with total nitrogen uptake data which showed that the maximum fababean aerial nitrogen content occurred during the mid pod-fill stages, and that fababean aerial nitrogen content decreased during the mid pod-fill to senescence growth periods. The decrease was attributed to leaf abscision. These data are not consistent with 1974 field trial data in which maximum fertilizer nitrogen uptake into fababean aerial portions occurred during the interval from early pod-fill to senescence. This discrepancy could have been caused by the dry environmental conditions encountered during the early fababean growth stages in 1974 field trials which reduced the availability of surface applied nitrogen fertilizers.

Data indicate that nitrogen fertilizer applied

TABLE 35

Utilization of 90 kg N/ha Surface Broadcast at Seeding by Aerial Portions of Fababeans Harvested at Various Times as Determined by ^{15}N in Carman Field Trial 1975.

Time of harvest (days after seeding)		Aerial fababean nitrogen derived from fertilizer nitrogen (kgN/ha)	Percent fertilizer recovered by aerial fababean portions
50 days (full bloom stage)		14	16.1%
80 days (mid pod stage)		17	19.0%
90 days (senescence)	grain	10.1	14.6%
	straw	1.9	
	total	12.0	

at seeding, though taken up into the plant mainly before full bloom stage, were readily translocated to the seed during pod-fill stages. Thus it appears that even when fababeans were grown in an environment which contained high amounts of available nitrogen, translocation of nitrogen from vegetative plant parts to the developing pods occurred. Hence at maturity, 84% of the total fertilizer recovered by fababean aerial portions was located in the fababean seed. High rates of nitrogen translocation from leaves to developing seeds have been shown to cause premature leaf abscission in soybeans (Lathwell and Evans, 1951), resulting in premature nodule senescence and hence reduced yield (Sinclair and deWit, 1976). Amelioration of premature nodule senescence has been accomplished by growing soybeans in media containing high quantities of available nitrogen (Lathwell and Evans, 1951) and by foliar application of N:P:K:S solution during the pod-filling stages (Garcia and Hanway, 1976). In fababeans grown in the Carman field trial intra-plant nitrogen translocation occurred, indicating that in fababeans nitrogen translocation within the plant was independent of soil inorganic nitrogen contents. These results suggest that fababeans behave similarly to soybeans in terms of nitrogen nutrition during the later stages of growth.

Results from ^{15}N-labelled single fertility treatment are presented in Table 36. Recovery of fertilizer nitrogen was highest when fertilizer was applied at seeding

TABLE 36

EFFECT OF SPLIT APPLICATIONS OF NITROGEN FERTILIZER ON FERTILIZER NITROGEN UPTAKE AND DISTRIBUTION WITHIN MATURE FABABEAN AERIAL PLANT PARTS AS DETERMINED BY ^{15}N-LABELLED SINGLE FERTILITY TREATMENT IN CARMAN FIELD TRIAL 1975.

nitrogen fertilizer applied (kgN/ha)			nitrogen distribution within fababean				
time of nitrogen application			% fababean nitrogen derived from fertilizer		kgN/ha in fababean aerial portions derived from fertilizer		% nitrogen fertilizer recovered by fababean aerial portions
seeding	full bloom	early pod fill	grain	straw	grain	straw	
30*	30	30	7.2	7.4	3.6	0.8	14.7
30	30*	30	5.8	3.8	3.2	0.5	12.3
30	30	30*	2.4	0.9	1.4	0.1	5.0
			Total seasonal		8.2	1.4	10.7

* nitrogen fertilizers enriched with ^{15}N

and lowest when fertilizer nitrogen was applied at mid-pod filling stage. Fababeans recovered 14.7% of nitrogen fertilizer applied at seeding, 12.3% of nitrogen fertilizer applied at full bloom stage, and 5.0% of fertilizer nitrogen applied at mid pod. The total quantity of fertilizer nitrogen added in three applications was 90 kg N/ha of which fababean above-ground portions recovered 9.6 kg N/ha, the overall efficiency of fertilizer utilization being 10.7%. Fababeans fertilized with 90 kg N/ha at seeding recovered 19% of the applied fertilizer in above ground portions harvested at mid pod-filling stage, (Table 35). These results were unexpected because it is usually considered that split applications of fertilizer are more efficiently recovered by crops than single applications at seeding, due to the plant's higher ability to extract inorganic nitrogen during later growth stages, and due to the plant's increased need for nitrogen during later growth stages. Examination of the data (Table 36) indicates that low overall recoveries in split application treatments were caused by extremely low nitrogen fertilizer uptake during later growth stages. This could have been caused by dry soil conditions and low precipitation which reduced availability to fababeans of surface applied fertilizers, and/or by inability of fababean plant itself to extract fertilizer nitrogen during later growth stages.

Comparison of the percent seed and straw nitrogen derived from the fertilizer (Ndff) in the three split application (Table 36), show that straw NdFF values are somewhat higher than seed values when nitrogen was applied at seeding. However, seed NdFF values are larger than straw NdFF values when nitrogen was added at full bloom, and even larger when nitrogen was added at mid pod-fill stage. These data are in agreement with wheat results which indicate late season nitrogen applications were preferentially adsorbed into the grain (Soper and Rennie, 1974, Mouchova et al., 1974).

BARLEY FERTILIZER NITROGEN UPTAKE

Utilization of fertilizer nitrogen by barley grown in 1975 field trials, except for the Carman site was higher than in 1974 (Table 37). This was probably caused by more favorable growing conditions encountered in 1975. Since recovery of fertilizer nitrogen into barley shoots was calculated by the difference method, and since application of 90 kg N/ha had no effect upon aerial nitrogen uptake into barley, the percent utilization of applied fertilizer was calculated to be zero at Carman.

EFFECT OF NITROGEN FERTILIZERS ON FABABEAN SYMBIOTIC NITROGEN FIXATION

Data from field trials indicate that mature unfertilized fababeans derived from 0 to 71% of their total aerial nitrogen content from symbiotic nitrogen fixation (Table 38). Fababeans grown at Carman were calculated to have fixed zero percent of their aerial nitrogen contents.

TABLE 37

EFFICIENCY OF FERTILIZER NITROGEN RECOVERY BY BARLEY IN FIELD TRIALS 1975.

% Fertilizer Nitrogen Recovered — Field Trial Location									
Carman		St. Claude			Teulon		Zhoda		
50 d	80 d	50 d	80 d	Final	50 d	80 d	50 d	Final	
0%	0%	37.8	37.8	41.1	36.6	32.6	34.8	36.7	

TABLE 38

EFFECT OF NITROGEN FERTILIZER APPLICATION ON PERCENT OF TOTAL FABABEAN AERIAL NITROGEN DERIVED FROM SYMBIOTIC NITROGEN FIXATION IN FIELD TRIALS 1975.

Nitrogen applied (kg N/ha)	Percent of Fababean Aerial Nitrogen Derived from Symbiosis — Field Trial Location			
	Carman	St. Claude	Teulon	Zhoda
0	0%	71%	71%	37%
90	0%	25%	48%	0%

This was due to the high soil inorganic nitrogen contents and low fababean yields which resulted in a nitrogen demand which was adequately supplied by the soil reserves. However, fababeans grown at Carman were well nodulated, and since the difference method is not always totally correct, it can be postulated that fababeans did fix some nitrogen and that the quantity fixed was small. Addition of 90 kg N/ha of nitrogen decreased symbiotic nitrogen fixation in fababeans grown at Zhoda from 37% to zero percent of aerial nitrogen. This effect also occurred at Teulon and St. Claude where 90 kg N/ha fertilizer decreased symbiotic nitrogen contribution from 71% of total aerial nitrogen to 25% at St. Claude, and to 48% at Teulon. Though unfertilized fababeans in St. Claude and Teulon field trials symbiotically fixed the same proportion of aerial nitrogen, the quantities of nitrogen symbiotically fixed were not similar. Control fababeans at St. Claude symbiotically fixed 69 kg N/ha, while control fababeans grown in the Teulon field trial symbiotically fixed 87 kg N/ha in aerial plant portions. The estimates of proportion of plant nitrogen symbiotically fixed were calculated on aerial fababean portions only and may be subject to some variation if total plant (aerial + root nitrogen) nitrogen is considered. Proportions of aerial plant nitrogen derived from symbiotic nitrogen in 1975 field trials are similar to the proportions calculated from 1974 field trial data.

Fababeans were found to be efficient symbiotic nitrogen fixers. Based on results obtained from seven field trials conducted during the summers of 1974 and 1975, fababeans were calculated to have derived 54% of their nitrogen from symbiotic fixation, with five of the seven trials having fixed 63 to 71% of their aerial nitrogen contents. The assumption that fababeans are efficient symbiotic nitrogen fixers is also supported by evidence from 1973 field trials in which high aerial yields and nitrogen uptake into aerial portions occurred but in which no response to applied nitrogen fertilizers occurred. Since these field trials were conducted in soils which did not contain sufficient inorganic nitrogen to achieve these high results, it must be assumed that symbiotic nitrogen fixation was producing sufficient quantities of nitrogen. Fababeans also appear to have had sufficient nitrogen in later growth stages, as nitrogen applications during full bloom and/or mid pod stages had no effect upon fababean growth performance. These data are in agreement with McEwen (1970), who reported that yield of fababeans was affected by only high (336 kg N/ha) applications of nitrogen at seeding, and that the response was generally less than 10%. McEwen considered that symbiotic nitrogen fixation in fababeans produced quantities of nitrogen which were sufficient for plant needs. These data also concur with reports by Rinno _et al._ (1973) in which neither low rates at seeding, nor heavy late applications of nitrogen fertilizer had an effect upon fababean growth. They considered that fababeans fixed sufficient quantities of nitrogen throughout their entire growth cycle, unlike Pisum arvense and Pisum sativa which responded to late heavy nitrogen fertilization.

GROWTH CHAMBER EXPERIMENT ONE:

Two growth chamber experiments were conducted in which the effects of rates and times of nitrogen fertilization upon aerial yield, percent protein, and upon symbiotic nitrogen fixation in fababeans were studied. Growth chamber experiment one and two differed only in that fababeans grown in experiment one were inoculated with an ineffective Rhizobia strain while fababeans grown in growth chamber experiment two were inoculated with an effective Rhizobia strain. Experimental design and procedures are outlined in the Methods and Materials section.

Fababeans grown in growth chamber experiment one exhibited large variations in measured characteristics both among treatments and among replicates. Throughout most of the experiment nitrogen treatments could be visually identified. Increasing rates of nitrogen fertilization increased growth and decreased chlorotic plant tissue in fababeans. Since only scattered nodule initiation was observed in some fababean roots when plants were thinned four weeks after seeding, ineffective inoculum was suspected. This suspicion was confirmed at harvest when roots were separated from soil and inspected. Scattered, poor nodulation was observed, nodules when present were mainly located in smaller lateral roots instead of in the larger main roots. Presence of small nodule clusters was also observed in many roots. It was assumed that these nodules were generally ineffective.

Fababeans became nitrogen deficient early in their life cycle. Nitrogen deficiency symptoms were first observed in control treatment when fababeans attained plant height of 10 to 12 cm which corresponded to the 8 to 12 leaf stage. It was postulated that the control treatments had depleted seed and soil nitrogen reserves and were not actively fixing sufficient nitrogen. In time all treatments became chlorotic, the time at which the plants became chlorotic being related to the rate of nitrogen application. Hence fababeans grown in treatments which received low rates of fertilizer became chlorotic before treatments which received higher rates of nitrogen. With increasing severity of nitrogen deficiency older leaves became yellow and abscised prematurely. In extreme cases of nitrogen deficiency all leaves except those contained in the growing point abscised. Leaves in growing points of nitrogen deficient fababeans were observed to be more profuse and smaller than those contained in more normal plants. When nitrogen was applied to chlorotic plants the younger leaves became greener, this was followed by a general greening of the older leaves, and then by a proliferation of leaf growth. The extreme experimental variability was well illustrated in the case where one plant in a pot was severely N deficient and the other plant was normal, indicating that nodulation and hence nitrogen fixation of fababeans grown in this experiment was sporadic.

SOILS USED IN GROWTH CHAMBER EXPERIMENT

Soil used was an Ap horizon of a Stockton SL (Ehrlich *et al.*,1957). The soil was neutral in reaction and had a low calcium carbonate equivalent (Table 39). Soluble salt concentration as measured by electrical conductivity was low. Percent organic matter, as determined by Wakley-Black dichromate oxidation method, was 4.3%, a value which is high for a Stockton Ap. The soil was moderately well supplied with $NaHCO_3$ extractable phosphorus, and NH_4OAc exchangeable potassium, but contained low concentrations of available NO_3-N. Percent water content of the soil on an oven dry basis when at field capacity was determined to be 24.5%.

TABLE 39

SOME CHARACTERISTICS OF SOIL USED IN GROWTH CHAMBER EXPERIMENTS I AND II

Soil type	Stockton
Soil texture	SL
Soil pH	6.6
Conductivity (mmhos/cm)	0.1
NO_3-N (ppm)	1.5
$NaHCO_3$ extractable P(ppm)	9.9
Exchangeable K(ppm)	329
Percent organic matter	4.3
Percent calcium carbonate equivalent	0.77

EFFECT OF NITROGEN FERTILIZER UPON FABABEAN GROWTH PERFORMANCE

Results from this experiment were extremely variable, hence only generalized trends can be discussed. Application of nitrogen fertilizer increased fababean aerial yield, with the increase being proportional to increased application rate (Table 40). Thus lowest aerial yield was obtained in fababeans which grew in the control treatment, while the highest yield was obtained in fababeans which were grown in the 900 mg N/Pot treatment, the highest rate of application employed. Fababeans which received split applications of nitrogen and fababeans which received the same quantity of fertilizer in one application at seeding or six weeks after seeding had similar aerial yields. However fababeans which received 300 mg N/Pot of nitrogen at floral initiation and/or early pod filling stage had significantly lower aerial yields than fababeans which received 300 mg N/Pot at seeding or six weeks after seeding (Table 40), suggesting that fababeans fertilized in mid-season were not capable of efficiently using combined nitrogen for aerial dry matter production.

Percent nitrogen content of fababean aerial tissues was variably affected by nitrogen fertilization (Table 40). Values ranged from 1.47% nitrogen to 2.30% nitrogen (oven dry moisture basis). Due to high variability no treatment effect could be discerned. Values obtained were much lower than results reported in field trials, and indicate faba-

TABLE 40

EFFECT OF NITROGEN FERTILIZATION ON YIELD, PERCENT NITROGEN CONTENT, AND NITROGEN UPTAKE INTO AERIAL FABABEAN PORTIONS IN GROWTH CHAMBER EXPERIMENT I.

	Nitrogen applied (mg N/Pot)				Aerial fababean		
	time nitrogen applied						
crop	seeding	6 weeks after seeding	pre-bloom	early pod-fill	oven dry yield g/Pot	nitrogen content %N**	nitrogen uptake mg N/Pot
Fababean	0	0	0	0	14.00a	1.68abc	223a
"	75*	0	0	0	21.97ab	2.30e	565abc
"	150*	0	0	0	21.97ab	2.17de	539abc
"	300*	0	0	0	35.10bc	1.97cde	710bcd
"	600*	0	0	0	31.07ab	1.47abc	455abc
"	900*	0	0	0	50.83c	1.75abcd	945d
"	75*	75	75	75			
"	75	75*	75	75	34.73b	2.14de	699bcd
"	75	75	75*	75			
"	75	75	75	75*			
"	0	300*	0	0	39.90bc	1.93bcde	758cd
"	0	0	300*	0	26.53ab	1.30a	345ab
"	0	0	0	300*	28.03ab	2.30de	634bcd
Barley	0	0	0	0	4.17	0.97	39
"	300*	0	0	0	36.97	0.71	269

* Nitrogen fertilizers enriched with ^{15}N
** %N determined on oven dry moisture content

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

beans grown in growth chamber experiment one were nitrogen deficient.

Nitrogen uptake into fababean aerial portions was apparently increased by all rates of nitrogen fertilization used, though due to large experimental error only the 900 mg N/Pot treatment significantly increased nitrogen uptake (Table 40). The 300 mg N/Pot application at seeding increased nitrogen uptake into fababean aerial portions by 314%, but the increase was not significant. These data illustrate the extreme variability which plagued this experiment.

SYMBIOTIC NITROGEN FIXATION

In order to quantitatively determine symbiotic nitrogen fixation specific values were determined for sources of nitrogen. The sources of nitrogen which were available to fababeans were seed nitrogen, combined soil and/or fertilizer nitrogen, and symbiotic nitrogen. Seed nitrogen contribution to fababean aerial nitrogen content was determined to be 20.0 mgN/Pot or 10 mg N/ plant. This was calculated by multiplying the nitrogen content of two fababean seeds (22.5 mg) by the proportion of nitrogen located in fababean aerial portions (81%), a value determined in growth chamber experiment two.

Barley (*Hordeum vulgare* L. var. conquest) was used to determine quantities of mineralized nitrogen which were available to fababean aerial portions. Nitrogen fertilizer applied to barley were tagged with ^{15}N thus allowing direct determination of the quantity of soil nitrogen contained in barley shoots. Total uptake of nitrogen into fertilized barley shoots was determined to be 269 mg N/Pot of which 180 mg N/Pot was derived from fertilizer (Table 41). Hence soil nitrogen contributed 89 mg N/Pot to barley shoots. Aerial barley portions of control barley plants contained only 39 mg N/Pot. This discrepancy could have been caused by the stimulation nitrogen fertilizers have been reported to have upon mineralization of soil organic matter or to poor growth of unfertilized barley resulting in a high root to shoot nitrogen ratio. Since barley was used to measure quantity of nitrogen available to fababeans which were supposedly not suffering nitrogen deficiencies as severe as those encountered in control barley treatment, the contribution of soil nitrogen to aerial nitrogen content of fertilized barley was assumed to be equal to that which was available to fababeans.

TABLE 41

EFFECT OF NITROGEN FERTILIZATION ON NITROGEN UPTAKE INTO BARLEY SHOOTS IN GROWTH CHAMBER EXPERIMENT ONE.

Nitrogen applied (mgN/Pot)	barley aerial nitrogen: Total Uptake (mgN/Pot)	barley aerial nitrogen: derived from fertilizer (mgN/Pot)	barley aerial nitrogen: derived from Soil (mgN/Pot)	Percent nitrogen fertilizer recovered by barley shoots
0	39	-	39	-
300	269	180	89	60.00

Determination of quantity of fertilizer nitrogen contained in fababean aerial portions was accomplished by ^{15}N techniques. Therefore quantity of symbiotic nitrogen contained in aerial fababean portions was determined by subtracting seed nitrogen, soil nitrogen and fertilizer nitrogen from total plant nitrogen.

Superficially symbiotic nitrogen fixation appears to have been progressively increased by the three lowest nitrogen fertilization rates used (Table 42), while the second highest rate (600 mg N/Pot) appears to have decreased symbiotic nitrogen fixation. However, due to the increased growth which accompanied application of the first three rates, the percent of plant nitrogen derived from symbiotic nitrogen fixation remained unchanged. However, since these data were variable symbiotic nitrogen fixation results can not be interpreted.

RECOVERY OF NITROGEN FERTILIZER

Percent fertilizer nitrogen uptake into fababean aerial portions was extremely low (Table 42). Percent recovery of nitrogen fertilizer into fababean aerial portions was rate dependent, increasing with increasing fertilization rate. Aerial portions of fababeans grown in the 900 mg N/Pot treatment recovered 2.6 times more of the applied nitrogen than did aerial portions of fababeans grown in the 75 mg N/Pot treatment. Delaying time of nitrogen application generally increased percent fertilizer nitrogen recovery, thus 77% of the 300 mg N/Pot rate

TABLE 42

Effect of Nitrogen Fertilization on Nitrogen Fertilizer Uptake and Symbiotic Nitrogen Fixation in Aerial Portions of Fababeans in Growth Chamber experiment one.

nitrogen applied (mg N/Pot) time nitrogen applied				aerial fababean nitrogen			percent fertilizer nitrogen recovered by faba-bean shoots
seeding	6 weeks after seeding	pre-bloom	early pod fill	derived from fertilizer (mg N/Pot)	derived from fixation mg N/Pot	derived from fixation Percent	
0	0	0	0	-	114	51.1	-
75*	0	0	0	14	442	78.2	18.2
150*	0	0	0	55	377	69.9	36.4
300*	0	0	0	119	482	67.0	39.6
600*	0	0	0	280	66	14.5	46.6
900*	0	0	0	420	416	44.0	46.7
75*	75	75	75	15			20.0
75	75*	75	75	27	565	80.8	36.0
75	75	75*	75	39			52.0
75	75	75	75*	18			24.4
0	300*	0	0	162	384	50.7	54.0
0	0	300*	0	146	90	26.1	48.7
0	0	0	300*	230	295	46.5	76.9

* nitrogen fertilizers enriched with ^{15}N

applied during early pod stages was taken up into fababean aerial portions, while only 40% of the 300 mg N/Pot rate applied at seeding was taken up into fababean aerial portions. Since aerial yield of fababeans grown in the 300 mg N/Pot application at seeding treatment were higher than aerial yield of fababeans grown in the 300 mg N/Pot application at early pod stages, data indicate that fababeans grown in late season application treatments were incapable of efficiently using fertilizer nitrogen for increased aerial yield even though they managed to take up a large portion of applied fertilizer into aerial portions. Delaying time of addition to six weeks after seeding resulted in a 35% increased fertilizer recovery over that obtained in the application at seeding.

Split nitrogen applications were performed in the manner outlined by Fried et al. (1975). ^{15}N-labelled single fertility treatments consisted of four 75 mg N/Pot additions applied at seeding, six weeks after seeding, floral initiation, and early pod-fill. Experimental design was such that fababean nitrogen fertilizer recovery for each application time was determined. Percent fertilizer nitrogen recovery by fababeans for nitrogen applied at seeding for the split application treatment and for 75 mg N/Pot applied at seeding were low but similar (Table 42). Recovery of fertilizer nitrogen into fababean aerial portions was higher when applied six weeks after seeding, and at floral initiation than when applied at seeding and early pod-fill. Efficiency of recovery of the total 300 mg N/Pot applied in the split application was determined to be 33%, the lowest recovery obtained in any 300 mg N/Pot treatment. Efficiency of recovery of 300 mg N/Pot applied at seeding into barley shoots was 60.0%.

SOILS

Soils in all pots were sampled upon termination of the experiment, and were analyzed for NO_3-N concentrations. Data indicate (Table 43) that soils in which fababeans grew had virtually no NO_3-N present at harvest time. Data indicate that nitrogen fertilization had no effect upon concentration of available NO_3 present in soil at harvest, hence NO_3-N concentrations of soils in which 900 mg N/Pot was added were similar to NO_3-N concentration in control treatment soils. Since virtually no available inorganic soil nitrogen was present in the soils at time of harvest, low uptake of nitrogen fertilizers into fababean aerial portions could have been due to lack of translocation of absorbed nitrogen from roots to shoots. However root data for this experiment was not determined, hence this theory can not be substantiated. Low uptake of fertilizer nitrogen into fababean aerial portions could also have been caused by losses such as denitrification and/or immobilization, though this seems unlikely as barley shoots in experiments one and two recovered similar quantities of fertilizer nitrogen.

TABLE 43

NITRATE-NITROGEN CONCENTRATIONS IN SOILS OF TREATMENTS USED IN GROWTH CHAMBER EXPERIMENT ONE AT TIME OF HARVEST

Treatment number	mg N added/Pot	ppm NO_3-N
1	0	2.2
2	75	1.9
3	150	1.5
4	300	1.5
5	600	1.2
6	900	1.3
7a	300	1.8
7b	300	1.8
7c	300	1.9
7d	300	1.4
8	300	1.6
9	300	1.6
10	300	1.5

GROWTH CHAMBER EXPERIMENT II

The inoculum used in growth chamber experiment II (Nitragin Corp Q culture) proved to be effective, hence the large variability in yield, protein content (%) and other plant characteristics which occurred in growth chamber experiment I did not occur in growth chamber experiment II. As mentioned previously methodology used in experiment I and experiment II were identical.

Fababeans germinated seven to ten days after seeding, with 50% emergence occurring 12 days after seeding. Profuse nodule initiation was observed at the time of thinning, four weeks after seeding. Fababeans grew well throughout the experiment, with only the control treatments exhibiting nitrogen deficiency symptoms. These symptoms were mild, appearing 3½ to 4 weeks after seeding, and disappearing approximately ten days later. No other visual treatment differences could be detected throughout the remainder of the experiment. Floral initiation was observed 49 days after seeding, with full bloom stage occurring ten days later. First pods were observed 75 days after seeding. Upon termination of the experiment fababeans had grown to a height of approximately one meter with little variation occurring among pots. Nodulation was examined visually and no significant differences among treatments were observed. Fababean root growth, however was observed to be much more variable than aerial plant portions.

RATES OF FERTILIZER NITROGEN APPLIED AT SEEDING

Nitrogen fertilizer, as NH_4NO_3, were applied at 75, 150, 300, 600 and 900 mg N/Pot to fababeans at seeding. The general rates used were selected to study several phenomena. The two lowest rates (75 and 150 mg N/Pot) were used to investigate starter effect fertilizer nitrogen has been reported to have upon fababean symbiotic nitrogen fixation. The deleterious effects which high concentrations of inorganic soil nitrogen have been reported to have upon legume nodulation and symbiotic nitrogen fixation were investigated by higher rates 150, 300, 600, and 900 mg N/Pot of nitrogen applied at seeding.

Nitrogen fertilizer applied at 0, 75, 150, 300 and 600 mg N/Pot at seeding had no significant effect upon fababean aerial yield (Table 44). The highest rate employed (900 mg N/Pot) caused a significant increase in fababean aerial yield, the increase being 13.7% of the control treatment yields. Percent protein content and nitrogen uptake (mg N/Pot) into aerial fababean portions were unaffected by all rates of nitrogen fertilizer applied at seeding (Table 44). Percent nitrogen contents of fababeans grown in experiment two were higher than percent nitrogen contents of fababeans grown in experiment one (Table 40). Aerial tissues of fababeans grown in the control treatment in experiment one contained 1.68% nitrogen (on oven dry basis), while aerial tissue of control treatment fababeans grown in experiment two contained 2.45% nitrogen. Nitrogen fertilizer applied to fababeans grown in experiment one had no effect on fababean nitrogen contents, but did increase aerial yields substantially, such that oven dry aerial yield of fababeans grown in the 900 mg N/Pot treatment in experiment one was similar to oven dry aerial yields of fababeans grown in experiment two. Since the only difference between experiment one and two was that an ineffective inoculum was used in experiment one, and an effective inoculum was used in experiment two, it can be postulated fababeans grown in 900 mg N/Pot treatment had approached their aerial yield potential. Since nitrogen contents of aerial tissues of fababeans grown in 900 mg N/Pot treatment were not significantly different from the control treatment in experiment one, but were lower than

TABLE 44

EFFECT OF NITROGEN FERTILIZATION ON YIELD, PERCENT NITROGEN CONTENT, AND NITROGEN UPTAKE INTO AERIAL FABABEAN PORTIONS IN GROWTH CHAMBER EXPERIMENT II

	Nitrogen applied (mg N/Pot) time nitrogen applied				Aerial fababean		
crop	Seeding	6 weeks after Seeding	pre-bloom	early pod-fill	oven dry yield g/Pot	Nitrogen content %N**	nitrogen uptake mg N/Pot
Fababean	0	0	0	0	50.50a	2.45a	1237a
"	75*	0	0	0	48.04a	2.55a	1227a
"	150*	0	0	0	48.86a	2.66a	1297a
"	300*	0	0	0	51.61ab	2.53a	1300a
"	600*	0	0	0	52.54ab	2.59a	1347a
"	900*	0	0	0	57.17b	2.42a	1380a
"	75*	75	75	75			
"	75	75*	75	75	49.11a	2.51a	1228a
"	75	75	75*	75			
"	75	75	75	75*			
"	0	300*	0	0	53.58ab	2.50a	1357a
"	0	0	300*	0	47.02a	2.50a	1173a
"	0	0	0	300*	49.11a	2.56a	1257a
Barley	0	0	0	0	2.76	1.47	40
"	300*	0	0	0	36.95	1.27	343

* indicates nitrogen fertilizers enriched with ^{15}N
** %N determined on oven dry moisture content

(numbers followed by same letters in columns are not significantly different at P = 0.05 by Duncan's Multiple Range.)

those obtained in experiment two, it can be postulated that in fababeans, a competitive effect between yield and percent nitrogen content exists such that in nitrogen deficient fababeans supplemental nitrogen additions tend to increase aerial yield before nitrogen content. Percent nitrogen content, it appears, will be increased only after nitrogen demands for potential yield have been satisfied.

Quantities of nitrogen symbiotically fixed by fababeans were calculated in the same manner described previously in growth chamber experiment one. Hence barley was again used to measure quantities of soil nitrogen mineralized during the experiment. Total nitrogen uptake into barley shoots was determined to be 343 mg N/Pot, of which 203 mg N/Pot was derived from fertilizer sources as measured by ^{15}N. Thus soil contributed 140 mg N/Pot to barley shoots (Table 45). Again as was the case in experiment one (Table 42) nitrogen uptake into control treatment barley shoots was less than the soil contribution to fertilized barley shoots. However, the value used for fababean nitrogen uptake from soil nitrogen was 140 mg N/Pot, as it was considered that comparison of two species grown in the presence of sufficient or nearly sufficient nitrogen would be more valid than comparison of one species grown in nitrogen deficient media to another species grown in environmental conditions which contained adequate nitrogen.

TABLE 45

EFFECT OF NITROGEN FERTILIZATION ON NITROGEN UPTAKE INTO BARLEY SHOOTS IN GROWTH CHAMBER EXPERIMENT TWO

Nitrogen applied (mgN/Pot)	barley aerial nitrogen Total Uptake (mgN/Pot)	derived from fertilizer (mgN/Pot)	derived from Soil (mgN/Pot)	Percent nitrogen fertilizer recovered by barley shoots
0	40	-	40	-
300	343	203	-	67.7

The quantity of symbiotically fixed nitrogen was calculated and results are depicted in Table 46. Results obtained, as were all results obtained in this experiment, were subject to low variability, suggesting uniform <u>Rhizobium</u> and fababean material were used. Control treatment fababeans derived 87.1% or 538.5 mg N/Plant of their aerial nitrogen from symbiotic nitrogen fixation. Roots of these fababean plants contained 195 mg N/Plant (Table 47). Assuming that 87.1% of root nitrogen was derived from symbiotic nitrogen fixation, fababeans grown in the control treatment symbiotically fixed 708.3 mg N/plant. This is similar to the result obtained by Candlish and Clark (1975), who reported fababeans grown in their second greenhouse experiment symbiotically fixed 840 mg N/plant.

Application of nitrogen fertilizer caused a decrease in the quantity of nitrogen symbiotically fixed by the fababean. The decrease in the quantity of nitrogen fixed symbiotically appeared to be inversely proportional to the

TABLE 46

Effect of Nitrogen Fertilization on Nitrogen Fertilizer Uptake and Symbiotic Nitrogen Fixation in Aerial Portions of Fababeans in Growth Chamber Experiment Two.

nitrogen applied (mg N/Pot)				aerial fababean nitrogen			percent fertilizer nitrogen recovered by faba-bean shoots
time nitrogen applied				derived from fertilizer (mg N/Pot)	derived from fixation		
seeding	6 weeks after seeding	pre-bloom	early pod fill		mg N/Pot	Percent	
0	0	0	0	-	1077	87.1	-
75*	0	0	0	32	1035	84.4	42.2
150*	0	0	0	105	1032	79.6	69.5
300*	0	0	0	195	945	72.6	65.0
600*	0	0	0	417	768	57.0	69.6
900*	0	0	0	642	578	41.9	71.3
75*	75	75	75	47			63.2
75	75*	75	75	52	864	70.6	68.9
75	75	75*	75	49			65.3
75	75	75	75*	46			74.7
0	300*	0	0	215	981	72.3	71.9
0	0	300*	0	191	822	70.0	63.7
0	0	0	300*	239	858	68.3	79.6

* nitrogen fertilizers enriched with ^{15}N

quantity of nitrogen fertilizer taken into the fababean. Thus symbiotic nitrogen fixation accounted for 87.1% of aerial nitrogen in control fababeans, 72.7% of the aerial nitrogen in the 300 mg N/Pot treatment and 41.9% of the aerial nitrogen in the 900 mg N/Pot treatment. This phonomenom is illustrated in Figure 5. Data indicate every milligram fertilizer nitrogen used by the fababean replaced one milligram of symbiotically produced nitrogen. These data suggest fababeans grown in experiment two were capable of symbiotically fixing the majority of their nitrogen demand. These data are in agreement with results reported by Allos and Bartholomew (1955), which indicated supplemental nitrogen applied to legumes in excess of the total quantity needed for maximum growth tended to reduce symbiotic nitrogen fixation, the reduction being inversely proportional to the quantity of nitrogen applied.

^{15}N-LABELLED SINGLE FERTILITY TREATMENT

Nitrogen, in four split applications each consisting of 75 mg N/Pot added at seeding, 6 weeks after seeding, floral initiation and at early pod-fill had no effect upon fababean aerial yield, percent protein content, and nitrogen uptake. Times of nitrogen application were selected on basis of soybean data and are discussed more fully in the following section. Split application of nitrogen treatments were inserted into the experimental paragin in order to determine symbiotic nitrogen fixation in plants which had been supplied with combined nitrogen at several

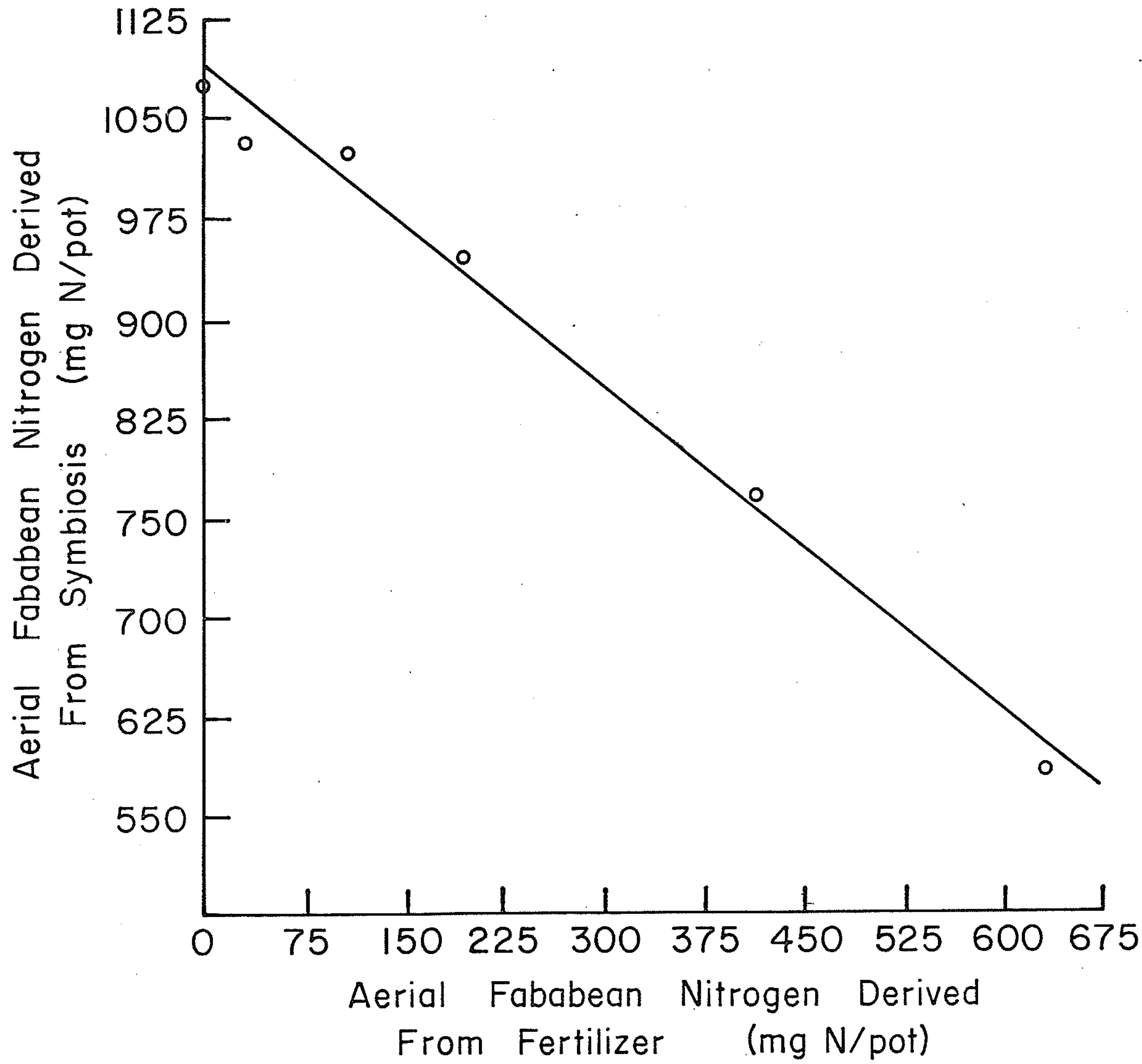

FIGURE 5: Effect of increasing increments of nitrogen fertilizer uptake into fababean aerial portions upon quantity of symbiotically fixed nitrogen contained in aerial portions of fababeans grown in growth chamber experiment two.

critical growth stages.

Since aerial yield, percent protein content and nitrogen uptake into fababeans grown in split application treatments were similar to values obtained in check treatments, data suggest fertilizer nitrogen uptake decreased symbiotic nitrogen fixation. Hence quantity of aerial fababean nitrogen derived from symbiotic nitrogen fixation was decreased from 1077 mg N/Pot (538.5 mg N/Plant) in control treatment fababeans to 864 mg N/Pot (432 mg N/Pot) in fababeans grown in split nitrogen application treatments. That is, 300 mg N/Pot added in four applications of 75 mg N/Pot each, decreased percent aerial nitrogen derived from symbiotic nitrogen from 87.1% to 70.6%.

Nitrogen was added to fababeans in single application of 300 mg N/Pot at seeding, six weeks after seeding, pre-bloom to bloom and early pod-fill stages. These treatments had no effect upon yield, protein content and nitrogen uptake into aerial fababean portions (Table 44). These treatments, though physically identical, differed in their physiological effect upon fababean growth. Application of 300 mg N/Pot at seeding could reduce and/or delay fababean nodulation possibly resulting in decreased yields and/or protein content. Application of 300 mg N/Pot six weeks after seeding would not affect nodulation, but would supply the fababean with adequate nitrogen during the initial growth stages when fababean nitrogen demand may exceed nitrogen supply. Soybeans have been reported to be occasionally lacking available nitrogen during floral initiation to full bloom stages, and application of fertilizer nitrogen at these times has been at times beneficial (Lathwell and Evans, 1951, de Mooy et al., 1973, Lawn and Brun, 1974). In order to determine if fababean symbiotic nitrogen fixation was adequate for plant needs during these growth stages, 300 mg N/Pot was added to fababeans at prebloom to bloom stages. In soybeans maximum rates of symbiotic nitrogen fixation have been reported to occur during early to mid pod-filling stages, and shortly after have been observed to decrease rapidly (Thibodeau et al., 1975). In order to determine if fababeans could symbiotically fix sufficient nitrogen during pod-fill stages, 300 mg N/Pot was applied at early pod-fill.

Aerial fababean yield, percent protein content and nitrogen uptake were unaffected by 300 mg N/Pot applied to fababeans at the four selected stages. These results suggest that available soil and symbiotically produced nitrogen were sufficient for plant needs during all growth periods. Data indicate that nitrogen fertilizers applied to fababeans were efficiently recovered by aerial portions (Table 45), suggesting fertilizer nitrogen contained in plant tissues merely substituted for symbiotically produced nitrogen. Percent of aerial nitrogen derived from symbiotic fixation was reduced from 87.1% in control treatment fababeans to 72.6% when 300 mg N/Pot was added at seeding, to 72.3% when 300 mg N/Pot was added six weeks after seeding, to 70.0% when 300 mg N/Pot was added at pre-bloom, and to 68.3% when 300 mg N/Pot was added at early pod-fill.

The symbiotic process in fababeans occurred rapidly and was able to satisfy fababean nitrogen requirements throughout its entire growth cycle. Data indicate fababeans symbiotically fixed nitrogen during the early pod-fill to senescence period of growth. Since control treatment fababeans and fababeans fertilized with 300 mg N/Pot at early pod-fill had similar aerial yields, percent protein content and nitrogen uptake values, it can be assumed that every milligram of fertilizer nitrogen located in fababean aerial tissues replaced an equal amount of symbiotically fixed nitrogen. Since fababeans fertilized with 300 mg N/Pot at early pod-fill contained 239 mg N/Pot in their aerial tissues from the fertilizer, it can be assumed that at least 239 mg N/Pot would have been symbiotically fixed during early pod to senescence periods of growth. This represents 28% of the nitrogen symbiotically fixed in this treatment. Hence data indicate at least 28% of fababean's symbiotic nitrogen was fixed during the early pod-fill to senescence growth period. These data are in agreement with Candlish and Clark (1975) who reported fababeans symbiotically fixed nitrogen after pod formation.

PERCENT FERTILIZER NITROGEN RECOVERED BY FABABEAN AERIAL PORTIONS

Percent of applied nitrogen fertilizer taken up into fababean aerial portions, and into the whole plant appeared to be unaffected by various rates of nitrogen fertilizer applied at seeding. Percent of applied fertilizer recovered by fababean aerial tissue as determined by ^{15}N was high (Table 46) ranging from 42.2% recovery of 75 mg N/Pot rate to 71.3% recovery of the 900 mg N/Pot rate. The recoveries obtained in this experiment were generally much higher than those encountered in experiment one where aerial portions of fababeans recovered 18.2% of 75 mg N/Pot applied at seeding and 46.7% of 900 mg N/Pot applied at seeding. Differences in aerial recovery of applied nitrogen fertilizers between the experiments was probably caused by different root to shoot ratios of plant nitrogen, but unfortunately root data from experiment one is unavailable and this theory can not be validated.

Efficiency of recovery of 75 mg N/Pot applied at seeding by fababean aerial portions was lower than fababean efficiency of recovery from other fertilizer nitrogen treatments. Aerial fababean portions recovered 42.2% of the 75 mg N/Pot applied at seeding while aerial portions of fababeans grown in the split treatment in which 75 mg N/Pot was added at seeding, six weeks after seeding, floral initiation, and early pod-filling stage recovered 63.2% of the 75 mg N/Pot applied at seeding. This discrepancy also existed in roots, therefore shoots and roots of fababeans grown in 75 mg N/Pot application at seeding contained 59.6% of applied fertilizer, while fababeans grown in the split treatment recovered 78.8% of the 75 mgN/Pot applied at seeding in their shoots and roots. Since the fertilizer solution used in both treatments was the same, no explanation can be advanced for this discrepancy.

Data from split application treatments and from the 300 mg N/Pot mid-season applications indicate efficiency of nitrogen fertilizer utilization by fababean aerial portions was highest when fertilizer was applied at early pod-fill and lowest when fertilizer was applied at seeding (Table 46). Hence aerial fababean portions fertilized with 300 mg N/Pot at early pod recovered 79.6% of the applied fertilizer, and analysis of root data (Table 47) indicate that roots and shoots of these fababeans recovered 89.9% of the applied fertilizer. These data are in agreement with results obtained from growth chamber experiment one in which utilization of applied fertilizer was highest in late applications, and lowest in early applications. Data are in agreement with results reported for wheat grown in similar experiments (Soper and Rennie, 1974) and for fababeans (Mouchova et al., 1974), in which efficiency of fertilizer recovery was higher when nitrogen was applied in split applications than when the same amount of nitrogen was applied at seeding. The higher efficiency of nitrogen fertilizer utilization was attributed to more efficient extraction during the later growth stages.

Fababeans were as adept as barley in extracting fertilizer nitrogen. Aerial portions of barley recovered 67.7% of the 300 mg N/Pot applied at seeding, while aerial fababean portions recovered 65.0% of the 300 mg N/Pot applied at seeding. These data indicate fababeans preferentially fed from combined nitrogen (fertilizer and inorganic soil) sources. Hence data suggest fababeans symbiotically fix nitrogen only when grown in media which does not contain sufficient available inorganic nitrogen for optimum growth. Fababeans appear to fix only the amount of nitrogen needed to insure maximum growth in prevailing environmental conditions.

FABABEAN ROOTS

Extremely high variability occurred among fababean root yields. Variability was caused in part by the difficulty encountered in separating fababean roots from the soil, resulting in loss of a large proportion of fine root hairs. Root data were used to measure total quantity of fertilizer nitrogen adsorbed into the whole fababean plant. Data indicate that 87% of the fertilizer applied to fababeans was adsorbed into the whole fababean plant (Table 47). Due to high root variability no treatment effect could be discerned. The average root : shoot nitrogen ratio was determined to be 0.19 to 0.81. Thus at senescence 19% of the total plant nitrogen was located in fababean roots and 81% was in fababean shoots.

SOILS

Soils in all pots were sampled at completion of

TABLE 47

EFFECT OF NITROGEN FERTILIZATION ON YIELD, PERCENT NITROGEN CONTENT, AND NITROGEN UPTAKE INTO FABABEAN ROOTS IN GROWTH CHAMBER EXPERIMENT II.

Nitrogen applied (mgN/Pot)				Fababean roots			
time nitrogen applied							
seeding	6 weeks after seeding	pre-bloom	early pod-fill	oven dry yield (g/Pot)	nitrogen content (%N)**	nitrogen uptake (mgN/Pot)	fertilizer nitrogen uptake (mg N/Pot)
0	0	0	0	20.31	1.86	390	0
75*	0	0	0	20.01	1.13	222	12.7
150*	0	0	0	21.39	1.40	292	37.0
300*	0	0	0	24.81	0.95	230	46.2
600*	0	0	0	30.08	1.34	389	121.5
900*	0	0	0	18.61	1.64	288	-
75*	75	75	75	18.16	1.44	218	12.1
75	75*	75	75	16.87	1.21	307	11.1
75	75	75*	75	25.54	1.81	478	24.9
75	75	75	75*	21.13	1.18	246	12.1
0	300*	0	0	20.91	1.51	298	57.6
0	0	300*	0	18.39	1.04	181	30.2
0	0	0	300*	20.00	1.12	225	30.5

* nitrogen fertilizers enriched with ^{15}N

**%N determined on oven dry moisture content experiment and were analyzed for NO_3-N concentrations. The data are presented in Table 48. The results were similar to those obtained in growth chamber experiment one which revealed that virtually no available nitrogen was contained in fababean and barley soils upon completion of the experiment. These data confirm ^{15}N data which indicate that fababeans feed preferentially from combined nitrogen and appear to symbiotically fix nitrogen only when inorganic soil and fertilizer nitrogen availability is below that needed for maximum growth.

TABLE 48

NITRATE-NITROGEN CONCENTRATIONS IN SOILS OF TREATMENTS USED IN GROWTH CHAMBER EXPERIMENT TWO AT TIME OF HARVEST

Crop	Treatment number	nitrogen applied mg N/Pot	NO_3-N Concentration (ppm)
Fababean	1	0	2.2
	2	75	2.1
	3	150	1.3
	4	300	0.7
	5	600	1.2
	6	900	1.1
	7	300	1.8
	8	300	1.2
	9	300	1.7
	10	300	3.3
Barley	11	0	5.6
	12	300	7.4

V SUMMARY AND CONCLUSIONS

Results obtained from nine field experiments and two growth chamber experiments showed that yield and protein content of effectively nodulated fababeans were not increased by addition of fertilizer nitrogen, even when fertilizers were applied at substantial rates. No evidence was found to indicate fababeans required additional nitrogen to that supplied by the soil and seed during their initial growth stages. Small amounts of nitrogen applied to fababeans at seeding in an attempt to induce a starter effect had no effect upon aerial yield or protein content of fababeans grown in soils with available nitrogen contents ranging from very low to very high at seeding. In a growth chamber experiment fababeans which received 75 and 150 mg N/Pot at seeding and control fababeans had similar aerial yields and protein contents at maturity. Since the soil used in these experiments had a very low NO_3-N concentration at seeding, it can be concluded that initiation of fababean symbiotic nitrogen fixation occurred rapidly, and that small amounts of nitrogen fertilizer applied at seeding were not required for achievement of maximum yield.

Medium rates of spring applied fertilizer nitrogen had no consistent effect upon fababean aerial yield and protein content. In two 1974 field trials, and in one 1975 field trial, biweekly sampling of fababeans from seeding to maturity showed that the application of 90 kg N/ha at seeding had no significant effect upon dry matter accumulation and percent protein content in nodulated fababeans. Maximum rate of dry matter accumulation and maximum rate of nitrogen uptake into fababeans occurred during the full bloom to mid pod-fill stages.

Large rates of fertilizer nitrogen applied to fababeans at seeding in an attempt to satisfy the majority of fababeans' nitrogen requirements by inorganic nitrogen sources generally had no effect upon aerial yield and protein content. In 1974 application of fertilizer nitrogen at rates in excess of that needed for aerial growth (300 kg N/ha) significantly increased fababean seed yield in only one out of three field trials. In growth chamber experiments aerial fababean yield was increased by 13.7% by application of 900 mg N/Pot at seeding, however nitrogen uptake into aerial fababean portions was unaffected. These results suggest that soil and symbiotically produced nitrogen was generally present in sufficient quantities for plant needs.

Field trial data showed that 34 and 67 kg N/ha, as NH_4NO_3 placed in direct contact with fababean seed had no effect upon fababean yield, nitrogen uptake. These field trials were located on soils containing low and medium quantities of available nitrogen at seeding. Since seasonal nitrogen uptake into fababean seed and straw was high, it must be concluded that fababeans symbiotically fixed large quantities of nitrogen, thus indicating fababean rhizobia was able to effectively nodulate fababeans when in direct contact with fertilizer nitrogen.

Single applications of 90 kg N/ha applied at full bloom or early pod-fill had no effect upon fababean seed yield and protein content. Nitrogen application times were selected on the basis of 1974 field trial data which indicated full bloom to early - mid pod-fill were periods of maximum fababean growth and nitrogen accumulation. Since no response occurred results indicate soil and symbiotic nitrogen were sufficient for plant needs during periods of maximum growth. In growth chamber experiments 300 mg N/Pot applied six weeks after seeding, or at pre-bloom or at early pod-fill showed fertilizer nitrogen had no effect upon fababean yield, and protein content, even though ^{15}N measurements indicated fertilizer nitrogen had been efficiently recovered by fababeans. Since these fababeans were grown in soils containing very low concentrations of NO_3-N, it can be concluded fababeans symbiotically fixed sufficient quantities of nitrogen for plant growth throughout the growing season.

Fertilizer nitrogen applied to uninoculated fababeans and/or barley increased aerial yield and protein content at all sites except one which had very high contents of available nitrogen at spring. Results showed non-nodulated fababeans required 300 kg N/ha in order to approach aerial yield and protein content of nodulated control fababeans. In growth chamber experiments aerial yields of ineffectively nodulated fababeans were increased by nitrogen fertilization. Aerial yield of ineffectively nodulated fababeans fertilized with 900 mg N/Pot at seeding approached aerial yield of effectively nodulated control treatment fababeans. However, aerial portein content of the ineffectively nodulated fababeans fertilized with 900 mg N/Pot was lower than protein content of effectively nodulated control fababeans. These results suggest a competitive effect between yield and protein content exists in fababeans. Evidence indicates nitrogen fertilizer applied to nitrogen deficient fababeans was preferentially used for increased yield, and that fertilizer nitrogen increases fababean protein content only after nitrogen demand for yield has been satisfied.

Fababeans were found to be capable of efficiently recovering applied nitrogen fertilizer . In growth chamber experiments aerial portions of fababeans and barley extracted similar quantities of fertilizer nitrogen. In fact roots and shoots of mature fababeans grown in growth chamber experiments were found to contain 87% of applied fertilizer. Efficiency of fertilizer nitrogen uptake into aerial fababean portions was higher for midseason applications than for nitrogen applications at seeding. Fababeans which received 300 mg N/Pot at early pod-fill recovered 79.6% of the applied fertilizer in their aerial portions, while aerial portions of fababeans which received 300 mg N/Pot at seeding recovered 65.0% of the applied fertilizer. Analysis of soils used in growth chamber experiments indicated fababeans absorbed virtually all available NO_3-N. Results indicate fababeans preferentially fed from combined nitrogen sources, fixing nitrogen only when combined nitrogen was insufficient for plant needs.

Evidence obtained indicate fababeans were efficient symbiotic nitrogen fixers. No response was obtained from starter amounts of fertilizer nitrogen applied nor from large mid-season applications of fertilizer nitrogen. Results indicate fababeans were capable of symbiotically fixing sufficient nitrogen throughout their entire growing period. Fababeans appear to be capable of fixing a large portion of their nitrogen requirements. Control fababeans grown in a growth chamber experiment symbiotically fixed 87.1% of their nitrogen requirements, corresponding to 708.3 mg N/Plant. Fababeans grown in seven field trials symbiotically fixed, on the average, 54% of their nitrogen requirements with individual values ranging from 0 to 71%, however five of the seven field trials had values ranging from 63 to 71%. Since fababeans preferentially feed from combined nitrogen sources addition of fertilizer nitrogen was found to decrease symbiotic nitrogen fixation in growth chamber experiments. The decrease in symbiotic nitrogen fixation was shown to be inversely proportional to the quantity of fertilizer nitrogen taken up into fababean tissue. Fababeans appear to be capable of fixing considerable quantities of nitrogen in their later growth stages. In growth chamber experiments fababeans were found to fix at least 28% of their symbiotic nitrogen during the early pod-fill to senescence stages of growth, hence nitrogen fertilization of fababeans during early to mid pod-fill stages proved to be ineffective in increasing yield and protein content of fababean aerial portions.

The proportion of nitrogen contained in roots, straw and seed at maturity was calculated to be 0.2 : 0.2 : 0.6 based on field trial data and growth chamber data. Since field trial data indicate fababeans symbiotically fixed 54% of their nitrogen requirements, the quantity of nitrogen contained in fababean seed appears to be a good estimate of the quantity of nitrogen symbiotically fixed by fababeans. Using the derived nitrogen distribution ratio, it was calculated that a 2000 kg/ha fababean seed yield containing 30% protein would require 194 kg N/ha, of which 116 kg N/ha is contained in the seed, 39 kg N/ha is contained in the straw, and 39 kg N/ha is contained in the roots.

Evidence obtained from experiments showed fababeans did not require supplemental fertilizer nitrogen in order to achieve potential yield and protein content. Therefore, in Manitoba, nitrogen fertilization of fababeans is not recommended.

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TABLE I A

ADJUSTED MEAN BRANDON TEMPERATURES USED IN GROWTH CHAMBER EXPERIMENTS

		Temp. °C	
Date	Week	Day	Night
May 7	1	13.1	4.2
14	2	14.2	4.6
21	3	16.3	6.7
28	4	17.7	7.9
June 4	5	18.9	9.6
11	6	19.2	10.3
18	7	21.0	11.8
25	8	21.7	12.2
July 2	9	22.5	13.4
9	10	23.8	14.5
16	11	24.6	15.0
23	12	25.1	15.2
30	13	24.7	14.5
Aug. 6	14	24.4	14.4
13	15	23.6	14.3
20	16	23.0	13.0
27	17	22.3	12.6
Sept. 3	18	20.5	11.2

TABLE II A

AERIAL FABABEAN YIELD AT SUCCESSIVE HARVEST DATES IN SEVEN SISTER FIELD TRIAL 1974.

Harvest Time (days after seeding)	oven dry aerial yield (kg/ha) treatment	
	control	90 kg N/ha
25	197.4	169.1
38	895.4	831.3
52	2090.6	2085.0
71	3810.4	3923.0
78	5622.4	6172.3
109	7039.5	8087.1

TABLE III A

AERIAL FABABEAN YIELD AT SUCCESSIVE HARVEST DATES IN ALTONA FIELD TRIAL 1974.

Harvest Time (days after seeding)	oven dry aerial yield (kg/ha) treatment	
	control	90 kg N/ha
27	189.9	264.3
41	795.7	1019.7
55	1821.3	1622.0
69	2203.2	1924.6
75	2754.9	2786.3
97	2672.3	2972.0

TABLE IV A

AERIAL NITROGEN UPTAKE INTO FABABEANS AT SUCCESSIVE HARVEST DATES IN SEVEN SISTERS FIELD TRIAL 1974.

Harvest Time (days after seeding)	Nitrogen uptake into fababean aerial portions (kg N/ha)	
	Treatment	
	Control	90 kg N/ha
25	8.5	7.9
38	33.1	33.3
52	62.4	66.2
71	118.9	128.5
78	167.8	188.9
109	182.9	183.3

TABLE V A

AERIAL NITROGEN UPTAKE INTO FABABEANS AT SUCCESSIVE HARVEST DATES IN ALTONA FIELD TRIAL 1974.

Harvest Time (days after seeding)	Nitrogen uptake into fababean aerial portions (kg N/ha)	
	Treatment	
	Control	90 kg N/ha
27	6.6	9.9
41	27.7	31.5
55	54.5	55.9
69	47.8	46.3
75	69.5	68.7
97	81.4	91.0

TABLE VI A

AERIAL FABABEAN YIELD AT SUCCESSIVE HARVEST DATES IN CARMAN FIELD TRIAL 1975.

Harvest Time (days after seeding)	oven dry aerial yield (kg/ha) treatment: control	oven dry aerial yield (kg/ha) treatment: 90 kg N/ha
21	57.2	54.9
35	239.2	257.2
49	802.1	1004.0
63	1851.2	2081.8
77	2513.0	2642.8
90	2652.0	2721.4

TABLE VII A

AERIAL NITROGEN UPTAKE INTO FABABEANS AT SUCCESSIVE HARVEST DATES IN CARMAN FIELD TRIAL 1975.

Harvest Time (days after seeding)	Nitrogen uptake into fababean aerial portions (kg N/ha) Treatment: Control	Nitrogen uptake into fababean aerial portions (kg N/ha) Treatment: 90 kg N/ha
21	2.88	3.08
35	6.76	9.16
49	30.32	42.71
63	54.65	73.28
77	72.49	91.39
90	66.44	75.80