



Nitrogen economy and agronomic evaluation of annual legume-cereal grain rotations
by Richard Stephen Speilman

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Agronomy

Montana State University

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Abstract:

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NITROGEN ECONOMY AND AGRONOMIC EVALUATION OF
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Richard Stephen Spielman

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

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APPROVAL

of a thesis submitted by

Richard Stephen Speilman

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citation, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Nitrogen fertility is a limiting factor to cereal grain production in many Montana soils. An annual legume could supply N to a subsequent cereal crop while providing an alternative cash crop.

Nitrogen economy and agronomic performance of fababean, lentil, fieldpea, chickpea, fieldbean, and Austrian winter fieldpea hay and green manure, respectively, in rotation with barley was compared to wheat-barley, barley-barley, and fallow-barley cropping systems.

Legume biomass and seed yield were high enough to warrant further consideration for commercial production. Overall, barley performance following legumes was comparable to barley following fallow and superior to barley following wheat or barley. Nitrogen contribution to the cropping system, except for fieldbean, was greater for legumes than for fallow. High nitrogen fertility levels from legume N plus added N fertilizer resulted in premature soil moisture depletion. Optimum rotation performance will depend on balancing nitrogen fertility with expected available moisture.

CHAPTER I

INTRODUCTION

Nitrogen is the essential nutrient most likely to first become limiting to crop growth worldwide. Nitrogen was not a common limiting factor when crops were first grown in Montana because of the high native organic matter content of the soils. The major portion of soil nitrogen is usually derived from organic matter, and becomes available for plant growth through microbial decomposition.

Reduced soil organic matter levels have resulted in nitrogen becoming one of the most limiting nutrient factors in many Montana soils. Annual nitrogen fertilizer consumption in Montana has increased from less than 1800 t before 1950 to more than 58,000 t in 1980 (USDA, 1971; USDA, 1981).

Most commercial nitrogen fertilizers are derived from processes dependent on natural gas. Nitrogen fertilizer costs have increased with the increasing cost of fossil fuels during the 1970s and 1980s. The price of anhydrous ammonia has increased 312% from 1970 to 1980 (Auld et al., 1982a). This cost increase has generated interest in alternative means for meeting crop nitrogen requirements.

One alternative to applied nitrogen fertilizers for cereal grain production is the use of a legume crop rotation in place of the traditional crop-fallow or continuous cropping systems. Leguminous crops can utilize both soil and atmospheric nitrogen. A legume crop potentially could supply residual soil nitrogen to be used by the subsequent cereal grain crop in addition to providing an alternative cash crop.

The objective of this research was to evaluate the agronomic performance and nitrogen economy of fababean (*Vicia faba* L.), lentil (*Lens culinaris* Medik.), chickpea (*Cicer arietinum* L.), fieldpea (*Pisum sativum* subsp. *arvense* (L.) Poir.), Austrian winter fieldpea (*Pisum sativum* subsp. *arvense* (L.) Poir.), and fieldbean (*Phaseolus vulgaris* L.) in rotation with 'Clark' barley (*Hordeum distichum* L.).

CHAPTER II

LITERATURE REVIEW

Montana Dry Land Cropping Systems

Three dry land cropping systems used by cereal grain growers include continuous cropping with rotations among two or more different cereal grains, crop-fallow, and the flexible cropping system.

Soil moisture available for crop growth generally determines the dry land cropping system used. Continuous cropping systems are often used in areas of high precipitation ($> 50 \text{ cm yr}^{-1}$), crop-fallow is used in areas with low precipitation ($< 50 \text{ cm yr}^{-1}$). Soil moisture storage capacity should be considered in a crop-fallow system because some soil types do not store significant moisture amounts.

Summer fallowing became popular between 1915 and 1930 when many crop failures occurred due to drought (Ford and Krall, 1979). Crop failures were reduced when crops were grown on fallowed land. Fallowing increased the soil water content; and increased spring soil moisture provided for better germination, stand establishment, and crop yield. Additionally, fallowing improved weed control and increased available soil nitrate due to decomposition of organic matter during the fallow period. Increased yield and reduced crop failures increased summer-fallowed land in the Northern Great Plains from two million hectares in 1910 to fifteen million hectares in 1967 (Haas et al., 1974).

Recent research involving crop-fallow systems has revealed problems which have led agronomists to question the use of this system for many situations. The crop-fallow system accelerates soil organic matter decline and eventually decreases nitrogen levels (Haas et al.,

1974). This occurs because soil microorganisms decompose organic matter annually while the organic matter supply is replenished by crop residues only during alternate years. At Havre, Montana, 31 years of crop-fallow decreased the organic matter content of the 0-15 cm depth by 53% (Haas and Evans, 1957). At Moccasin, Montana, 39 years of crop-fallow decreased the organic matter content of this same layer by 32%. Estimated losses in Alberta, Canada after 40 years of crop-fallow include 25% for nitrogen and 19% for organic matter (Hill, 1954). Additionally, increased wind and water erosion on the uncovered soil surface has occurred in many areas.

Definite costs are associated with maintaining fallowed land. Yields are often high per cropped hectare, but only half of the land is used at one time. Actual yield and monetary return for the total land area should be divided by two (Dubbs and Krall, 1981). Estimated operations cost to maintain weed control, fertilize, and cultivate for one year of fallow in Idaho is \$156.00 per hectare (Auld et al., 1982b). The estimated cost of maintaining one year of an Austrian winter fieldpea green manure crop is \$146.00 per hectare with the additional benefit of adding an average of 13 t ha^{-1} of crop residue to the soil (Auld et al., 1982a; Auld et al., 1982b). The inherent cost associated with declining organic matter levels and erosion of topsoil under the crop-fallow system is a variable that is often difficult to estimate.

Fallowing is an inefficient means of moisture conservation. At Sidney, Montana, Black et al. (1981) reported 20% water storage efficiency for grass barriers during the 21 month fallow period. The rest was lost to evaporation, run off, and percolation below the root zone. Haas and Willis (1962) reported that over a 40 year period in North Dakota an average of 11.1 cm out of a possible 57.7 cm precipitation was stored during the fallow period. Summer fallowing increased stored moisture over continuous cropping only 4.4 cm

per year. In the Great Plains states summer fallowing increases stored soil moisture an average of 4.9 cm per year over continuous cropping (Mathews and Army, 1960). The difference is 4.2 cm at Havre, Montana and 3.3 cm at Huntley, Montana (Mathews and Army, 1960).

The volume of stored moisture is dependent on soil type. In western Manitoba approximately 42 cm of water was stored per 122 cm of a clay loam soil versus 18.5 cm of water stored per 122 cm of a sandy loam soil (Spratt et al., 1975). However, the difference in moisture stored between fallow and continuous cropping systems for either soil types was not statistically significant.

Fallowing may lead to saline seeps. Saline seeps occur when excessive moisture leaches below the root zone, contacts an impermeable subsoil layer, and then moves laterally to an area of lower elevation. Moisture evaporation at the lower elevation results in an excessive accumulation of salts dissolved in the soil solution. It is estimated that 6.2 cm of precipitation falling on a 10 hectare recharge area may deposit 32.9 metric tons of salt in a one hectare saline seep discharge area (Halvorson and Black, 1974). Between 60,500 and 101,000 hectares of crop land have been removed from production to date in Montana due to saline seeps (Ford and Krall, 1979).

Crop failures are common with continuous-cropping systems when stored soil water is not adequate. The flexible cropping system proposed by Sims (1971), and further developed by others, offers protection against crop failure. A crop is planted when the amount of stored soil moisture plus the expected precipitation during the crop season provides a good probability for producing an economical crop (Brown et al., 1981; Dubbs and Krall, 1981; Halvorson and Kresge, 1982; Sims, 1971). Summer-fallow is used within the flexible cropping system when low stored soil moisture indicates a low probability of producing satisfactory yield. This low probability occurs an average of two and a half fallow years in a

ten year period under the flexible cropping system compared to five fallow years in a ten year period under a fixed crop-fallow system.

An annual legume-cereal grain rotation may be incorporated into the flexible cropping system. A grain or hay legume may be planted instead of cereal grain during a high stored soil moisture year. During a low soil moisture year a shallow rooted green manure legume could be planted in place of fallow. Benefits from a shallow rooted legume include nitrogen and organic matter accumulation that is not offset by soil moisture depletion (Power et al., 1983).

Determining whether to use a legume in place of a small grain should be based on expected marketing conditions and/or expected savings in nitrogen fertilizer costs.

Crop Rotations Utilizing Legumes

Legumes may be grown for the purpose of harvesting hay or grain, with increases in soil nitrogen and organic matter levels accrued from the crop residue; or they may be grown as green manure and plowed under to improve soil physical properties and fertility. Yield responses are often greatest in crops following a legume green manure and less with crops following legumes used as hay. Crops following grain legumes harvested for seed generally have shown the least benefit.

Corn (*Zea mays* L.) yield increased 13.4% following soybean (*Glycine max* (L.) Merr.) and 44% following alsike clover (*Trifolium hybridum* L.) when compared to continuously cropped corn without applied fertilizer in Ohio (Page and Willard, 1946). Similarly, corn yield increased 20% after soybean and 36% following one year of alfalfa (*Medicago sativa* L.) hay when compared to corn following oats (*Avena sativa* L.) in a Minnesota rotation trial (Schmid et al., 1959). A corn-crimson clover (*Trifolium incarnatum* L.) green manure

rotation in Georgia showed a 57% yield increase over a corn-fallow rotation system (Fleming et al., 1981).

Yield increases of non-legume crops following legumes have largely been attributed to increased levels of soil nitrogen. Studies comparing alfalfa-corn rotations with continuously cropped corn plus nitrogen fertilizer applications showed that yield response curves are similar for both treatments (Baldock and Musgrave, 1980; Shrader et al., 1966). Nitrogen was the most important factor in increasing corn yields under semi-arid conditions in Nigeria with corn following peanut (*Arachis hypogea* L.) (Lombine, 1981).

Conflicting data exists regarding the efficiency of residual legume nitrogen and commercial fertilizer nitrogen. Wagner (1954) compared the effect of white clover (*Trifolium repens* L.) versus fertilizer nitrogen sources on brome grass (*Bromus* sp.) and orchardgrass (*Dactylis glomerata* L.). Protein contents of the forage grasses treated with fertilizer were initially high but decreased markedly at the second and third cuttings. Protein content remained constant, however, throughout the season with residual fixed nitrogen. This was attributed to residual fixed nitrogen's more uniform availability rate throughout the season. Auld et al. (1982a) suggested that a legume green manure crop could be helpful both in contributing additional nitrogen to the soil and in stabilizing soil nitrates that otherwise might be rapidly leached. Soil nitrates are converted to an organic form which is slowly released as the green manure is decomposed.

Stickler et al. (1959) estimated that 2 kg of nitrogen contained in yellow sweetclover (*Melilotus officinalis* Lam.) green manure is as effective as 1 kg of inorganic nitrogen and that 3.8 kg of nitrogen contained in alfalfa is equivalent to 1 kg of inorganic nitrogen. However, Fribourg and Bartholomew (1956) reported nitrogen response curves of corn to be similar when comparing equal amounts of nitrogen contained in alfalfa residue with

ammonium nitrate fertilizer. Pinck et al. (1948) indicated that nitrogen utilization efficiency is dependent on the carbon:nitrogen ratio of the legume residue. Increased efficiency was correlated to younger tissues having a lower C:N ratio.

Studies conducted in Wisconsin (Baldock et al., 1981), North Dakota (Carlson et al., 1963), and Minnesota (Schmid et al., 1959) have shown corn and wheat (*Triticum aestivum* L.) yields following alfalfa to be greater than corn and wheat continuously cropped with additional nitrogen fertilizer. Baldock et al. (1981) stated that the effect of legume crops on subsequent non-legume crops can be divided into nitrogen effects and "additional legume effects." Sources of the additional effects may include decreased disease levels, improved soil physical properties, elimination of phytotoxins secreted by the non-legume crop, and/or unknown growth promoting substances in the legume residue. Direct comparisons of growth response due to legume and fertilizer nitrogen are complicated by the "additional legume effects."

Curl (1963) suggested several reasons for the beneficial crop rotation effects on disease incidence in major crop species. These include: (1) "starving out" of disease microorganisms that may increase when host plants are repeatedly grown in the same location; (2) plant rhizosphere effects that may encourage growth of some microorganisms while inhibiting growth of others; and (3) environmental interaction effects in which rotations at one location were not successful at a second location.

Legume rotations often improve soil structural properties by increasing soil organic matter content. Continuously cropped corn had 13.5% soil air space in a long-term study on an Ohio silty, clay-loam while corn-soybean, corn-vetch (*Vicia sativa* L.), and corn-alsike clover rotations had 14.8, 21.0, and 21.8% air space, respectively (Page and Willard, 1946). Four years of kudzu (*Pueraria lobata* (Willd.) Ohwi) green manure increased soil organic matter 25% in Georgia (Lewis and Hunter, 1940) and Mississippi (Jordan et al., 1956).

Beneficial green manure residue effects on soil structure have been consistent under humid conditions. However, results have been variable under semi-humid and semi-arid conditions. With continuous cropping in eastern Kansas, green manured plots maintained higher nitrogen and carbon levels than did control plots (Brown, 1964). Under semi-arid conditions, losses of organic carbon were similar for green manure and non-green manure rotations in Montana, North Dakota, Wyoming, and Kansas (Army and Hide, 1959; Brown, 1964).

Yield responses may not be realized under stress conditions. Significant corn yield differences were not detected among fallow, fertilizer nitrogen rates, or crimson clover green manure treatments in Georgia under stress conditions of low precipitation, high temperature, and insect infestation (Fleming et al., 1981). Wheat yields were depressed following yellow sweetclover and fieldpea green manure due to soil moisture depletion under semi-arid conditions in long term rotation studies in North Dakota, Wyoming, western South Dakota, and Colorado (Brown, 1964).

Army and Hide (1959) reported that limited moisture levels resulted in poor yellow sweetclover and fieldpea green manure stand establishment at three Montana locations, with average nitrogen contribution estimated at less than 24 kg ha^{-1} . Wheat yields following fieldpea and yellow sweetclover green manure were 30% lower than following fallow at Havre and Huntley, Montana with 29.4 and 32.4 cm average annual precipitation, respectively. Wheat yields were not significantly different following fieldpea green manure or fallow at Moccasin, Montana with 38 cm average annual precipitation. Test weight and protein percentage of the wheat were not significantly different with any of the treatments. They concluded that the green manure treatments were not beneficial when compared to summer fallow because of soil moisture relations in these low precipitation areas.

Successful legume-cereal rotations in semi-arid regions may depend on appropriate legume species selection. Wheat yield following black medic (*Medicago lupulina* L.), Maral

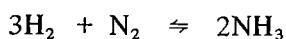
Schaftal clover (*Trifolium resupinatum* L.), and 'Nangeela' subclover (*T. subterraneum* L.) at Bozeman, Montana with 41 cm annual precipitation was increased by 92, 57, and 44%, respectively compared to wheat yield following fallow (Koala, 1982).

Kroontje and Kehr (1956) reported that cereal grain yield responses depended upon both environmental conditions and the legume species. 'Madrid' yellow sweetclover contributed 219 kg ha⁻¹ yr⁻¹ nitrogen while 'Madison' common vetch (*Vicia sativa* L.) and hairy vetch (*Vicia villosa* Roth) averaged 106 kg ha⁻¹ yr⁻¹ nitrogen contribution in a Nebraska green manure experiment. Barley grown the following year under limited moisture conditions had lowest yields following sweetclover, intermediate yields following fallow, and highest yields following vetch. They concluded that yield differences may be attributed both to the nitrogen contributed and the soil moisture remaining after the green manure. Vetch used less water than sweetclover, resulting in higher barley yields.

Legume Symbiotic Dinitrogen Fixation

Molecular nitrogen, N₂, composes approximately 78% of the earth's atmosphere. It must be in a fixed form (either as ammonium, NH₄⁺, or as nitrate, NO₃⁻) to be utilized by higher plants (Bidwell, 1974; Brill, 1977; Havelka et al., 1982). Fixed nitrogen is usually the nutrient most limiting to plant growth because of the high energy requirement associated with breaking the triple covalent bond of N₂ (Brill, 1977; Havelka et al., 1982). Nitrogen fixation can be produced industrially through the Haber-Bosch process, naturally during lightning discharges, and biologically by free-living or symbiotic microorganisms (Havelka et al., 1982; Noggle and Fritz, 1983). Annually approximately 50 million t of N₂ is fixed industrially, 10 million t is fixed by lightning, and 190 million t is fixed biologically (Noggle and Fritz, 1983).

Chemical reactions involved with N₂ fixation are similar for industrial and biological processes. The reaction for the Haber-Bosch processes is



The reaction is carried out with an iron or molybdenum catalyst, under 200 atmospheres pressure, at 500°C (Brill, 1977; Follett et al., 1981; Noggle and Fritz, 1983). Hydrogen and heat are supplied by natural gas. The cost of natural gas is reflected in the increasing cost of nitrogen fertilizer production (Brill, 1977; Follett et al., 1981).

The primary chemical reaction for biological nitrogen fixation is the same as for the Haber-Bosch process except that the reaction occurs at normal atmospheric pressure and temperature (Stevenson, 1982). This is possible through supply of energy by ATP derived from carbohydrate breakdown; hydrogen derived from carbohydrates; and reaction mediation by nitrogenase, an enzyme common to all N₂ fixing organisms (Brill, 1977; Noggle and Fritz, 1983).

The biological N₂ fixation process most important to agriculture is the symbiotic relationship between Leguminosae plant family members and *Rhizobium* bacteria species (Brill, 1977; Havelka et al., 1982; Noggle and Fritz, 1983). The symbiotic relationship begins with legume root infection by rhizobia. Specific proteins are secreted from the legume plant roots and bind to a distinct *Rhizobium* species (Brill, 1977; Dazzo and Brill, 1978; Havelka et al., 1982). Root hairs invaginate after infection allowing the rhizobia to enter the root cortex (Brill, 1977; Noggle and Fritz, 1983). Root cortex cells undergo massive division to form nodules where the rhizobia reside (Noggle and Fritz, 1983). Within the nodule the bacteria are protected from direct contact with oxygen which deactivates nitrogenase. The rhizobia supply ammonium to the plant and the plant provides carbohydrates to the rhizobia (Brill, 1977; Havelka et al., 1982).

Methods of Assessing Dinitrogen Fixation

Experimental methods used to estimate the amount of N₂ fixed by a legume crop have been outlined by LaRue and Patterson (1981). Direct methods include the use of

$^{15}\text{N}_2$ isotope, and acetylene reduction. With the $^{15}\text{N}_2$ method nodulated roots or excised nodules alone are placed in a chamber with $^{15}\text{N}_2$ isotope. The plant tissue is then analyzed for ^{15}N content by mass spectrometry.

Nitrogenase reduces acetylene, C_2H_2 , to ethylene, C_2H_4 similar to the reduction of N_2 to NH_4^+ (Brill, 1977; LaRue and Patterson, 1981). Conversion of acetylene to ethylene by nitrogenase is a means of determining N_2 fixation at a given time.

Indirect methods of estimating N_2 fixation include nitrogen accumulation, lysimeter studies, difference methods, and N fertilizer equivalence (LaRue and Patterson, 1981). With the accumulation method, beginning and ending soil N levels plus the amount of N in removed crop materials is determined by Kjeldahl or a similar total N analysis to estimate the amount of N that was accumulated through N_2 fixation.

In lysimeter studies a large tank with openings in the bottom is sunk into the ground and the soil, plant material, and leached soil solution is analyzed to determine changes in the nitrogen balance (LaRue and Patterson, 1981).

With difference methods a N_2 fixing crop is grown concurrently with a non-fixing crop and the total N within the non-fixing crop is subtracted from that of the fixing crop (LaRue and Patterson, 1981). This method is based on the assumption that the fixing crop is accumulating nitrogen in the plant material both from atmospheric and soil reserves whereas the non-fixing crop is acquiring nitrogen only from soil reserves. Comparisons include legumes to non-legumes, nodulating to non-nodulating legume isolines, and inoculated with uninoculated legumes.

In the N fertilizer equivalence method the contribution of N by a legume to a non-legume crop is estimated by comparing plots with a legume to plots with different amounts of applied N fertilizer (LaRue and Patterson, 1981). Non-legumes can be grown with legumes in the same plot and the yields compared with plots containing only non-legumes and various N fertilizer rates (usually a forage legume study). Responses of a non-legume

crop following a legume crop can also be compared to a non-legume crop following a non-legume crop plus different fertilizer rates.

Dinitrogen Fixation Estimates for Legume Species

Estimates of N_2 fixation within a species (Table 1) varies with environment, cultivar, and experimental technique (LaRue and Patterson, 1981).

Table 1. Estimates of Nitrogen Fixed by Different Legume Species in One Growing Season.

Species	Nitrogen Fixed kg ha ⁻¹	Source
Alfalfa	135-290	Baldock and Musgrave, 1980 Heichel et al., 1981 Lyon and Bizzell, 1934 LaRue and Patterson, 1981
Fababean	68-171	Dean and Clark, 1977 Rizk, 1966 Wagner and Zapata, 1982
Chickpea	67-141	Rizk, 1966
Lentil	62-103	Rizk, 1966
Soybean	40-263	Bezdicek et al., 1978 Bhangoo and Albritton, 1976 Deibert et al., 1979 Rizk, 1966 Rennie et al., 1982
Fieldpea	17-69	Lyon and Bizzell, 1934 Mahler et al., 1979
Fieldbean	10-57	Lyon and Bizzell, 1934 LaRue and Patterson, 1981

Conditions Affecting Dinitrogen Fixation

The amount of N_2 fixed is highly dependent on macrosymbiont photosynthetic capacity due to the high energy requirements by the microsymbiont for the reduction of N_2 to NH_4^+ (Havelka et al., 1982). Rhizobia require 10 to 17 kg of carbohydrate from the

legume for each kg of N_2 fixed, and 25 to 28 molecules of ATP for each molecule of N_2 (Havelka et al., 1982; Mahon, 1977). In fieldpea photosynthetic rate is correlated to N_2 fixation rate (Bethany et al., 1978). Decreased N_2 fixing ability in soybean has been correlated with partial shading and defoliation which reduced photosynthetic capacity (Lawn and Brun, 1974). Schweitzer and Harper (1980) reported that nitrogen fixation in soybean continues during ten hour dark periods apparently by utilizing reserve root carbohydrates. Lawn and Brun (1974) reported that increased light intensity and duration increased N_2 fixation in growth chamber produced soybean. Other studies have indicated that the total amount of N_2 fixed may not be dependent on the rate of photosynthesis per given leaf area, but on the plant's overall photosynthetic capacity which is dependent on total leaf area of the plant and the length of time during the growing season in which photosynthesis is occurring (Mahon, 1982; Westerman and Kolar, 1978).

Nitrogen fixation rates during the growing season of soybean (Deibert et al., 1979; Harper, 1974; Lawn and Brun, 1974), fieldbean (Westerman and Kolar, 1978), and southernpea (*Vigna unguiculata* L. Walp) (Zary and Miller, 1980) peak at bloom time and decrease or cease during pod fill. Photosynthate is switched from nodule support to a reproductive sink and the energy available for the rhizobia is inadequate for N_2 fixation. However, fababean continues N_2 fixation during pod fill (Richards and Soper, 1979). This may, in part, account for its high N_2 fixing capability.

Moisture stress decreases N_2 fixation (Dean and Clark, 1980; Havelka et al., 1982; Mahler et al., 1979). This may be due to decreased photosynthetic capacity (Huang et al., 1975) or nodule deterioration (Denison et al., 1983; Sprent, 1972; Tjepkema and Yocum, 1974).

High levels of soil NO_3^- or NH_4^+ inhibits N_2 fixation of alfalfa (McAuliffe et al., 1958), fababean (Dean and Clark, 1980; Richards and Soper, 1979), fieldbean (Dean and Clark, 1980), fieldpea (Dean and Clark, 1980), lentil (Wong, 1980), soybean (Bhangoo and

Albritton, 1976; Criswell et al., 1976; Dean and Clark, 1980; Deibert et al., 1979; Harper, 1974; Johnson and Hume, 1972; Kohl et al., 1980; Rennie et al., 1982; Semu and Hume, 1979), and white clover (McAuliffe et al., 1958). Nitrogenase synthesis is suppressed within the microsymbiont, and the amount of "recognition proteins" exuded by the root hairs of the macrosymbiont decreases thus limiting infection by the rhizobia (Brill, 1977; Dazzo and Brill, 1978).

Starter fertilizer solutions of NO_3^- or NH_4^+ at planting may reduce nitrogen deficiency between the time of cotyledon depletion and nodule formation. Robust plant development from the starter solution aids N_2 fixation after nodule formation by increasing carbohydrate supply (Eaglesham et al., 1983; Havelka et al., 1982).

The reason legumes use available soil N rather than fixed atmospheric N remains uncertain. Fixed atmospheric N may be inadequate for maximum growth or the high energy costs to the macrosymbiont may cause it to use soil N rather than atmospheric N. The nitrogen form within the plant that is actually used is NH_4^+ . Schubert (1982) suggests that the energy costs for reduction of NO_3^- to NH_4^+ are similar to the costs for N_2 fixation based on theoretical energetics for each process for fieldpea, southernpea, and soybean.

Dinitrogen fixation may be affected by environmental factors unrelated to photosynthetic capacity of the macrosymbiont. Increased potassium levels increased N_2 fixation in fababean (Mengel et al., 1974). Rhizobia require molybdenum for synthesis of nitrogenase. Molybdenum may increase N_2 fixation in deficient soils (Follett et al., 1981). Any other essential element that is in limited supply to the macrosymbiont may reduce the N_2 fixing capacity of the microsymbiont by reducing the supply of carbohydrate.

Increased organic material added to the soil may increase N_2 fixation, but not necessarily legume seed yield (Criswell et al., 1976; Johnson and Hume, 1972). This possibly occurs due to the depression of available soil N by raising the carbon:nitrogen ratio.

Soil or atmospheric temperatures above 30°C or below 20°C decrease nodulation and rate of N₂ fixation within individual nodules (Cralle and Heichel, 1982; Havelka et al., 1982; Schweitzer and Harper, 1980). Decreased soil aeration due to compaction, poor soil structure, or waterlogged soils may restrict the amount of air reaching the nodules (Criswell et al., 1976; Havelka et al., 1982).

The amount of N₂ fixed is primarily dependent on the legume cultivar, *Rhizobium* strain, soil type, and environmental interactions. These parameters have a direct effect on management practices for efficient legume utilization and in cultivar/strain selection (Hardason et al., 1982; Sekhorn et al., 1978; Uratsu et al., 1982; Westerman and Kolar, 1978).

Specific Legume Crop Descriptions

Chickpea

Chickpea originated in Asia Minor and has been cultivated in India, the Middle East, and Mediterranean regions since antiquity (Duke, 1981). Major production areas include India, Pakistan, Spain, Algeria, Mexico, Argentina, Chile, Peru, and California in the United States (Auld and Lee, 1981; Welty et al., 1982). India has 74% of the world production. Annual world production is 8 million t with 3,500 t being produced in the United States (Auld and Lee, 1981). The United States presently imports 10,000 t yr⁻¹ (Auld et al., 1981).

Chickpea is valued as a grain crop, with seed protein content ranging from 14 to 30%. Nutritionally, it is high in lysine and low in methionine (Solsulski and Holt, 1980). Chickpea is utilized either as livestock feed or for human consumption (Duke, 1981). It may be eaten fresh, as a dry pulse, canned, processed as Dahl (split chickpea used in soups), or ground into flour. It is mainly marketed as a canned product and used in salads in the

United States. Light colored, large seed command the highest prices in world markets (Auld et al., 1981; Welty et al., 1982).

Chickpea is an annual with much diversity in growth habit among cultivars (Duke, 1981; Welty et al., 1982). Plants are highly branched, erect or spreading, 0.2 to 1 m in height, with roots up to 2 m long. Flowers are solitary and axillary. Seed weight ranges from 0.06 to 0.68 g seed⁻¹. Leaves are pinnately compound, light yellow-green to dark green in color. Leaves are pubescent with glands that secrete malic and oxalic acids.

Two main groups of chickpea are recognized. The 'Kabuli' type is of Middle Eastern/Mediterranean distribution and the 'Desi' type is of Indian distribution (Duke, 1981). The Kabuli type is generally larger seeded with large plant leaflets. The Desi type is smaller seeded with finer plant leaflets (Welty et al., 1982).

Chickpea is a cool season crop usually grown in dry climates, but it may respond to irrigation (Duke, 1981). The optimum environmental conditions include 18° to 26°C day temperature with lower night temperature and heavy dew. Soils should be well drained with a pH of 5.5 to 8.6. Chickpea yield potential is best with annual precipitations ranging from 60 to 100 cm. A relative humidity of 21 to 41% is optimal for seed set. Mature plants are frost tolerant to -2.2°C (Auld et al., 1981; Duke, 1981). The Desi type is generally fall planted in areas with cool dry winters. The Kabuli type is generally spring planted (Welty et al., 1982). World yields range from 400 to 3,350 kg ha⁻¹ with an average yield of 630 kg ha⁻¹ (Duke, 1981; Welty et al., 1982). Symbiotic N₂ fixation is considered adequate for maximum crop production since additional nitrogen fertilizer usually will not increase yield (Duke, 1981). 'UC-5', a Kabuli type, is the major variety in the United States. Yields of this variety range from 2,250 to 3,350 kg ha⁻¹ (Auld and Lee, 1981; Welty et al., 1982). The pods are shatter resistant and taller cultivars may be direct combined (Duke, 1981).

Fieldbean

Fieldbean is native to Central America and is grown worldwide with the exception of tropical Asia (Duke, 1981). It is the most widely cultivated temperate bean with a world production of 13.25 million t. Central America has 30% of world production. The United States produces 800,000 t annually which is utilized domestically and exported. Michigan has 40% of U.S. production with other growing areas in California, Colorado, Idaho, Wyoming, New York, and North Dakota.

Fieldbean is used primarily for human consumption (Duke, 1981). Immature pods are eaten as fresh, frozen, or canned vegetables. Mature beans are utilized as a dry pulse. They are high in vitamins and contain 17 to 20% protein (Duke, 1981; Solsulski and Holt, 1980). Fieldbean is the primary protein source for lower income groups in Central and South America and an important protein source for other areas (Duke, 1981).

Growth habit is diverse depending on the cultivar (Duke, 1981). The plant ranges from dwarf bush types that are 20 cm in length to vining types over 3 m in length. Flowering habit may be determinate or indeterminate depending on the cultivar. Flowers are solitary and axillary. Seed weight ranges from 0.67 to 10 g seed⁻¹. Seed color is cultivar dependent. Leaves are trifoliate, arranged in an alternate pattern, and range from green to purple in color.

Fieldbean is a warm season crop adapted to temperate and tropical climates (Duke, 1981). Optimum temperature ranges from 15.6° to 21.1°C. Temperatures above 30°C will suppress flower set. Fieldbean responds to irrigation in arid areas, but does not tolerate excessive soil moisture. Optimum soil pH is 6.5.

World yields range from 313 kg ha⁻¹ to 2374 kg ha⁻¹, with an average of 535 kg ha⁻¹ (Duke, 1981). Yields in the United States average 1300 kg ha⁻¹. Yield response to nitrogen fertilizer is common due to poor nodulation (Edje et al., 1975; Westerman et al., 1981).

Symbiotic nitrogen fixation may not be adequate for optimum yields with some cultivars and soil conditions.

Fababean

Fababean, a native to the Near East, is cultivated in North America, South America, Europe, North Africa, the Mideast, and portions of Asia (Duke, 1981). Fababean is one of the most important crops for human consumption in the Mideast and North Africa. World production is approximately 6.44 million t annually. China has 74% of the total production. North America produces 43,000 t yr⁻¹, with Canada accounting for the majority of the crop.

Large seeded cultivars are mostly used for human consumption. They may be eaten as a fresh or canned vegetable, as textured protein, or as a dry pulse (Duke, 1981). Fababean grain has 28 to 32% protein, low oil content, high lysine, and low methionine (Kaldy and Kasting, 1974; Lockerman et al., 1982; Solsulski and Holt, 1980).

Small seeded cultivars are used as livestock feed (Duke, 1981). The low oil content allows the seed to be fed directly as a protein supplement or the whole plant may be utilized as dairy silage (Duke, 1981; Lockerman et al., 1982). Fababean is occasionally used as a green manure crop (Duke, 1981).

Fababean is an unbranched upright annual 0.3 to 2 m tall (Duke, 1981). It has an indeterminate flowering habit with clustered axillary flowers. Seed weight ranges from 1.1 to 6.6 g seed⁻¹. Dark green leaves are compound with up to six large leaflets.

Fababean is a frost tolerant, cool season crop grown as a summer annual in cool temperate regions or as a winter annual in warm temperate and subtropical regions (Duke, 1981). It is not drought tolerant and responds to irrigation. Fababean cultivars are adapted to regions with annual precipitation ranging from 23 to 209 cm. Fababean tolerates

temperatures ranging from 5.6° to 27.5°C. It grows in a variety of soil types but prefers rich loams. Fababean is tolerant of acidic soil.

World yields range from 500 to 4000 kg ha⁻¹ (Duke, 1981). Yields are correlated to the number of pods per plant. Yields in Montana have ranged from 912 to 4300 kg ha⁻¹. In Canada, commercial production ranges from 2500 to 3500 kg ha⁻¹ with experimental field trial yields of up to 7 t ha⁻¹ (Duke, 1981; Lockerman et al., 1982). The crop is mechanically harvested by swathing and combining when the lower third of the pods turn black. Shattering is common due to the indeterminate growth habit and subsequent maturation differential.

Lentil

Lentil originated in the Near East and Mediterranean regions and is one of the oldest known cultivated crops (Duke, 1981). Lentil is cultivated worldwide in temperate, subtropic, and high altitude tropic regions. The major producer is India with 22% of the world crop. Other major producers include Pakistan, Ethiopia, Syria, Turkey, and Spain. World production is 1.2 million t annually. The United States produces 56,950 t annually with 95% of total production located in the Pacific Northwest (Duke, 1981; Blain, 1982).

Lentil is the most nutritious of the dry pulses. It is high in vitamins, has 22 to 34% protein, but the protein is low in the amino acids methionine and cystine (Duke, 1981; Muehlbauer and Short, 1981; Solsulski and Holt, 1980). It may be used as a dry pulse, ground into flour, or eaten as a fresh vegetable. Plants are used as a livestock feed and as a green manure in several countries (Duke, 1981).

Lentil is a multi-branched, bushy annual with slender stems 25 to 75 cm tall (Duke, 1981; Muehlbauer and Short, 1981). Axillary flowers are arranged in 1 to 4 flowered racemes. Seeds are lens shaped and vary in color from orange, yellow, green, or red depending

on cultivar. Seed weight ranges from 0.02 to 0.08 g seed⁻¹. Leaves are small, pinnately compound, light green in color, and usually end in a tendril.

Lentil prefers a warm soil for germination, and tolerates a wide range of soil types with a pH ranging from 4.5 to 8.2 (Duke, 1981). Optimum temperature range is 19° to 29°C. Lentil cultivars grow in regions with 28 to 243 cm annual precipitation. It does not respond well to irrigation and is adversely affected by waterlogged soils.

World yields range from 450 to 3,000 kg ha⁻¹ with an average of 640 kg ha⁻¹ (Duke, 1981). Yields in the United States average 1,100 kg ha⁻¹. Lentil is commonly grown in rotation with wheat in the Pacific Northwest region of the United States (Muehlbauer and Short, 1981).

Pea

Pea originated in Europe and western Asia and is presently grown worldwide (Duke, 1981). Pea subspecies include sweet garden pea (subsp. *hortense* Asch. & Graebn.), fieldpea and Austrian winter pea (subsp. *arvense* L. Pior.), edible podded pea (subsp. *macrocarpon* L.) and early dwarf pea (subsp. *humile* L.) (Auld et al., 1983; Bailey, 1976; Duke, 1981). Major production areas include portions of every continent with Russia producing 35% and Asia producing 50% of the world crop (Duke, 1981). World production is 10.6 million t yr⁻¹. The United States produces 750,000 t yr⁻¹.

Fieldpea (subsp. *arvense* (L.) Pior.) is utilized as a dry pulse for human consumption and for livestock feed. Austrian winter pea (subsp. *arvense* (L.) Pior.) is most commonly utilized as a hay or green manure crop (Auld et al., 1982a; Auld et al., 1982b; Duke, 1981). All other subspecies of fieldpea are eaten fresh, frozen, or canned as a vegetable (Duke, 1981). Fieldpea seed protein content is 26 to 31% (Ali-Khan, 1977; Solsulski et al., 1974; Solsulski and Holt, 1980). Seed is high in lysine and low in methionine and cystine. Austrian winter pea hay has 10 to 21% protein (Duke, 1981).

Fieldpea is grown as a summer or winter annual depending on cultivar and location (Duke, 1981). Growth habit is cultivar dependent. Bush or vine forms range from 30 to 150 cm long. Axillary flowers are born in one to three flowered racemes. Seed weight is 0.15 to 0.25 g seed⁻¹. Alternate leaves are pinnately compound with one to three pairs of leaflets usually with a terminal tendril.

Fieldpea is a cool season crop with optimum yields obtained at 13° to 21°C (Auld et al., 1983; Duke, 1981). It is adversely affected by temperatures above 27°C. Some cultivars are frost tolerant to -6°C (Auld et al., 1983). Most cultivars grow best under a precipitation range of 80 to 100 cm (Duke, 1981). Fieldpea may respond to irrigation but will not tolerate waterlogged soils. It grows on a variety of soil types with a pH range of 4.2 to 8.3 (Duke, 1981).

World average dry pulse yields range from 400 to 5200 kg ha⁻¹ (Duke, 1981). The United States average yield is 1800 kg ha⁻¹ (Blain, 1982; Duke, 1981). Average forage yield of Austrian winter pea in northern Idaho is 6.9 t ha⁻¹ for spring planted and 13.0 t ha⁻¹ for autumn planted peas (Auld et al., 1982a).

CHAPTER III

MATERIALS AND METHODS

Post Farm Experiment1982

Field plots were planted June 11, 1982 at the Montana State University Arthur H. Post Field Research Laboratory, Bozeman, Montana. Soil type was an Amsterdam silt loam (fine-silty, mixed Typic Haploboroll). The experimental site had been cropped to wheat in 1980 and fallowed in 1981. Soil samples, taken June 12, 1982, were analyzed by the Montana State University Soil and Plant Testing Laboratory. The pH was 7.5, organic matter was 1.8%, electrical conductivity was $1.0 \text{ mmhos cm}^{-1}$, Olsen phosphorus was 16.5 ppm, and potassium was 365 ppm at the 0-15 cm depth. $\text{NO}_3\text{-N}$ was 5.0, 3.6, and 3.6 ppm at 0-15, 15-60, and 60-120 cm depths, respectively.

The experiment was a two-factor factorial with four replications arranged in a split-plot design as described by Little and Hills (1978). Main plots comprised seven legume crop treatments and three non-legume control treatments. The seven legume treatments included: 'Ackerperle' fababean, 'Chilean-78' lentil, 'Garfield' fieldpea, 'UC-5' chickpea, 'Viva Pink' fieldbean, 'Melrose' Austrian winter fieldpea for hay and green manure. Non-legume treatments included 'Newana' spring wheat, 'Clark' two-rowed barley, and fallow. Each main plot was divided into five subplots that received varying nitrogen fertilizer levels at the beginning of the second crop year.

All crops were planted with a cone-seeder in eight row subplots with 30 cm row spacings. Subplots were $2.44 \times 3.05 \text{ m}$. Seeding rate per linear meter was twelve seeds for

fababean, chickpea, and fieldbean; twenty-four seeds for Austrian winter fieldpea; thirty seeds for lentil and fieldpea; and thirty-six seeds for barley and wheat. Granular *Rhizobium* sp. inoculum obtained from D. F. Bezdicek (Washington State University) was applied through the cone-seeder with each legume crop.

All crops emerged between June 17 and 19. Daily observations were made to record first bloom and spikelet formation. Hand weeding was done when necessary.

Fieldpea was harvested August 26, lentil August 31, Austrian winter fieldpea September 1, fieldbean September 17, fababean October 11, chickpea October 12, and barley and wheat October 13. Above ground biomass was obtained by harvesting four 2.44 m long center rows of Austrian winter fieldpea and one 2.44 m long randomly selected center row for other crops. Grain yields were obtained by harvesting four 2.44 m long center rows in each subplot. Grain was weighed immediately after removal from the field, dried in a forced air oven for 24 hr at 95°C and reweighed to determine percent moisture.

Yields were determined by weighing grain and biomass from each plot and then converting to kg ha⁻¹. Grain yield was reported at 11% moisture. Grain was analyzed for total nitrogen content by the Montana State University Soil and Plant Testing Laboratory. Total nitrogen was multiplied by 6.25 to obtain an estimate of protein content. The 6.25 constant is a standard for the conversion of nitrogen percentage to protein percentage.

All crop residues except Austrian winter fieldpea was returned to the individual subplots and tilled 15 cm deep after the grain was removed. Austrian winter fieldpea hay was cut 5 cm above the ground surface and removed when the seventh flowering node bloomed. Austrian winter fieldpea green manure treatment was rototilled 15 cm deep when the seventh flowering node bloomed (September 1).

Soil samples were taken at 0-15, 15-60, and 60-120 cm depths on September 23. Soil samples were weighed immediately after removal from the field, dried in a forced-air oven at 95°C for 36 hr and reweighed to determine soil moisture percent (calculated on a dry

weight basis). Soil samples were analyzed for $\text{NO}_3\text{-N}$ and organic matter percent by the Montana State University Soil and Plant Testing Laboratory.

Precipitation and average temperatures were recorded daily near the experimental site by a Weather Service Climatological Station (Tables 2 and 3).

Table 2. Average Monthly Temperatures at the Post Farm Location in 1982 and 1983.

Month	1982			1983		
	Max	Min	Ave	Max	Min	Ave
	-----°C-----					
May	16.2	1.7	8.9	16.3	1.8	9.0
June	20.8	6.5	13.7	21.7	6.1	13.9
July	25.6	9.6	17.6	26.7	8.0	17.4
August	28.5	8.8	18.7	28.3	11.7	20.0
September	19.2	4.2	11.7	20.0	3.7	11.9
October	12.8	.3	6.6	15.0	.6	7.8

1982 – 105 frost free days.

1983 – 116 frost free days.

Table 3. Monthly Precipitation at the Post Farm Location in 1981, 1982, and 1983.

Month	1981	1982	1983
	-----cm-----		
January	.30	2.13	.25
February	2.26	1.62	.89
March	2.31	5.72	2.24
April	4.19	3.76	2.90
May	15.62	6.65	4.75
June	8.28	8.97	8.41
July	2.71	3.76	6.55
August	.71	2.03	5.26
September	3.56	6.78	
October	4.62	3.07	
November	2.64	.84	
December	1.62	2.24	
Total	48.82	47.57	

September 1981 through August 1982 total – 47.08.

September 1982 through August 1983 total – 44.18.

January 1983 through August 1983 total – 31.25.

Data were analyzed by analyses of variance and Fisher's protected LSD mean separation using the MSUSTAT computer program developed by Dr. Richard E. Lund.

1983

All previously cropped subplots were planted with 'Clark' barley May 27, 1983. Barley was planted with a cone-seeder with 30 cm row spacings at a rate of thirty-six seeds per linear meter. Ammonium nitrate fertilizer was applied to randomized subplots within mainplot treatments on June 3 at rates of 0, 28, 56, 84, and 112 kg ha⁻¹ of actual nitrogen.

The crop emerged June 1. Daily observations were made to record spikelet formation. Hand weeding was done when necessary. The crop was harvested August 26. Grain yields and above ground biomass were obtained by harvesting four center rows 2.44 m long in each subplot.

Grain yield and biomass yield in kg ha⁻¹ was determined as in 1982. Grain samples were analyzed for protein content using a Technicon InfraAlyzer 400 near infrared reflectance analyzer manufactured by Technicon Industrial Systems, Tarrytown, New York.

Test weight was determined using a United States Department of Agriculture Grain Standard test weight scale. Percent plump seed was determined by screening samples through a 0.238 × 1.905 cm slotted screen and recording the percentage of seed remaining on the screen.

Soil samples were taken on May 22 and August 28 at 0-15, 15-60, and 60-120 cm depths. Moisture percentage was determined as in 1982. Soil samples were analyzed for NO₃-N by the Montana State University Soil and Plant Testing Laboratory.

Data were analyzed by analyses of variance, Fisher's protected LSD mean separation, and linear regression using the MSUSTAT computer program developed by Dr. Richard E. Lund.

Schutter Farm Experiment1983

Field plots were planted May 26, 1983 on a private farm owned by John Schutter located near Manhattan, Montana. Soil type was a Manhattan very fine sandy-loam (coarse-loamy, mixed Typic Calciborolls). The experiment site had been cropped to barley in 1982. Preplant soil samples were analyzed by the Montana State University Soil and Plant Testing Laboratory. The pH was 8.2, organic matter was 1.2%, electrical conductivity was 0.8 mmho cm⁻¹, NH₄ OH extractable calcium cations were 43 ppm, magnesium was 3.2 ppm, sodium was 0.1 ppm, Olsen phosphorus was 17.5 ppm, and potassium was 224 ppm; all at the 0-30 cm depth. NO₃-N was 7.6, 6.7, and 4.7 ppm at 0-15, 15-60, and 60-120 cm depths, respectively.

Legume, non-legume, and fallow crop treatments were the same as described for the 1982 Post Farm experiment. All crops were planted with a cone-seeder in eight row subplots with 30 cm row spacings. Each subplot was 2.44 × 3.05 m. Lentil was planted June 6, all other crops were planted May 26. Seeding rate and legume inoculation was the same as described for the 1982 Post Farm experiment. A randomized complete block design with three replications was used. No nitrogen fertilizer was applied.

Barley and wheat emerged June 1, lentil emerged June 15, and the remaining crops emerged June 6. Daily observations were made to record first bloom and spikelet formation. Hand weeding was done when necessary.

Austrian winter fieldpea was harvested August 12, barley and wheat September 1, fieldpea September 15, chickpea and fieldbean September 22, lentil September 23, and fababean September 24. Grain yield and above ground biomass was obtained by harvesting four 2.44 m long center rows in each subplot. Grain yield and biomass yield in kg ha⁻¹ was determined as in the 1982 Post Farm experiment. Fababean seed were analyzed for total

nitrogen content by the Montana State University Soil and Plant Testing Laboratory. Total nitrogen was multiplied by 6.25 to obtain an estimate of protein content. Seed (except fababean) were analyzed for protein content by the Udy Dye Binding method as described by Udy (1956). Conversion tables for converting percent light transmittance to percent protein in cereal and legume grains were obtained from the Udy Corporation, Fort Collins, Colorado.

All crop residue, except Austrian winter fieldpea, was returned to the individual subplots after the grain was removed. Austrian winter fieldpea hay was cut 5 cm above the ground surface and removed when the seventh flowering node had bloomed. The Austrian winter fieldpea green manure treatment was rototilled 15 cm deep when the seventh flowering node had bloomed (August 12).

Soil samples were taken at 0-15, 15-60, and 60-120 cm increments on September 24. Soil moisture was determined as described for the 1982 Post Farm experiment. Soil samples were analyzed for $\text{NO}_3\text{-N}$ by the Montana State University Soil and Plant Testing Laboratory.

Precipitation and average temperatures were recorded daily at the experiment site (Table 4).

Data were analyzed by analyses of variance and Fisher's protected LSD mean separation using the MSUSTAT computer program developed by Dr. Richard E. Lund.

All other materials and methods were as described for the 1982 Post Farm experiment.

Table 4. Average Monthly Temperatures and Precipitation Totals at the Schutter Farm Location for 1983.

Month	Temperature			Precip.
	Maximum	Minimum	Average	
	----- °C -----			-- cm --
June [†]	26.2 [‡]	11.3 [‡]	18.8 [‡]	2.83
July	25.7	10.0	17.9	6.82
August	28.3	11.4	19.8	3.06
September [§]	21.1 [¶]	3.6 [¶]	12.3 [¶]	6.52
Total				19.23

[†] Full profile of soil moisture at planting time.

[‡] Includes June 22 through June 30.

[§] Frost on September 19.

[¶] Includes September 1 through September 27.

CHAPTER IV

RESULTS AND DISCUSSION

First Year Rotation: Legume, Cereal Grain, and Fallow Performance

Locations

Legume, cereal grain, and fallow first year rotations evaluated at the Post Research Farm (1982) and Schutter Farm (1983) were markedly affected by environmental differences. Inclement weather in 1982 delayed planting until June 11. Consequently, crops at the Post Farm were unable to fully utilize spring moisture. Crop growth was also suppressed as a result of limited precipitation during the later part of the growing season (Table 3). Additionally, initial soil nitrate levels were low (35.4 kg ha^{-1}) at the Post Research Farm. In contrast, the effects of early planting date, high initial soil nitrate and 19.23 cm of crop year precipitation at the Schutter Farm in 1983 are reflected in the markedly higher crop performance.

Biomass Yield

Biomass yields (above ground plant portions) were 33, 56, 42, 26, 25, 3, 68, and 55 percent lower for fababean, lentil, fieldpea, chickpea, fieldbean, Austrian winter fieldpea hay, barley, and wheat, respectively, at the Post Farm compared to the Schutter Farm (Table 5). Biomass yield of Austrian winter fieldpea was least affected by location and year. The hay was cut at both locations before late season drought conditions occurred.

Fababean in 1982 and fababean, fieldpea, and barley in 1983 had the highest biomass yield. Fababean biomass yield under two diverse environments indicates a high potential for use as hay, silage, and green manure.

Table 5. Biomass Yield at the Post Research and Schutter Farms for 1982 and 1983, Respectively.

Crop	Post Farm (1982)	Schutter Farm (1983)
	Biomass Yield kg ha ⁻¹	
Fababean	4840 d [†]	7263 d
Lentil	1911 a	4353 ab
Fieldpea	4269 c	7345 d
Chickpea	4177 c	5646 c
Fieldbean	2506 b	3356 a
Winter pea hay	4226 c	4351 ab
Barley	2184 ab	6787 d
Wheat	2136 ab	4763 bc
LSD 0.05	462	1109

[†] Biomass yield means within a column not followed by a common letter are significantly different by Fisher's protected LSD ($P = 0.05$).

Lentil and fieldbean biomass yield was consistently low in 1982 and 1983. Fieldpea was equal to fababean biomass yield in 1983 indicating high potential under favorable conditions.

Barley and wheat biomass yield was markedly suppressed in 1982 due to unfavorable growing conditions. An earlier planting date and favorable 1983 environmental conditions resulted in higher biomass production for barley and wheat.

Austrian winter fieldpea was harvested at an early growth stage and biomass yields cannot be readily compared to the other crops. However, Austrian winter fieldpea may have equal potential for hay, silage, and green manuring as fababean and fieldpea if all three were harvested at the optimum growth stage for utilization. Legume hay and silage crops may need to be harvested at an early stage for best palatability and nutrition (Van Soest, 1980; Raymond, 1969). Additionally, green manure crops may have to be plowed under at an early growth stage to prevent nitrogen immobilization because of excessive carbon:nitrogen ratios (Alexander, 1977; Brady, 1974; Jansson and Persson, 1982; Pinck et al., 1948).

Biomass Production Water Use Efficiency

Water use efficiency (WUE) is an important consideration for crop selection in semi-arid regions where moisture may be limited. Biomass production WUE (kg biomass yield m^{-3} H_2O used) was markedly lower in 1982 than in 1983 due to environmental constraints (Table 6).

Table 6. Biomass Production Water Use Efficiency[†] at the Post Research and Schutter Farms for 1982 and 1983, Respectively.

Crop	Post Farm (1982)	Schutter Farm (1983)
	Biomass WUE kg m^{-3}	
Fababean	1.73 bc [‡]	2.83 d
Lentil	0.74 a	1.64 ab
Fieldpea	1.97 c	2.92 d
Chickpea	1.52 b	2.19 c
Fieldbean	0.98 a	1.45 a
Winter pea hay	1.65 b	2.03 bc
Barley	0.87 a	2.66 d
Wheat	0.93 a	1.84 abc
LSD 0.05	0.28	0.42

[†] WUE = kg yield m^{-3} H_2O used.

[‡] Biomass yield WUE means within a column not followed by a common letter are significantly different by Fisher's protected LSD ($P = 0.05$).

Fababean, fieldpea, chickpea, and Austrian winter fieldpea had the highest biomass WUE in 1982. Highest biomass WUE under more favorable 1983 conditions was for fababean, fieldpea, and barley.

Lentil, fieldbean, barley, and wheat had the lowest biomass WUE in 1982. Crops with the lowest biomass WUE in 1983 were lentil, chickpea, fieldbean, Austrian winter fieldpea hay, and wheat.

The consistently high biomass WUE for fababean and fieldpea may be important for biomass yield stability under diverse environments and indicates potential for use as hay, silage, or green manure in semi-arid regions.

Evapotranspiration

The amount of water used by a crop may be important for cropping systems in semi-arid regions. Low evapotranspiration rates ($ET = \text{pre-plant available soil } H_2O + \text{growing season precipitation} - \text{post-harvest available soil } H_2O$) may result in a greater amount of soil moisture available for the next crop.

Fababean, lentil, and chickpea had the highest ET for 1982 (Table 7). The crops with highest 1983 ET included fababean, lentil, fieldpea, chickpea, barley, and wheat.

Table 7. Evapotranspiration[†] at the Post Research and Schutter Farms for 1982 and 1983, Respectively.

Crop	Post Farm (1982)	Schutter Farm (1983)
	ET cm	
Fababean	28.54 d [‡]	25.64 c
Lentil	25.99 bcd	26.01 c
Fieldpea	22.55 a	25.14 c
Chickpea	26.98 cd	25.81 c
Fieldbean	24.83 abc	23.21 b
Winter pea hay	24.60 abc	21.48 a
Barley	24.74 abc	25.51 c
Wheat	23.39 ab	25.88 c
LSD 0.05	2.96	1.73

[†] $ET = (\text{pre-plant available soil } H_2O + \text{growing season precipitation}) - \text{post-harvest available soil } H_2O$.

[‡] ET means within a column not followed by a common letter are significantly different by Fisher's protected LSD ($P = 0.05$).

Crops with the lowest 1982 ET included fieldpea, fieldbean, Austrian winter fieldpea, barley, and wheat. Fieldbean and Austrian winter fieldpea had the lowest 1983 ET. A low ET for Austrian winter fieldpea was expected due to the early harvest date.

The consistently low ET for Austrian winter fieldpea and fieldbean suggests that these crop treatments should leave more remaining available soil moisture than the other crops

tested. Evapotranspiration for other crops such as fababean and fieldpea may have been similar to those for Austrian winter fieldpea if they were harvested early.

Seed Yield

Fababean, lentil, fieldpea, chickpea, fieldbean, barley, and wheat seed yields were 44, 53, 42, 47, 50, 72, and 72 percent lower, respectively, for crops grown at the Post Farm compared to the Schutter Farm (Table 8). Suppressed grain yields at the Post Farm are attributed to late planting date and environmental constraints, particularly late season drought.

Table 8. Seed Yield at the Post Research and Schutter Farms for 1982 and 1983, Respectively.

Crop	Post Farm (1982)	Schutter Farm (1983)
	Seed Yield kg ha ⁻¹	
Fababean	1289 b [†]	2309 a
Lentil	894 a	1916 a
Fieldpea	1907 c	3299 bc
Chickpea	1744 c	3265 bc
Fieldbean	1224 b	2461 ab
Barley	965 a	3434 c
Wheat	937 a	3414 c
LSD 0.05	244	939

[†] Seed yield means within a column not followed by a common letter are significantly different by Fisher's protected LSD ($P = 0.05$).

Fieldpea and chickpea had the highest seed yield with 1907 and 1744 kg ha⁻¹, respectively, for 1982 at the Post Farm. Highest seed yielding crops under more favorable conditions in 1983 were barley, wheat, fieldpea, and chickpea with 3434, 3414, 3299, and 3265 kg ha⁻¹, respectively.

The Gallatin Valley was a commercial fieldpea production area from 1910 to 1958 with an average yield of 1180 kg ha⁻¹ (Burlingame, 1976; Herbert, 1978a; Monroe, 1942). Fieldpea production declined in the Gallatin Valley following the closure of local canning

plants. Hinman et al. (1982) reported an average yield of 1682 kg ha^{-1} for the Washington and Idaho Palouse region. These data suggest that the Gallatin Valley has fieldpea production potential equal to the Palouse if disease and marketing constraints are resolved.

Welty et al. (1982) reported that the average chickpea yield for four Montana locations was 2957 kg ha^{-1} in 1981. Chickpea yield at the Post Research and Schutter Farm was 41 percent lower and 9 percent higher, respectively than the Montana average. Chickpea yield potential in the Gallatin Valley should be similar to other high rainfall locations in Montana when planted early.

Average fieldbean yield for Montana (primarily based on irrigated acreage) is 1838 kg ha^{-1} (Herbert, 1978b). Yields at the Post Research and Schutter Farms were 33 percent lower and 25 percent higher, respectively than the Montana average. These data (Table 8) indicate that Gallatin Valley dryland fieldbean yields are similar to irrigated yields in other areas of the state. High yield in the Gallatin Valley is attributed to high precipitation. However, the short growing season may result in crop failure some years.

Average dryland 'Ackerperle' fababean seed yield for 10 locations in Montana is 1840 kg ha^{-1} under cool-wet conditions and 912 kg ha^{-1} under warm-dry conditions (Lockerman et al., 1982). Fababean seed yield at the Schutter Farm (2309 kg ha^{-1}) exceeded the "cool-wet" Montana average by 20 percent. Fababean seed yield at the Post Farm (1289 kg ha^{-1}) was 30 percent lower than the "cool-wet" average which may be due to late season water stress. These comparative yields suggest that the Gallatin Valley is a favorable area for fababean seed production.

Wheat and barley yields in 1982 were markedly suppressed due to the delayed planting date and late season moisture stress. Conversely, wheat and barley yields in 1983 were high. Average dryland 'Clark' barley yield at Bozeman, Montana is 3719 kg ha^{-1} (Bowman and Baldrige, 1984a). The Post Research and Schutter Farm yields were 74 and 8 percent lower, respectively than the average yield for Bozeman. Bowman and Baldrige (1984b)

reported an average of 2852 kg ha⁻¹ for dryland 'Newana' spring wheat yields at eight Montana locations. The Post Research and Schutter Farm yields were 67 percent lower and 16 percent higher, respectively than the Montana average.

Lentil seed production (894 kg ha⁻¹) was markedly suppressed under the unfavorable 1982 growing conditions. Lentil seed production in 1983 was 1916 kg ha⁻¹. Average 'Chilean' lentil seed production for the Palouse is 1392 kg ha⁻¹ (Auld and Murray, 1981; Muehlbauer and Short, 1981). Lentil yield at the Post Research and Schutter Farms was 36 percent lower and 27 percent higher than the Palouse average, respectively. These data suggest that lentil has excellent potential in the Gallatin Valley when planted early.

Seed Production Water Use Efficiency

Seed production WUE (kg seed yield m⁻³ H₂O used) was markedly lower in 1982 than in 1983 due to environmental constraints (Table 9).

Table 9. Seed Production Water Use Efficiency[†] at the Post Research and Schutter Farms for 1982 and 1983, Respectively.

Crop	Post Farm (1982)	Schutter Farm (1983)
	Seed WUE kg m ⁻³	
Fababean	0.46 b [‡]	0.89 a
Lentil	0.34 a	0.74 a
Fieldpea	0.90 d	1.13 b
Chickpea	0.60 c	1.27 b
Fieldbean	0.47 b	1.06 ab
Barley	0.39 ab	1.35 b
Wheat	0.43 ab	1.32 b
LSD 0.05	0.10	0.36

[†] WUE = kg yield m⁻³ H₂O used.

[‡] Seed production WUE means within a column not followed by a common letter are significantly different by Fisher's protected LSD (P = 0.05).

Fieldpea and chickpea had the highest and second highest seed production WUE, respectively in 1982. This suggests that fieldpea and chickpea are efficient in allocating water for seed production under stress conditions. Crops with the highest 1983 WUE included fieldpea, chickpea, fieldbean, barley, and wheat. The consistently high seed production WUE for fieldpea and chickpea may contribute to yield stability under diverse environments.

Fababean, lentil, fieldbean, barley, and wheat had the lowest 1982 seed production WUE. The lowest WUE crops for 1983 were fababean, lentil, and fieldbean (fieldbean WUE was not significantly different from the lowest or highest crops for 1983).

Fababean's indeterminate growth habit resulted in relatively low seed yield compared to total biomass yield. This is reflected in the low seed yield WUE compared to a high biomass WUE (Table 6).

Seed Protein Percentage

Seed protein percentage (Table 10) was less affected by site and year than were biomass and seed yields.

Table 10. Seed Protein Percentage at the Post Research and Schutter Farms for 1982 and 1983, Respectively.

Crop	Post Farm (1982)	Schutter Farm (1983)
	Seed Protein %	
Fababean	24.98 e [†]	27.19 d
Lentil	24.69 e	20.86 c
Fieldpea	25.38 e	23.85 cd
Chickpea	15.22 d	16.86 b
Fieldbean	12.16 b	12.32 a
Barley	9.07 a	11.96 a
Wheat	13.39 c	12.28 a
LSD 0.05	0.97	3.59

[†]Seed protein percent means within a column not followed by a common letter are significantly different by Fisher's protected LSD ($P = 0.05$).

Fababean, lentil, and fieldpea had the highest seed protein percentage for both 1982 and 1983. High seed protein percentage is an important quality consideration for world regions where protein production for the human diet is limited.

The 1982 and 1983 protein percentages for wheat are similar to statewide averages for 'Newana' spring wheat (Bowman and Baldrige, 1984b). Fababean, lentil, and fieldpea had similar protein percentages, while chickpea and fieldbean had lower protein percentages than are typical in major world production regions (Duke, 1981). Nitrogen fertilization may be required to raise the protein levels of chickpea and fieldbean (Edje et al., 1975; Westerman et al., 1981).

Seed Protein Yield

Seed protein yield (kg ha^{-1} seed yield $\times$ protein %) at the Post Farm compared to the Schutter Farm was markedly lower for all crops (Table 11). Low 1982 protein yield is attributed to the low seed yield resulting from unfavorable growing conditions.

Table 11. Seed Protein Yield at the Post Research and Schutter Farms for 1982 and 1983, Respectively.

Crop	Post Farm (1982)	Schutter Farm (1983)
	Seed Protein Yield kg ha^{-1}	
Fababean	322.0 d [†]	603.9 cd
Lentil	220.8 c	397.8 ab
Fieldpea	484.3 e	783.2 d
Chickpea	264.9 c	550.2 bc
Fieldbean	149.4 b	304.2 a
Barley	87.1 a	450.5 abc
Wheat	125.2 ab	418.8 abc
LSD 0.05	52.8	188.8

[†]Seed protein yield means within a column not followed by a common letter are significantly different by Fisher's protected LSD ($P = 0.05$).

Fieldpea had the highest (484.3 kg ha⁻¹) and fababean the second highest (322.0 kg ha⁻¹) seed protein yield under the unfavorable 1982 conditions. Fieldpea had higher protein yield (783.2 kg ha⁻¹) than all crops except fababean (603.9 kg ha⁻¹) in 1983.

Fieldbean, barley, and wheat had the lowest protein yield in 1982. Crops with the lowest 1983 protein yield were lentil, fieldbean, barley, and wheat.

Seed protein yield is an important consideration when selecting a crop for on-farm livestock feeding. These data indicate that fieldpea and fababean seed have the greatest potential as a livestock feed supplement for on-farm use.

Harvest Index

Harvest index (seed yield divided by total biomass yield) is a measure of crop efficiency in utilizing available resources to produce harvestable yield (Clark et al., 1984; Spaeth et al., 1984). Harvest index for fababean, lentil, fieldpea, and barley were affected the least by location and year (Table 12). This suggests that these crops were less sensitive to disruption of the reproductive-vegetative balance and growth cycles due to planting date and other environmental differences (Clark et al., 1984; Spaeth et al., 1984).

Table 12. Harvest Index[†] at the Post Research and Schutter Farms for 1982 and 1983, Respectively.

Crop	Post Farm (1982)	Schutter Farm (1983)
	Harvest Index	
Fababean	0.27 a [‡]	0.33 a
Lentil	0.48 bc	0.44 ab
Fieldpea	0.45 bc	0.45 ab
Chickpea	0.42 b	0.58 bc
Fieldbean	0.49 c	0.73 c
Barley	0.44 bc	0.51 ab
Wheat	0.44 bc	0.72 c
LSD 0.05	0.06	0.18

[†] Harvest Index = seed yield/biomass yield.

[‡] Harvest index means within a column not followed by a common letter are significantly different by Fisher's protected LSD (P = 0.05).

Fababean had a low harvest index for both years. The indeterminate fababean growth contributed to its low harvest index since seed on the upper plant portions were not ripe when lower seed were mature. The low harvest index of fababean may indicate more potential as a silage or green manure crop.

Higher harvest index values for fieldbean, chickpea, and wheat in 1983 may be due to environmental effects. Harvest index for spring wheat increases as post-anthesis available moisture increases (Clark et al., 1984). The high 1983 harvest index value for wheat (0.72) is attributed to greater available moisture after anthesis compared to 1982.

Available Soil Moisture

Available soil moisture at the end of the growing season is an important factor in selecting a legume for rotation with other crops in a semi-arid environment. Available soil moisture respective of each crop was compared to fallow to evaluate soil moisture depletion.

The Post Farm pre-plant composite soil sample on June 12, 1982 showed 1.37, 5.23, 7.38, and 13.98 cm of available water for the 0-15, 15-60, 60-120, and 0-120 cm soil depths, respectively (Table 13).

Table 13. Available Soil Moisture at Various Depths at the Post Research Farm on June 12, 1982 (pre-plant).

Crop	Soil Depth cm			
	0-15	15-60	60-120	0-120 [†]
	Available H ₂ O cm			
Preplant Composite	1.37	5.23	7.38	13.98

[†] Values for the 0 to 120 cm depth = values for (0 to 15) + (15 to 60) + (60 to 120).

Crop treatment had no effect on the post-harvest available soil moisture for the 0-15 cm depth at the Post Research Farm on September 23, 1982 (Table 14). Surface evaporation by fallow and evapotranspiration by crops resulted in the non-differential 0-15 cm soil moisture (Brown, 1971; Brown and Dickey, unpublished data, 1970 Annual Research Report, USDA-SWC, Northern Plains Branch, Bozeman, Montana). All crops had extensive root exploration of the 0-15 cm depth.

Table 14. Available Soil Moisture at Various Depths at the Post Research Farm on September 23, 1982 (post-harvest).

Crop	Soil Depth cm			
	0-15	15-60	60-120	0-120
	Available H ₂ O cm			
Fababean	0.34 a [†]	0.24 a	1.81 ab	2.40 a
Lentil	0.82 a	1.08 abc	3.05 cde	4.95 abc
Fieldpea	1.16 a	3.20 de	4.03 ef	8.40 de
Chickpea	1.02 a	1.31 abc	1.64 a	3.96 ab
Fieldbean	1.00 a	1.41 abc	3.70 de	6.11 bcd
Winter pea hay	1.38 a	2.11 bcde	2.85 bcd	6.34 bcd
Winter pea green manure	1.08 a	0.88 ab	2.34 abc	4.30 ab
Barley	0.72 a	1.72 abcd	3.75 def	6.20 bcd
Wheat	0.89 a	2.63 cde	4.03 ef	7.55 cde
Fallow	1.23 a	3.54 e	4.89 f	9.66 e
LSD 0.05	NS	1.58	1.15	2.81

[†] Available soil moisture means within a column not followed by a common letter are significantly different by Fisher's protected LSD (P = 0.05).

Available soil moisture following fieldpea, Austrian winter fieldpea hay, wheat, and fallow was not different at the 15-60 cm soil depth (Table 14). Post-harvest available soil moisture in decreasing order from fallow was fieldpea, wheat, Austrian winter fieldpea hay, barley, fieldbean, chickpea, lentil, Austrian winter fieldpea green manure, and fababean at the 15-60 cm depth.

Fieldpea, barley, wheat, and fallow showed no difference in available soil moisture at the 60-120 cm depth at the Post Research Farm (Table 14). Available soil moisture at the 60-120 cm soil depth in decreasing order from fallow included wheat, fieldpea, barley, fieldbean, lentil, Austrian winter fieldpea hay and green manure, fababean and chickpea. Lower soil moisture at the deepest soil depth sampled would suggest that fababean, chickpea, and Austrian winter fieldpea may have the deepest root penetration of the crops tested in 1982.

Fieldpea, wheat, and fallow had no difference in post-harvest available soil moisture at the 0-120 cm soil depth at the Post Farm (Table 14). Available soil moisture at the 0-120 cm depth in decreasing order from fallow was following fieldpea, wheat, Austrian winter fieldpea hay, barley, fieldbean, lentil, Austrian winter fieldpea green manure, chickpea, and fababean.

Shallow rooting depths due to late planting, low soil nitrate levels, and inherent species differences resulted in fieldpea, fieldbean, barley, and wheat having the remaining soil moisture levels most similar to fallow. The 2.04 cm available soil moisture difference between the Austrian winter fieldpea green manure and hay treatment is attributed to evaporation following the green manure plow-down.

Fallow showed a 21.28 cm loss of available soil moisture at the 0-120 cm depth at the Post Farm during the 1982 crop season (crop season precipitation = 16.96 cm) (Tables 13 and 14). This loss is attributed to evaporation due to three weed control tillage operations and water drainage below the 0-120 cm sampling depth.

Previous crop treatment had no effect on available soil moisture at the Post Research Farm on May 22, 1983 for the 0-15, 15-60, 60-120, and 0-120 cm soil depths (Table 15). Differential increases in available soil moisture between September 23, 1982 and May 22, 1983 by crop treatments compared to fallow is attributed to snow trapped by crop residue Koala (1982) reported non-differential 0-120 cm preplant soil moisture following

various *Medicago*, *Trifolium*, and *Lupinus* species, fababean, and fallow in a legume-wheat rotation study at the Post Farm location.

Table 15. Available Soil Moisture at Various Depths at the Post Research Farm on May 22, 1983 (pre-plant).[†]

Previous Crop	Soil Depth cm			
	0-15	15-60	60-120	0-120
	Available H ₂ O cm			
Fababean	1.58 a [‡]	4.11 a	4.01 a	9.70 a
Lentil	1.46 a	4.11 a	4.41 a	9.98 a
Fieldpea	1.30 a	3.94 a	4.91 a	10.15 a
Chickpea	1.51 a	3.71 a	4.66 a	9.88 a
Fieldbean	1.44 a	3.90 a	4.89 a	10.24 a
Winter pea hay	1.37 a	4.07 a	5.09 a	10.52 a
Winter pea green manure	1.31 a	3.77 a	4.81 a	9.90 a
Barley	1.42 a	4.09 a	4.18 a	9.69 a
Wheat	1.00 a	3.41 a	3.38 a	7.78 a
Fallow	1.42 a	3.61 a	4.54 a	9.65 a
LSD 0.05	NS	NS	NS	NS

[†] Barley planted on all plots May 27, 1983.

[‡] Available soil moisture means within a column not followed by a common letter are significantly different by Fisher's protected LSD ($P = 0.05$).

The Schutter Farm pre-plant soil composite on May 30, 1983 showed 1.06, 2.90, 4.02, and 7.98 cm available moisture for the 0-15, 15-60, 60-120, and 0-120 cm soil depths, respectively (Table 16). The higher pre-plant available soil moisture at the Post Farm compared to the Schutter Farm is attributed to greater precipitation immediately prior to sampling and greater water holding capacity of the soil.

Crop treatment had no effect on post-harvest available soil moisture at the 0-15 cm soil depth at the Schutter Farm on September 24, 1983 (Table 17). This is similar to results at the Post Farm (Table 14). Fallow had the highest post-harvest available soil moisture at the Schutter Farm at 15-60, 60-120, and 0-120 cm soil depths (Table 17). Fieldbean and Austrian winter fieldpea hay and green manure had intermediate available

Table 16. Available Soil Moisture at Various Depths at the Schutter Farm on May 30, 1983 (pre-plant).

Crop	Soil Depth cm			
	0-15	15-60	60-120	0-120
	Available H ₂ O cm			
Preplant Composite	1.06	2.90	4.02	7.98

Table 17. Available Soil Moisture at Various Depths at the Schutter Farm on September 24, 1983 (post-harvest).

Crop	Soil Depth cm			
	0-15	15-60	60-120	0-120
	Available H ₂ O cm			
Fababean	0.97 a [†]	0.67 a	0.53 a	1.57 a
Lentil	0.77 a	0.13 a	0.30 a	1.20 a
Fieldpea	1.40 a	0.27 a	0.40 a	2.07 a
Chickpea	1.07 a	0.10 a	0.23 a	1.40 a
Fieldbean	1.47 a	0.57 ab	1.97 b	4.00 b
Winter pea hay	1.10 a	1.17 b	3.47 c	5.73 b
Winter pea green manure	1.23 a	0.80 ab	2.37 bc	4.40 b
Barley	1.40 a	0.20 a	0.10 a	1.70 a
Wheat	1.33 a	0.00 a	0.00 a	1.33 a
Fallow	1.67 a	5.20 c	5.10 d	11.97 c
LSD 0.05	NS	0.70	1.34	1.78

[†] Available soil moisture means within a column not followed by a common letter are significantly different by Fisher's protected LSD (P = 0.05).

soil moisture at the 60-120 and 0-120 cm soil depths. Crop treatments with the lowest soil moisture at the 15-60, 60-120, and 0-120 cm soil depths included fababean, lentil, fieldpea, chickpea, barley, and wheat.

The lower remaining available soil moisture for crop treatments relative to fallow at the Schutter Farm compared to the Post Farm is attributed to environmental differences.

The consistently low soil moisture following fababean and chickpea at both locations indicates efficient soil moisture extraction under diverse environments. A consistently high soil moisture following fieldbean and Austrian winter fieldpea hay at both locations may indicate potential for utilization in crop rotations under limited soil moisture conditions.

Soil Nitrate

Soil $\text{NO}_3\text{-N}$ level following a legume is one measure of legume effectiveness in a crop rotation. Higher soil $\text{NO}_3\text{-N}$ levels will result in less expense for nitrogen fertilizer needed to produce the following crop. Soil $\text{NO}_3\text{-N}$ respective of each crop was compared to fallow to evaluate the nitrogen contribution of each crop. The Post Farm pre-plant composite on June 12, 1982 showed 11.2, 24.2, 32.3, and 67.7 kg ha^{-1} $\text{NO}_3\text{-N}$ for the 0-15, 15-60, 60-120, and 0-120 cm soil depths, respectively (Table 18).

Table 18. Soil $\text{NO}_3\text{-N}$ Levels at Various Depths at the Post Research Farm on June 12, 1982 (pre-plant).

Crop	Soil Depth cm			
	0-15	15-60	60-120	0-120
	$\text{NO}_3\text{-N}$ kg ha^{-1}			
Preplant Composite	11.2	24.2	32.3	67.7

Austrian winter fieldpea green manure and fallow had the highest soil $\text{NO}_3\text{-N}$ levels at the 0-15 and 15-60 cm soil depths at the Post Farm on September 23, 1982 (Table 19). Fieldpea post-harvest soil $\text{NO}_3\text{-N}$ at the 60-120 cm soil depth was higher than fallow and was not different from lentil, Austrian winter fieldpea green manure and hay, and fieldbean. Austrian winter fieldpea green manure and fallow showed no difference in soil $\text{NO}_3\text{-N}$ levels at 0-120 cm soil depth at the Post Farm. Post-harvest soil $\text{NO}_3\text{-N}$ levels at 0-120 cm soil depth in decreasing order from Austrian winter fieldpea green manure

included fallow, fieldpea, lentil, Austrian winter fieldpea hay, fieldbean, fababean, chickpea, wheat, and barley.

Table 19. Soil $\text{NO}_3\text{-N}$ Levels at Various Depths at the Post Research Farm on September 23, 1982 (post-harvest).

Crop	Soil Depth cm			
	0-15	15-60	60-120	0-120
	$\text{NO}_3\text{-N}$ kg ha^{-1}			
Fababean	5.3 ab [†]	10.7 ab	15.2 abc	31.3 ab
Lentil	10.3 c	22.6 c	25.1 de	58.0 de
Fieldpea	10.6 c	20.1 bc	27.7 e	58.5 de
Chickpea	4.5 a	9.1 a	8.0 a	21.7 a
Fieldbean	9.1 bc	13.4 abc	20.6 cde	43.2 bc
Winter pea hay	12.9 c	21.7 c	20.9 cde	55.6 cd
Winter pea green manure	17.5 d	38.7 d	25.4 de	81.7 f
Barley	3.7 a	9.8 a	7.4 a	21.0 a
Wheat	3.7 a	8.9 a	8.9 a	21.6 a
Fallow	17.5 d	36.1 d	17.3 bcd	71.0 ef
LSD 0.05	4.0	9.6	9.2	14.3

[†] Soil nitrate means within a column not followed by a common letter are significantly different by Fisher's protected LSD ($P = 0.05$).

Chickpea and fababean soil $\text{NO}_3\text{-N}$ levels at the 0-15 cm soil depth at the Post Research Farm on May 22, 1983 were higher than fallow and equal to Austrian winter fieldpea green manure, lentil, and Austrian winter fieldpea hay (Table 20). Austrian winter fieldpea green manure had the highest soil $\text{NO}_3\text{-N}$ level at the 15-60 cm soil depth. Soil $\text{NO}_3\text{-N}$ levels at the 15-60 cm depth in the decreasing order from Austrian winter fieldpea green manure were lentil, Austrian winter fieldpea hay, fallow, fieldpea, fieldbean, chickpea, fababean, wheat, and barley. Fallow had the highest soil $\text{NO}_3\text{-N}$ level at the 60-120 cm soil depth on May 22, 1983. Previous crop treatments in decreasing order having lower soil $\text{NO}_3\text{-N}$ levels than fallow at the 60-120 cm soil depth were lentil, Austrian winter fieldpea green manure and hay, fieldpea, fababean, fieldbean, chickpea, wheat, and barley.

Table 20. Soil NO₃-N Levels at Various Depths at the Post Research Farm on May 22, 1983 (pre-plant).[†]

Previous Crop	Soil Depth cm			
	0-15	15-60	60-120	0-120
	NO ₃ -N kg ha ⁻¹			
Fababean	10.3 de [‡]	24.4 bc	25.5 bc	59.2 bc
Lentil	8.3 bcde	35.2 e	43.0 d	86.6 ef
Fieldpea	7.2 abcd	27.8 cde	31.9 cd	67.0 cd
Chickpea	10.4 e	25.3 bcd	16.1 ab	51.9 b
Fieldbean	6.4 abc	25.9 cde	23.6 bc	56.1 bc
Winter pea hay	7.6 abcde	34.5 de	34.3 cd	76.5 de
Winter pea green manure	8.6 cde	58.5 f	42.1 d	109.3 g
Barley	5.3 ab	14.5 a	11.6 a	31.5 a
Wheat	4.9 a	15.6 ab	13.7 ab	34.3 a
Fallow	5.8 abc	34.3 de	58.9 e	99.0 fg
LSD 0.05	3.2	9.8	11.1	13.7

[†] Barley planted on all plots May 27, 1983.

[‡] Soil nitrate means within a column not followed by a common letter are significantly different by Fisher's protected LSD (P = 0.05).

Lower 0-15 and 15-60 cm NO₃-N levels and higher 60-120 cm NO₃-N levels for fallow between September 23, 1982 and May 22, 1983 at the Post Farm is attributed to leaching (Legg and Meisenger, 1982). Some nitrate may have leached below the 120 cm soil depth and would not likely be available for crop utilization.

Austrian winter fieldpea green manure and lentil soil NO₃-N levels were not different from fallow at the 0-120 cm soil depth at the Post Farm on May 22, 1983 (Table 20). Soil NO₃-N levels at 0-120 cm soil depth in decreasing order from Austrian winter fieldpea green manure were fallow, lentil, Austrian winter fieldpea hay, fieldpea, fababean, fieldbean, chickpea, wheat, and barley.

All crop treatments showed increased NO₃-N levels at the 0-120 cm depth between September 23, 1982 and May 22, 1983 due to mineralization of crop residue and soil organic matter (Alexander, 1977; Jansson and Persson, 1982). All legume treatments had

higher $\text{NO}_3\text{-N}$ levels than cereal grain treatments at the 0-120 cm soil depth. Austrian winter fieldpea green manure and lentil show short-term rotation potential comparable to fallow for nitrate availability at the beginning of the second crop season.

The Schutter Farm pre-plant soil composite on May 30, 1983 showed 15.1, 40.0, 40.3, and 95.4 kg ha^{-1} soil $\text{NO}_3\text{-N}$ for the 0-15, 15-60, 60-120, and 0-120 cm soil depths, respectively (Table 21). The pre-plant soil $\text{NO}_3\text{-N}$ level at the Schutter Farm was 27.7 kg ha^{-1} greater than at the Post Farm at 0-120 cm soil depth. Nitrogen fixation may have been suppressed at the Schutter Farm compared to the Post Farm due to the higher nitrate levels (Dean and Clark, 1980; Richards and Soper, 1979; Wong, 1980).

Table 21. Soil $\text{NO}_3\text{-N}$ Levels at Various Depths at the Schutter Farm on May 30, 1983 (pre-plant).

Crop	Soil Depth cm			
	0-15	15-60	60-120	0-120
	$\text{NO}_3\text{-N}$ kg ha^{-1}			
Preplant Composite	15.1	40.0	40.3	95.4

Fallow had the highest post-harvest soil $\text{NO}_3\text{-N}$ levels for the 0-15, 15-60, 60-120, and 0-120 cm soil depths at the Schutter Farm on September 24, 1983 (Table 22).

Soil $\text{NO}_3\text{-N}$ levels for the 0-15 cm soil depth at the Schutter Farm in decreasing order from fallow were Austrian winter fieldpea green manure, fieldpea, Austrian winter fieldpea hay, fababean, lentil, fieldbean, barley, chickpea, and wheat (Table 22). Crops lower than fallow at the 15-60 cm soil depth in decreasing order were Austrian winter fieldpea green manure, fieldpea, Austrian winter fieldpea hay, fieldbean, barley, fababean, wheat, lentil, and chickpea. Soil $\text{NO}_3\text{-N}$ levels at the 60-120 cm soil depth at the Schutter Farm in

Table 22. Soil NO₃-N Levels at Various Depths at the Schutter Farm on September 24, 1983 (post-harvest).

Crop	Soil Depth cm			
	0-15	15-60	60-120	0-120
	NO ₃ -N kg ha ⁻¹			
Fababean	9.8 ab [†]	6.0 a	18.4 bc	34.0 abc
Lentil	9.5 ab	5.6 a	11.2 ab	26.3 ab
Fieldpea	29.6 bc	18.4 ab	13.1 ab	61.1 c
Chickpea	5.2 a	5.4 a	11.2 ab	21.8 a
Fieldbean	8.2 a	14.0 a	8.8 ab	31.0 abc
Winter pea hay	16.5 abc	18.0 ab	20.3 bc	54.7 bc
Winter pea green manure	33.4 c	31.8 b	28.3 c	93.5 d
Barley	7.6 a	7.0 a	4.3 a	18.9 a
Wheat	3.4 a	5.8 a	3.5 a	12.7 a
Fallow	69.7 d	91.4 c	45.6 d	206.7 e
LSD 0.05	21.3	16.9	13.8	30.8

[†] Soil nitrate means within a column not followed by a common letter are significantly different by Fisher's protected LSD (P = 0.05).

decreasing order from fallow include Austrian winter fieldpea green manure and hay, fababean, fieldpea, lentil, chickpea, fieldbean, barley, and wheat.

Austrian winter fieldpea green manure had second highest post-harvest soil NO₃-N level at the 0-120 cm soil depth at the Schutter Farm (Table 22). Crops having 0-120 cm soil NO₃-N levels in decreasing order from Austrian winter fieldpea green manure include fieldpea, Austrian winter fieldpea hay, fababean, fieldbean, lentil, chickpea, barley, and wheat.

Consistently high 0-120 cm NO₃-N levels suggest that Austrian winter fieldpea green manure may be comparable to fallow for nitrogen supply to short-term rotations under diverse environments.

Soil nitrate levels may not be indicative of total nitrogen available to a second year rotation crop. Austrian winter fieldpea green manure and other legume crops may contribute more available nitrogen than fallow due to crop residue mineralization during the

second year growing season (Fribourg and Bartholomew, 1956; Jansson and Persson, 1982).

Second Year Rotation: Barley Performance

Barley performance during the second year rotation showed differences due to the previous crop. The main effects appear to be attributed to differences in nitrogen and available soil moisture. Barley response as influenced by each previous crop was compared to fallow to evaluate cropping system performance.

Biomass Yield

Barley biomass yield (above ground plant portions) at various N rates following legumes, wheat, barley, and fallow showed differential response at the Post Research Farm in 1983 (Fig. 1).

Barley biomass yield following fababean was lower than fallow at 0, 28, and 112 kg ha⁻¹ applied N rates, not different at 56 kg ha⁻¹ N, and higher at 84 kg ha⁻¹ N. Biomass yield following lentil was 4 percent higher than fallow with no applied N, higher at 28 through 84 kg ha⁻¹ N, and lower at 112 kg ha⁻¹ applied N.

Biomass yield following fieldpea, chickpea, and fieldbean was 16, 18, and 31% lower, respectively than yield following fallow at 0 added N. Biomass yield following fieldpea was greater than fallow at 28 through 84 kg ha⁻¹ and lower at 112 kg ha⁻¹ applied N. Biomass yield of barley following chickpea was lower than fallow at 28 and 112 kg ha⁻¹ N and not different from fallow at 56 and 84 kg ha⁻¹. Biomass yield following fieldbean was lower than fallow at 28 kg ha⁻¹ N, not different at 56 kg ha⁻¹ N, and higher at 84 and 112 kg ha⁻¹ applied N.

Barley biomass yield following Austrian winter fieldpea hay was not different from fallow at 0 and 112 kg ha⁻¹ N, and was higher than fallow at 28 through 84 kg ha⁻¹ N.

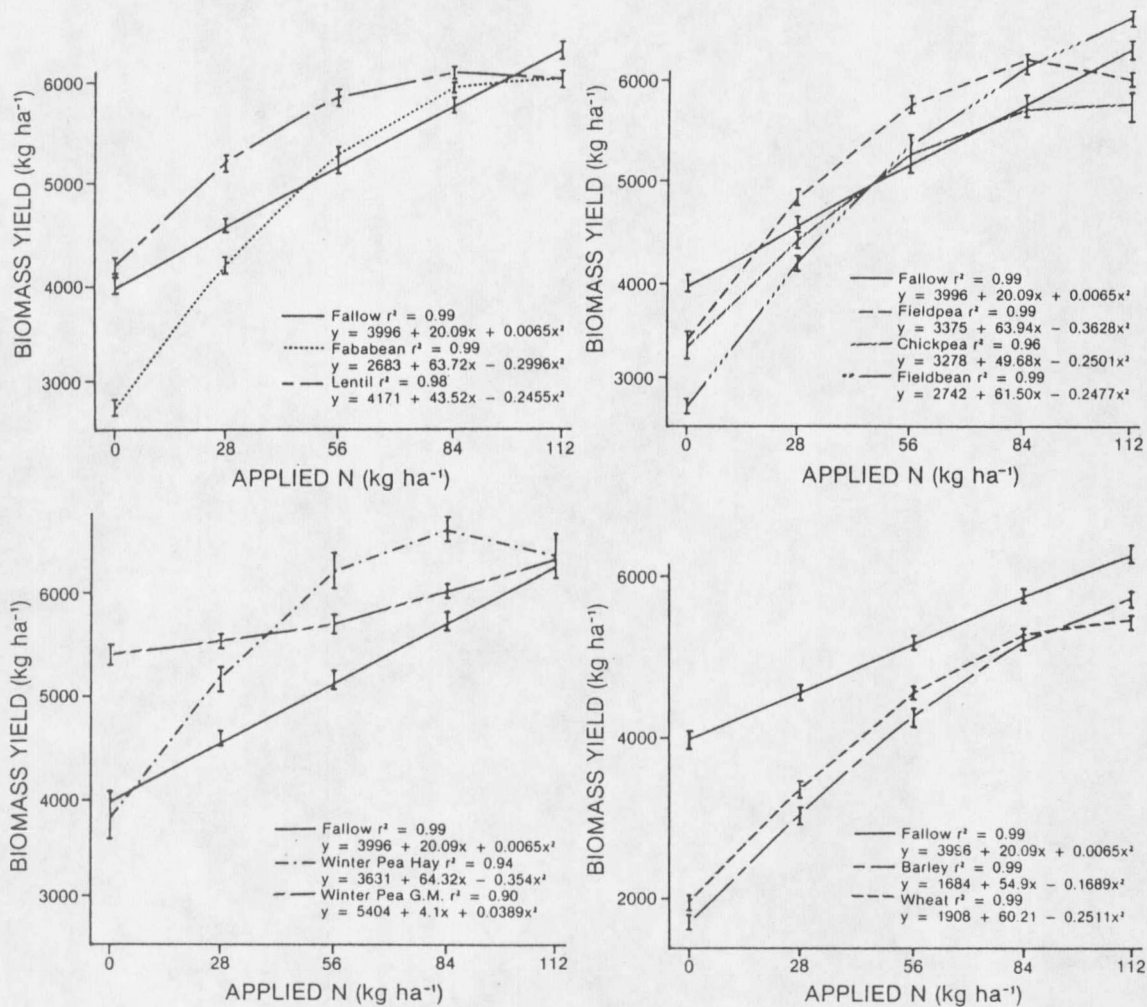


Figure 1. Barley biomass yield at various applied N rates following legumes, wheat, barley, and fallow at the Post Research Farm for 1983.[†]

[†]The slope of each line is significant at the 0.05 level.

Barley biomass yield following Austrian winter fieldpea green manure was 26 percent higher than fallow at 0 applied N, was higher than fallow at 28 through 84 kg ha⁻¹ N and not different from fallow at 112 kg ha⁻¹ N.

Barley biomass yield following wheat and barley was lower than fallow at all applied N rates.

Overall, barley biomass yield at the 0 N rate was highest following Austrian winter fieldpea green manure. The highest biomass yield with applied nitrogen was following fieldbean at 112 kg ha⁻¹ N.

Grain Yield

Barley grain yield at various N rates following legumes, wheat, barley, and fallow showed differential response at the Post Research Farm in 1983 (Fig. 2).

It is estimated that for the Gallatin Valley 54 kg ha⁻¹ grain yield is lost for each day delay in planting beyond April 25 (Robert Eslick, Montana State University; personal communication). Therefore, 1728 kg ha⁻¹ grain yield reduction may have occurred in each treatment due to the May 27 planting date. Barley grain yield following all treatments was lower than the average 'Clark' barley yield of 3719 kg ha⁻¹ at Bozeman, Montana (Bowman and Baldrige, 1984a).

Barley grain yield following lentil and fababean was lower than fallow at 0 through 112 kg ha⁻¹ applied N.

Barley grain yield following fieldpea was lower than following fallow at 0 and 112 kg ha⁻¹ applied N, not different from fallow at 28 kg ha⁻¹ N, and higher than following fallow at 56 and 84 kg ha⁻¹ applied N. Grain yield following chickpea was lower than fallow at all applied N rates. Yield following fieldbean was lower than fallow at 0, 28, 56, and 112 kg ha⁻¹ N, and not different from fallow at 84 kg ha⁻¹ applied N.

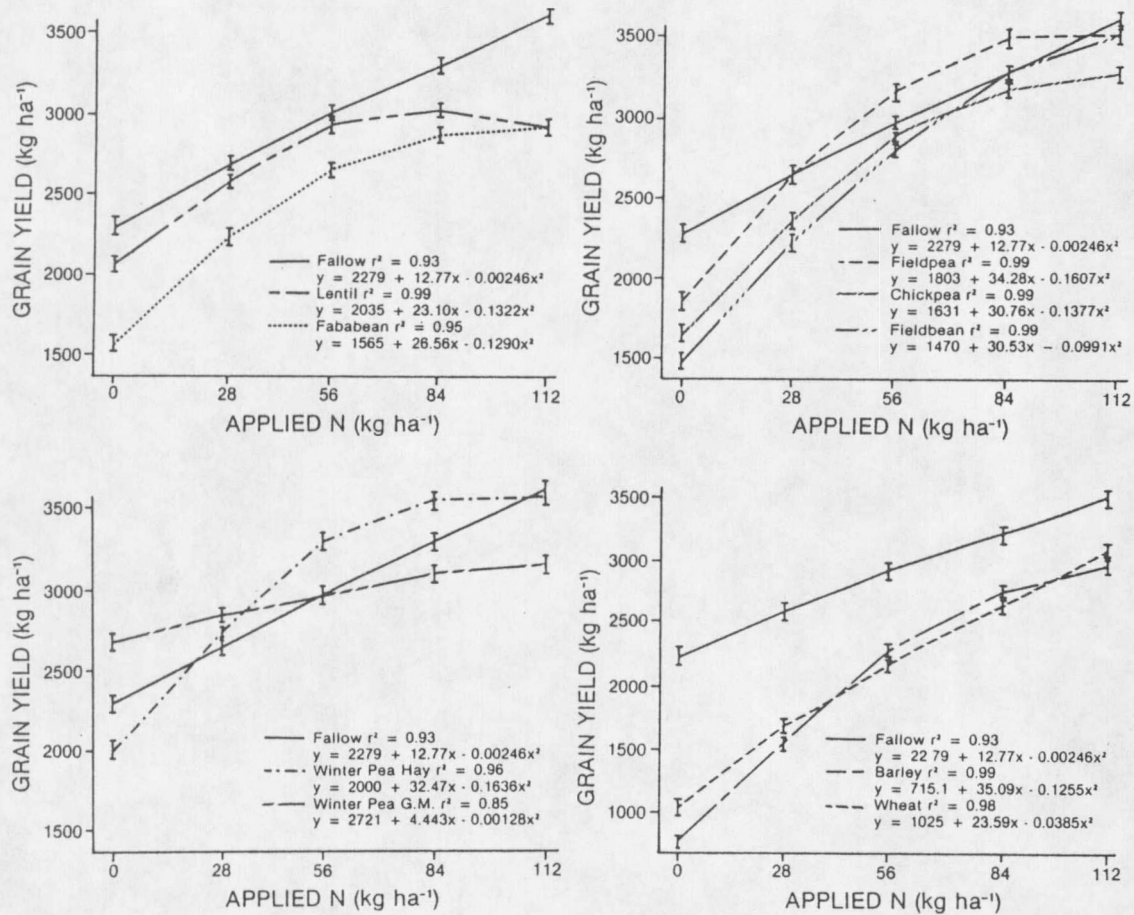


Figure 2. Barley grain yield at various applied N rates following legumes, wheat, barley, and fallow at the Post Research Farm for 1983.[†]

[†] The slope of each line is significant at the 0.05 level.

Grain yield following Austrian winter fieldpea hay was lower than fallow with no applied N, higher than fallow at 28 through 84 kg ha⁻¹ N, and not different from fallow at 112 kg ha⁻¹ applied N. Barley grain yield following Austrian winter fieldpea green manure was 16 percent higher than fallow at 0 applied N, higher at 28 kg ha⁻¹ applied N, not different from fallow at 56 kg ha⁻¹ N, and lower than fallow at 84 and 112 kg ha⁻¹ N. Austrian winter fieldpea green manure was the only previous crop treatment which had greater barley yield with no applied N than following fallow with no applied N.

Barley grain yield following barley and wheat was lower than following fallow at 0 through 112 kg ha⁻¹ applied N.

Overall, barley grain yield at the 0 N rate was highest following Austrian winter fieldpea green manure. Barley grain yield with no applied N was higher following all legumes than following wheat or barley. The highest grain yield with applied nitrogen was following Austrian winter fieldpea hay at 84 and 112 kg ha⁻¹ N and following fallow at 112 kg ha⁻¹ N.

Harvest Index

Barley harvest index at various applied N rates following legumes, wheat, barley, and fallow showed no differential response to either applied nitrogen or previous crop at the Post Research Farm in 1983 (Table 23).

Excessive nitrogen levels may stimulate excessive vegetative growth at the expense of reproductive growth (Chapman and Carter, 1976). Harvest index (grain yield divided by above ground biomass yield) is a measure of the reproductive-vegetative balance (Clark et al., 1984; Spaeth et al., 1984). The non-differential response indicates that available soil nitrogen levels were not high enough to upset the barley reproductive-vegetative balance in any of the cropping system treatments.

Table 23. Barley Harvest Index[†] Following Various Legumes, Wheat, Barley, and Fallow at the Post Research Farm for 1983; Means of All Added Nitrogen Fertilizer Levels.[‡]

Previous Crop	Barley Harvest Index
Fababean	0.52 a [§]
Lentil	0.50 a
Fieldpea	0.56 a
Chickpea	0.55 a
Fieldbean	0.53 a
Winter pea hay	0.56 a
Winter pea green manure	0.52 a
Barley	0.51 a
Wheat	0.53 a
Fallow	0.58 a
LSD 0.05	NS

[†] Harvest Index = Grain Yield/Total Above Ground Biomass.

[‡] There were no significant differences in harvest index due to added nitrogen fertilizer.

[§] Means followed by the same letter are not significantly different by Fisher's protected LSD ($P = 0.05$).

Test Weight

Barley grain test weight at various N rates following legumes, barley, wheat, and fallow showed differential response at the Post Research Farm in 1983 (Fig. 3). Increased test weight is an important quality factor for feed and malting barley (Chapman and Carter, 1976).

Barley test weight following fababean and lentil was greater than following fallow at 0 through 84 kg ha⁻¹ applied N, and was not different from fallow at 112 kg ha⁻¹ N. Barley test weight following fieldpea, chickpea, and fieldbean was greater than fallow at 0 through 112 kg ha⁻¹ applied N. Test weight for barley following Austrian winter fieldpea hay was greater than fallow at 0 through 112 kg ha⁻¹ N. Barley test weight following Austrian winter fieldpea green manure was lower than fallow at 0 through 112 kg ha⁻¹ N. Barley grain test weight following barley was not different from fallow at 0 through 56 kg ha⁻¹ N, and was lower than fallow at 84 and 112 kg ha⁻¹ applied N. Test weight for barley

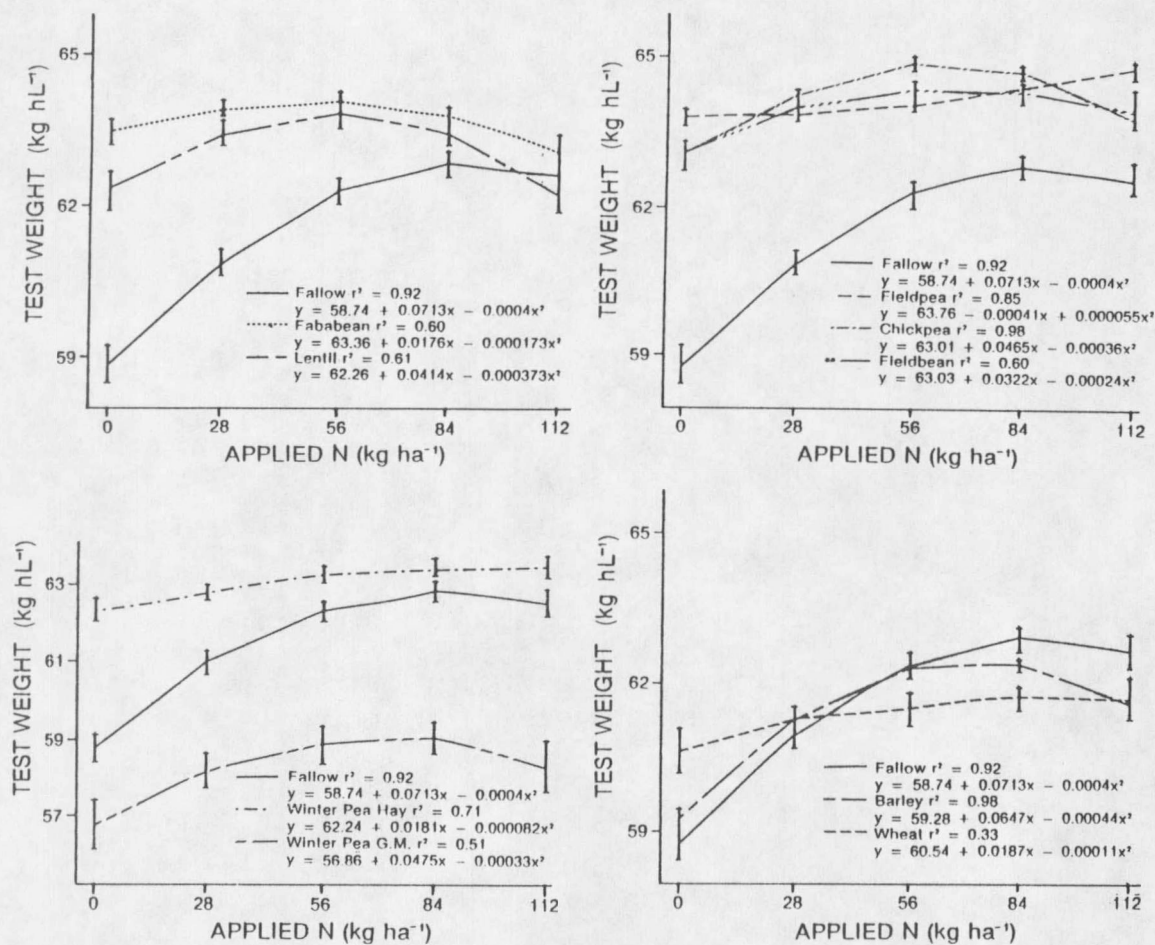


Figure 3. Barley grain test weight at various applied N rates following legumes, wheat, barley, and fallow at the Post Research Farm for 1983.[†]

[†]The slope for fallow is significant at the 0.05 level; all other slopes are not significant.

grain following wheat was higher than fallow at 0 applied N, not different from fallow at 28 and 112 kg ha⁻¹ N, and lower than fallow at 56 and 84 kg ha⁻¹ N.

Overall, barley test weight was highest at the 0 N rate following fieldpea. The highest barley test weight with applied nitrogen fertilizer was following fieldpea at 112 kg ha⁻¹ N and chickpea at 56 kg ha⁻¹ N.

Test weight is a determining factor for grading malting barley, with U.S. No. 1 to No. 3 two-rowed malting barley requiring at least 61.8 kg hL⁻¹. Barley grain following fallow at 56 through 112 kg ha⁻¹ N; following barley at 56 through 84 kg ha⁻¹ N; and following fababean, lentil, fieldpea, chickpea, fieldbean, and Austrian winter fieldpea hay at 0 through 112 kg ha⁻¹ applied N had a test weight greater than 61.8 kg hL⁻¹. Barley grain test weight following wheat and Austrian winter fieldpea green manure was below 61.8 kg hL⁻¹ at all applied N rates.

Water stress during kernel fill stages of growth may be the most important factor in decreased test weight for barley and wheat (Aspinall, 1965; Chapman and Carter, 1976). Differential barley test weights may be indicative of soil moisture differences during kernel fill. There was no difference in barley test weight due to applied N following all previous crop treatments except fallow (Fig. 3).

Percent Plump

Barley grain percent plump at various N rates following legumes, wheat, barley, and fallow showed differential response at the Post Research Farm in 1983 (Fig. 4). Increased percent plump is a desirable quality trait for malting and feed barley (Anonymous, 1984. Analytical Guidelines for Barley Breeders).

Barley grain percent plump following fababean, lentil, fieldpea, chickpea, and fieldbean was greater than fallow at 0 through 112 kg ha⁻¹ applied N.

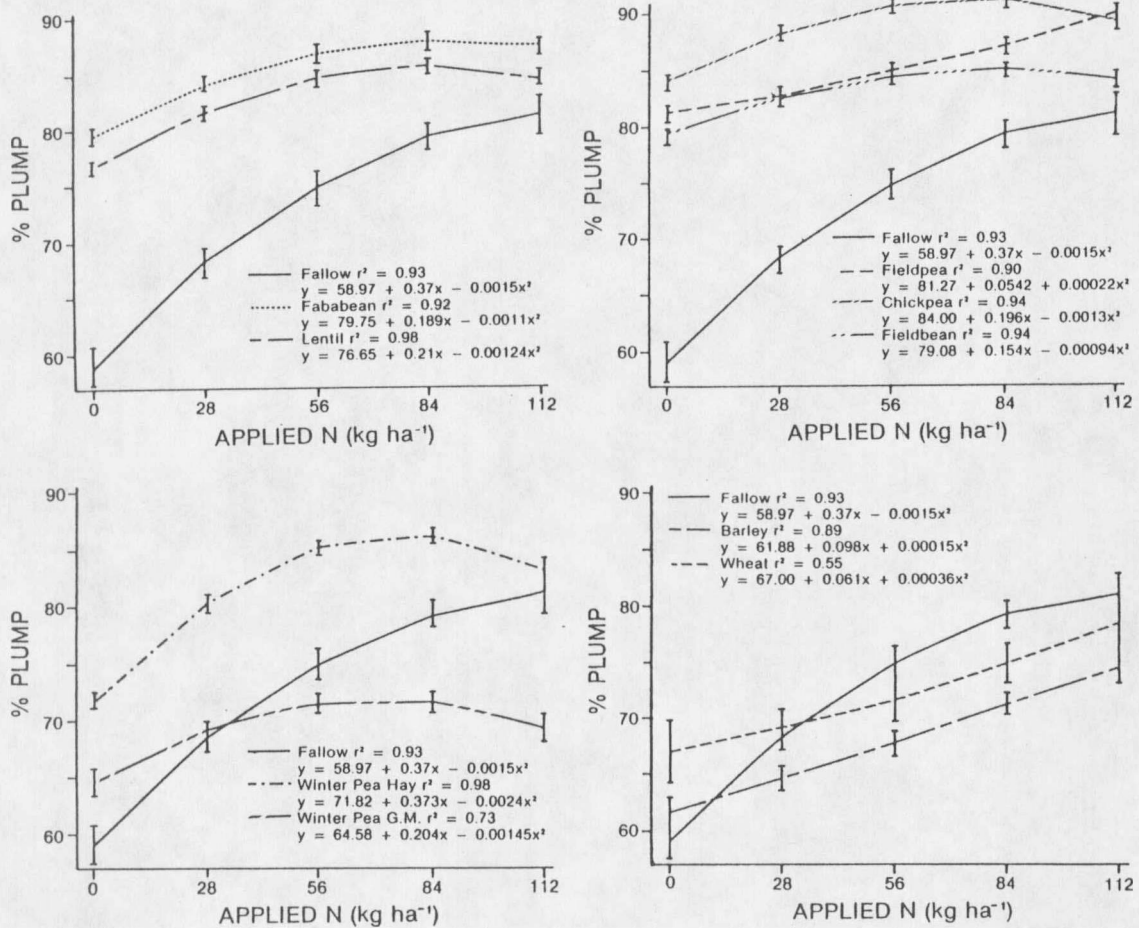


Figure 4. Barley grain percent plump at various applied N rates following legumes, wheat, barley, and fallow at the Post Research Farm for 1983.[†]

[†]The slopes for chickpea and Austrian winter fieldpea green manure are not significant; all other slopes are significant at the 0.05 level.

Percent plump for barley grain following Austrian winter fieldpea hay was higher than fallow at 0 through 84 kg ha⁻¹ applied N, and was not different from fallow at 112 kg ha⁻¹ N. Percent plump following Austrian winter fieldpea green manure was higher than fallow at 0 kg ha⁻¹ N, not different from fallow at 28 kg ha⁻¹ N, and less than fallow at 56 through 112 kg ha⁻¹ applied N.

Barley grain percent plump following barley was not different from fallow at 0 and 112 kg ha⁻¹ N, and less than fallow at 28 through 84 kg ha⁻¹ N. Percent plump following wheat was higher than fallow at 0 N, not different from fallow at 28, 56, and 112 kg ha⁻¹ N, and lower than fallow at 84 kg ha⁻¹ applied N.

Overall, barley percent plump at 0 applied N was highest following chickpea. The highest percent plump with applied N was following chickpea at 84 kg ha⁻¹ N.

Barley grain must be a minimum of 85 percent plump to be acceptable to the malting industry (Anonymous, 1984. Analytical Guidelines for Barley Breeders). Barley grain following fababean and chickpea with 28 through 112 kg ha⁻¹ applied N, lentil and fieldpea with 56 through 112 kg ha⁻¹ N, Austrian winter fieldpea hay with 56 through 84 kg ha⁻¹ N, and fieldbean at 84 kg ha⁻¹ N had a minimum of 85 percent plump.

Water stress during kernel fill may be a major factor in decreased kernel plumpness (Aspinall, 1965; Chapman and Carter, 1976). Aspinall (1965) states that the organ of barley growing most rapidly at the time of water stress will be the one most affected. Differences in barley percent plump may be an indication of water stress during the kernel fill period. However, there was increased percent plump with increased N rates following all previous crop treatments except chickpea and Austrian winter fieldpea green manure (Fig. 4).

Protein Percentage

Barley grain protein percentage at various N rates following legumes, wheat, barley, and fallow showed differential response at the Post Research Farm in 1983 (Fig. 5). This data shows increasing protein percentage as applied N is increased, and is comparable to results obtained by other researchers (Briggs, 1978; McGuire et al., 1979; Walker, 1975). Increased grain protein percentage is important for feed barley. Conversely, a mid-range of grain protein percentage from 11.5 to 13% is generally preferred by the malting industry (Anonymous, 1984. Analytical Guidelines for Barley Breeders).

Barley grain percent protein following fababean was less than following fallow at 0 through 56 kg ha⁻¹ N, not different from fallow at 84 kg ha⁻¹ N, and greater than fallow at 112 kg ha⁻¹ N. Percent protein following lentil was not different from fallow at 0 through 56 kg ha⁻¹ N and was higher than fallow at 84 and 112 kg ha⁻¹ applied N.

Barley grain protein percentage following fieldpea was lower than fallow at 0 and 28 kg ha⁻¹ N, not different from fallow at 56 and 84 kg ha⁻¹ N, and higher than fallow at 112 kg ha⁻¹ N. Protein percentage following chickpea was lower than fallow at 0 through 56 kg ha⁻¹ N, not different from fallow at 84 kg ha⁻¹ N, and higher than fallow at 112 kg ha⁻¹ N. Protein percent for barley grain following fieldbean was lower than following fallow at 0 through 84 kg ha⁻¹ applied N, and not different from fallow at 112 kg ha⁻¹ N.

Protein percentage for barley grain following Austrian winter fieldpea green manure was greater than following fallow at 0 through 112 kg ha⁻¹ applied N. Barley grain protein percentage following Austrian winter fieldpea hay was less than fallow at 0 through 56 kg ha⁻¹ N, not different from fallow at 84 kg ha⁻¹ N, and greater than fallow at 112 kg ha⁻¹ applied N.

Barley grain protein percentage following barley was less than following fallow at 0 through 84 kg ha⁻¹ N, and was not different from fallow at 112 kg ha⁻¹ applied N. Barley grain protein percentage following wheat was less than fallow at all applied N rates.

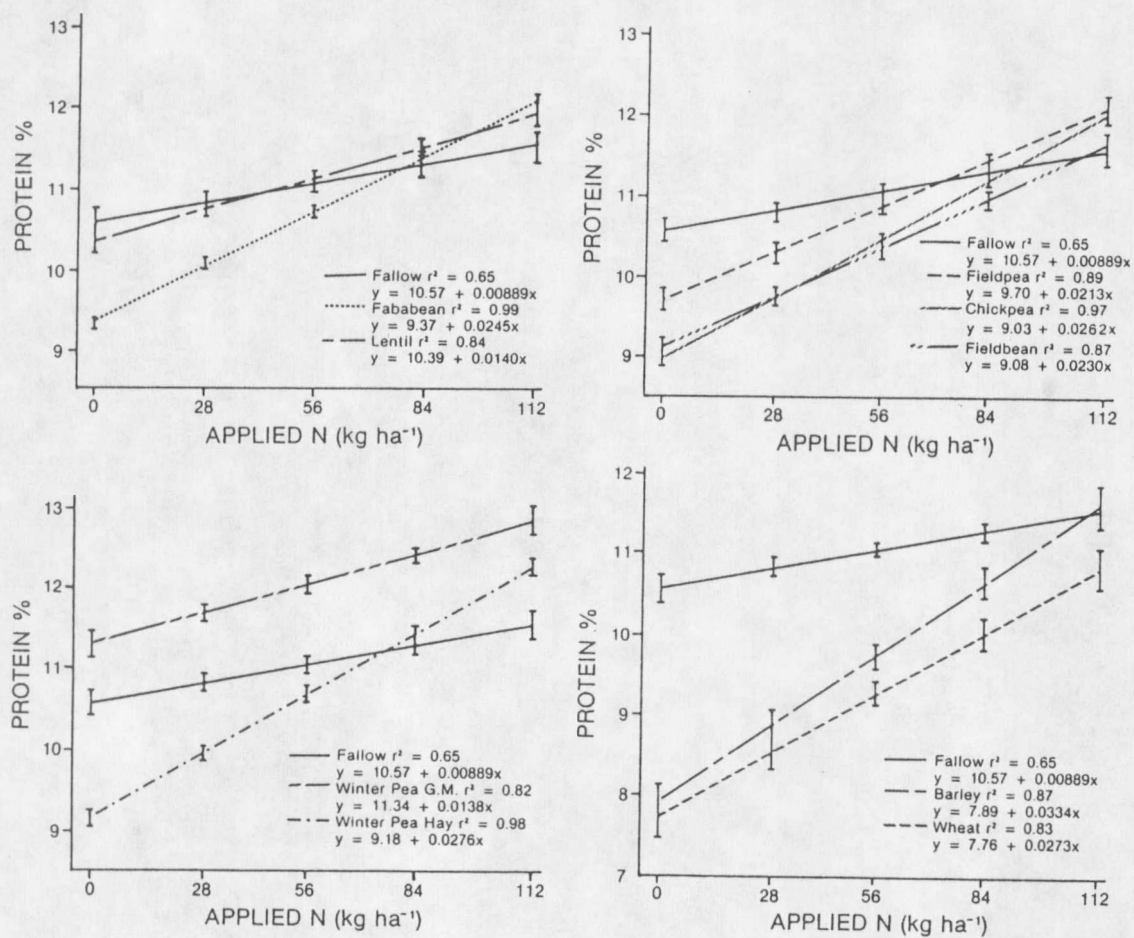


Figure 5. Barley grain protein percentage at various applied N rates following legumes, wheat, barley, and fallow at the Post Research Farm for 1983.[†]

[†] The slope for each line is significant at the 0.05 level.

Overall, protein percentage at the 0 N rate was highest following Austrian winter fieldpea green manure. Barley grain protein percentage with no applied nitrogen was higher following all legumes than following wheat or barley. Barley grain protein percent with applied nitrogen was highest following Austrian winter fieldpea green manure at 112 kg ha⁻¹ N.

Barley grain protein percentage acceptable to the malting industry varies depending on available supply, but is usually between 11.5 and 13.0 for two-rowed malting barley (Anonymous, 1983. Analytical Guidelines for Barley Breeders). Barley grain following all treatments was below 13.0% protein. Barley grain following fallow, chickpea, fieldbean, and barley at 112 kg ha⁻¹ N; following fababean, lentil, fieldpea, and Austrian winter fieldpea hay at 84 to 112 kg ha⁻¹ N; and following Austrian winter fieldpea green manure at 28 to 112 kg ha⁻¹ applied N was above 11.5% protein. Barley grain following wheat was below 11.5% protein at 0 through 112 kg ha⁻¹ applied N. The generally low grain protein percentages at the Post Research Farm are attributed to low initial soil nitrate levels (Table 18).

Timing of nitrogen availability to the barley crop may affect grain protein percentage. Fertilizer N applied prior to tillering may increase yield without affecting protein percentage (Briggs, 1978). Conversely, fertilizer nitrogen applied after tillering may increase grain protein percentage without affecting yield. Organic N sources may have the same effect as post-tiller fertilizer application due to nitrogen availability from mineralization throughout the growing season (Briggs, 1978; Wagner, 1954). High barley grain protein percentage following Austrian winter fieldpea green manure may partially be attributable to late season N availability.

Barley grain protein percentage may increase with increased water stress (Briggs, 1978). Greatest protein increases occur with water stress during the boot to soft dough stage (Wells and Dubetz, 1966). Therefore, differences in barley grain protein percentage may be attributed to both soil nitrogen and soil moisture availability.

Protein Yield

Barley grain protein yield (protein percent $\times$ grain yield) at various applied N rates following legumes, barley, wheat, and fallow showed differential response at the Post Research Farm in 1983 (Fig. 6). Our data show increased protein yield with increasing increments of applied N fertilizer. Premiums are not normally paid for high protein feed barley. However, protein yield per hectare would be an important consideration for feed grains raised for on-farm use.

Barley grain protein yield following lentil was not different from fallow at 0 kg ha⁻¹ N, and lower than fallow at 28 through 112 kg ha⁻¹ N. Protein yield following fababean was lower than fallow at all applied N rates.

Protein yield for barley grain following fieldbean and chickpea was lower than following fallow at 0 through 84 kg ha⁻¹ N, and was not different from fallow at 112 kg ha⁻¹ N. Grain protein yield following fieldpea was lower than fallow at 0 and 28 kg ha⁻¹ applied N, not different from fallow at 56 kg ha⁻¹ N, and greater than fallow at 84 and 112 kg ha⁻¹ N.

Protein yield following Austrian winter fieldpea green manure was higher than following fallow at 0 through 56 kg ha⁻¹ applied N, and not different from fallow at 84 and 112 kg ha⁻¹ N. Protein yield following Austrian winter fieldpea hay was lower than fallow at 0 and 28 kg ha⁻¹ applied N, was not different from fallow at 56 and 84 kg ha⁻¹ N, and higher than fallow at 112 kg ha⁻¹ N.

Barley grain protein yield following wheat and barley was lower than following fallow at 0 through 112 kg ha⁻¹ applied N.

Overall, grain protein yield with 0 applied N was highest following Austrian winter fieldpea green manure. Barley grain protein yield with no applied N was higher following all legumes than following cereals. The highest protein yield with applied nitrogen fertilizer was following fieldpea and Austrian winter fieldpea hay at 112 kg ha⁻¹ N.

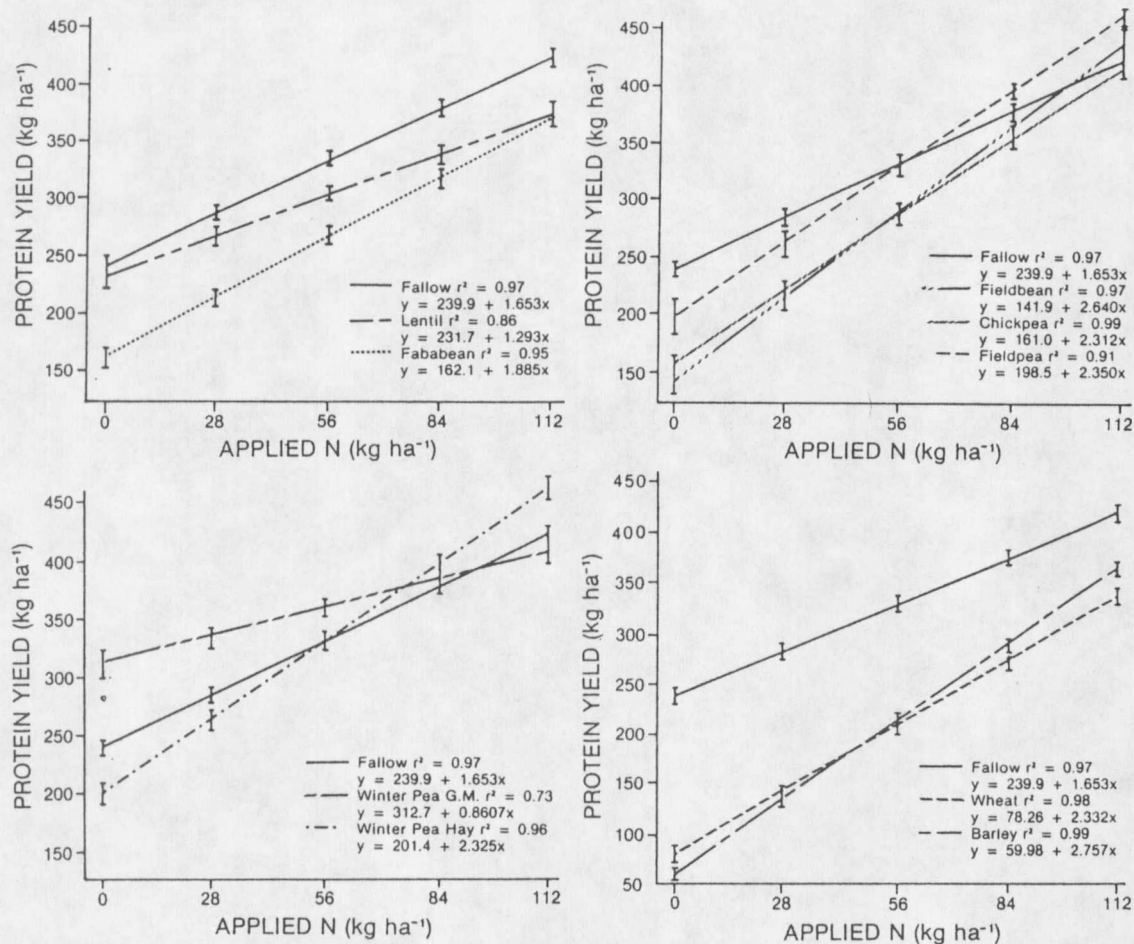


Figure 6. Barley grain protein yield at various applied N rates following legumes, wheat, barley, and fallow at the Post Research Farm for 1983.[†]

[†] The slope for each line is significant at the 0.05 level.

Soil Nitrate

Residual soil $\text{NO}_3\text{-N}$ levels at 0-15, 15-60, 60-120, and 0-120 cm soil depths following the barley crop showed a non-differential response due to previous crop or applied nitrogen fertilizer at the Post Research Farm on August 28, 1983 (Table 24). Soil nitrogen uptake by the barley crop plus other possible fates such as immobilization, volatilization, leaching, etc., resulted in the $\text{NO}_3\text{-N}$ levels showing no difference between the various treatments. Non-differential soil $\text{NO}_3\text{-N}$ levels were also observed following wheat in a legume-wheat rotation study at the Post Research Farm (Koala, 1982).

Table 24. Soil $\text{NO}_3\text{-N}$ Levels at Various Depths at the Post Research Farm on August 28, 1983 (post-harvest)[†]; Means of All Added N Fertilizer Levels.[‡]

Previous Crop	Soil Depth cm			
	0-15	15-60	60-120	0-120
	$\text{NO}_3\text{-N}$ kg ha^{-1}			
Fababean	2.8 a [§]	2.9 a	2.4 a	8.1 a
Lentil	3.4 a	3.1 a	2.4 a	8.9 a
Fieldpea	2.2 a	3.4 a	1.4 a	7.0 a
Chickpea	1.6 a	2.5 a	2.7 a	6.8 a
Fieldbean	2.4 a	2.7 a	2.7 a	7.8 a
Winter pea hay	1.9 a	2.7 a	2.4 a	7.0 a
Winter pea green manure	5.6 a	2.9 a	3.9 a	12.4 a
Barley	3.1 a	3.6 a	2.4 a	9.0 a
Wheat	1.8 a	2.5 a	2.1 a	6.3 a
Fallow	3.4 a	2.5 a	1.8 a	7.6 a
LSD 0.05	NS	NS	NS	NS

[†] Barley planted on all plots May 27, 1983.

[‡] There were no significant differences in NO_3 due to added N fertilizer.

[§] Soil nitrate means within a column not followed by a common letter are significantly different by Fisher's protected LSD ($P = 0.05$).

Available Soil Moisture

There was no available soil moisture at 0-15 and 15-60 cm soil depths following any crop or applied nitrogen fertilizer treatment at the Post Research Farm on August 28,

1983 at barley harvest. Available soil moisture at the 60-120 cm soil depth at barley harvest at various applied N rates following legumes, wheat, barley, and fallow showed differential responses at the Post Research Farm on August 28 (Fig. 7).

Available soil moisture at barley harvest for the 60-120 cm soil depth following all previous crops was not significantly different from fallow at 84 and 112 kg ha⁻¹ applied N. No available soil moisture remained for any previous crop treatment at 84 and 112 kg ha⁻¹ N.

Available soil moisture at barley harvest for the 60-120 cm depth following fababean was not different from fallow at all applied N rates. Available soil moisture following lentil was lower than following fallow at 0 and 28 kg ha⁻¹ N, and not different from fallow at 56 kg ha⁻¹ applied N.

Available soil moisture with fieldpea as the previous crop was greater than fallow at 0 and 28 kg ha⁻¹ applied N, and not different from fallow at 56 kg ha⁻¹ N. Available soil moisture at barley harvest following chickpea was less than fallow at 0 and 28 kg ha⁻¹ N, and not different from fallow at 56 kg ha⁻¹ N. Available soil moisture at barley harvest following fieldbean was greater than fallow at 0 through 56 kg ha⁻¹ applied N.

Available soil moisture at barley harvest following Austrian winter fieldpea hay was not different from fallow at all applied N rates. Available soil moisture following Austrian winter fieldpea green manure was less than fallow at 0 and 28 kg ha⁻¹ N, and not different from fallow at 56 kg ha⁻¹ N. There was no available soil moisture at barley harvest following Austrian winter fieldpea green manure at any applied N rate.

Available soil moisture at barley harvest following barley and wheat was greater than fallow at 0 through 56 kg ha⁻¹ applied N.

Overall, available soil moisture at barley harvest for the 60-120 cm soil depth with no applied nitrogen fertilizer was highest following barley and lowest following Austrian winter fieldpea green manure.

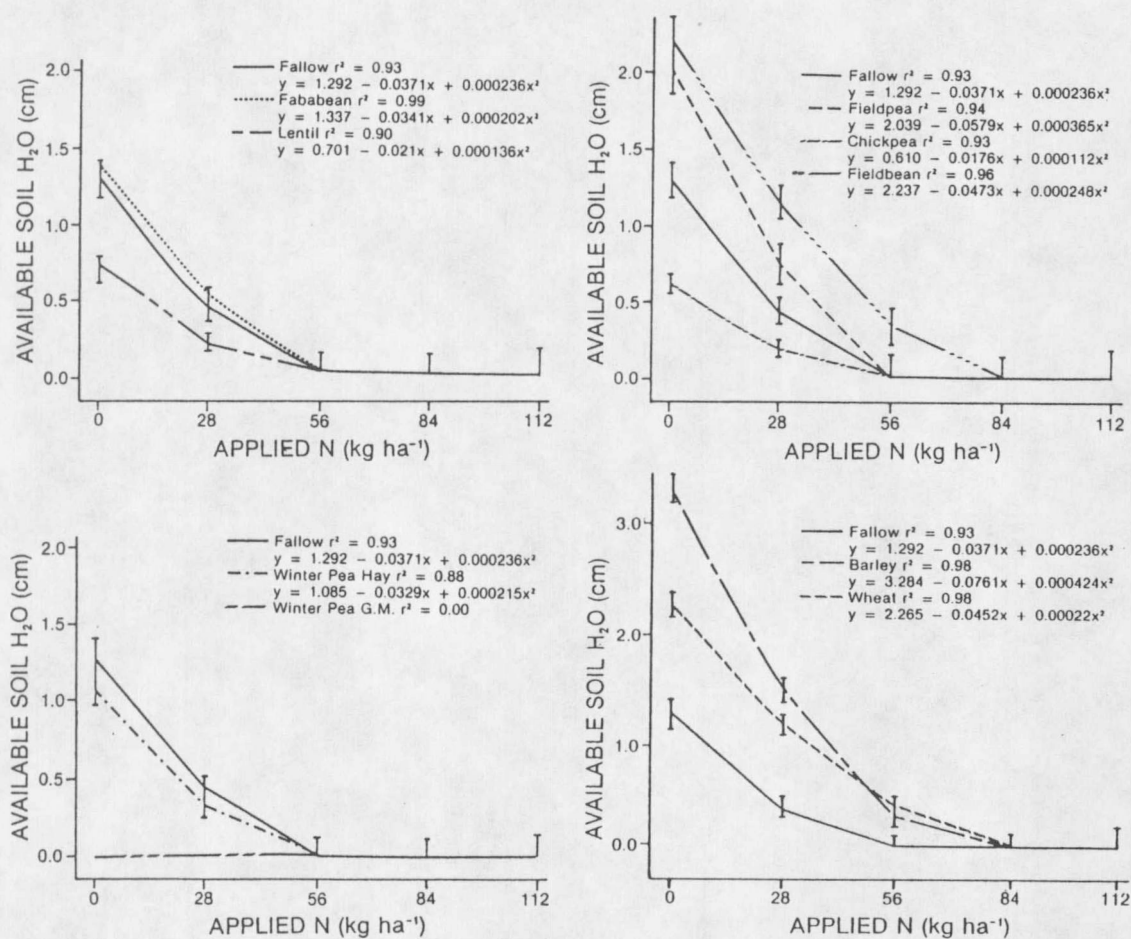


Figure 7. Available soil water for 60-120 cm soil depth at barley harvest at various applied N rates following legumes, wheat, barley, and fallow at the Post Research Farm on August 28, 1983.[†]

[†]The slopes for lentil, chickpea, and Austrian winter fieldpea green manure are not significant; all other slopes are significant at the 0.05 level.

Barley and wheat rooting depth has been shown to increase with increased nitrogen fertility (Brown, 1971; Brown and Dickey, unpublished data, 1970 Annual Research Report, USDA ARS-SWC, Northern Plains Branch, Bozeman, Montana). Increased rooting depth may result in greater moisture depletion at a lower soil depth. Koala (1982) reports greater soil moisture depletion by wheat following various legumes due to increased nitrogen fertility levels. These data (Fig. 7) show decreased available soil moisture with increasing increments of applied N fertilizer. Nitrogen contribution to the cropping system may account for differences in available soil moisture attributed to the previous crop treatment.

Nitrogen Fixation Estimates

Nitrogen fixation may be indirectly estimated by the N fertilizer equivalence method (LaRue and Patterson, 1981). Barley grain yield following a legume with no applied nitrogen may be compared to barley grain yield following a non-nitrogen fixing crop such as barley plus applied N fertilizer. For example, if the barley grain yield following fababean is equal to barley grain yield following barley with 11 kg ha^{-1} applied nitrogen fertilizer, then it is estimated that fababean contributed 11 kg ha^{-1} nitrogen to the rotation. Fababean contribution of 11 kg ha^{-1} N plus 52 kg ha^{-1} N removed with the fababean seed crop equals an estimated 63 kg ha^{-1} N fixed.

A criticism of this method is that grain yield differences may be due to rotational effects such as differing soil organic matter mineralization rates, release of other nutrient elements such as sulfur or phosphorus, improved soil structure, available soil moisture differences, and the interruption of disease cycles (Heichel and Barnes, 1984). Additionally, a portion of N removed with the legume crop is likely obtained from soil N uptake and not solely from N_2 fixation.

Barley grain yield following wheat with 0 N was equivalent to grain yield following barley plus 9 kg ha^{-1} applied N (Table 25). This difference is due to a rotational effect

since wheat is not a nitrogen fixing crop. Fallow nitrogen contribution would primarily be from soil organic matter mineralization and N_2 fixation by free living microbes which is usually not more than 5 to 10 kg ha⁻¹ yr⁻¹. Soil organic matter mineralization and N_2 fixation by free living microbes would also account for a portion of other crop treatment N contributions. Therefore, the N fertilizer equivalence is a comparison of total rotational effects rather than just differences in nitrogen fixation.

Table 25. Relative Nitrogen Fixation Comparisons for 1982 Legume Crops at the Post Research Farm Using the N Fertilizer Equivalence Method (LaRue and Patterson, 1981).

1982 Crop	Protein [†] Yield	N Removed [‡] with Crop	N Fertilizer [§] Equivalence kg ha ⁻¹	Relative N [¶] Fixation Estimates
Fababean	322.0	52	11	63
Lentil	220.8	35	40	75
Fieldpea	484.3	78	37	115
Chickpea	264.9	42	27	69
Fieldbean	149.4	24	13	37
Winter pea hay	676.0	108	43	151
Winter pea green manure	0.0	0	81	81
Wheat	125.2	20	9	—
Fallow	0.0	0	53	—

[†] Protein yield for seed crops obtained from Table 11; Austrian winter fieldpea hay protein yield = biomass yield (Table 1) × 15% protein.

[‡] N removed with crop = protein yield/6.25.

[§] N fertilizer equivalence comparisons obtained from Fig. 2.

[¶] Relative N fixation estimate = N fertilizer equivalence + N removed with crop.

If it is assumed that each legume treatment has the same proportion of harvested crop N obtained from soil N uptake, and that each legume N fertilizer equivalence has the same amount of rotation effect, then a comparative estimation of nitrogen fixation can be made between the legume crops even if there is limited confidence in the actual values (Table 25). The order of relative ranking from most to least nitrogen fixed is Austrian winter fieldpea

hay, fieldpea, Austrian winter fieldpea green manure, lentil, chickpea, fababean, and fieldbean. This relative ranking is similar to crops reported in LaRue and Patterson (1981) with the exception of fieldpea (Table 1). Fieldpea was reported to have greater nitrogen fixation than fieldbean, but less than fababean, chickpea, and lentil.

Austrian winter fieldpea hay and green manure had an estimated 151 and 81 kg ha⁻¹ N₂ fixed, respectively. This difference of 70 kg ha⁻¹ suggests incomplete mineralization of green manure residue during the 1983 crop season. Additional N may become available to a 1984 crop from further mineralization of legume crop residue, therefore the total value of the rotation may not become evident until two or more succeeding crops are evaluated.

Previous Crop Induced Nitrogen × Water Interaction

Barley grain yield response to added N fertilizer at the Post Research Farm for 1983 (Fig. 2) was comparable to the principle of diminishing returns (Briggs, 1978; Tisdale and Nelson, 1975). However, the response to added N fertilizer was dependent on the previous crop. Barley grain yields following legume crops returned less and less as the applied nitrogen rates increased. Grain yields following fallow, wheat, and barley maintained a higher return per unit of applied N.

Differential 1983 barley grain yields at the Post Research Farm appear to be primarily attributed to soil nitrogen contribution by the previous crop and soil moisture. Available soil moisture on May 22, 1983 at barley planting time showed no differences due to the previous crop (Table 15). However, post-harvest available soil moisture on August 28, 1983 showed differences at the 60-120 cm soil depth due to both applied nitrogen and 1982 crop treatment (Fig. 7).

Increased nitrogen fertility may promote faster cereal root growth and deeper soil penetration resulting in greater soil moisture usage (Brown, 1971; Brown and Dickey, unpublished data, 1970 Annual Research Report, USDA-SWC, Northern Plains Branch,

Bozeman, Montana). Excessively high nitrogen fertility levels under limited moisture conditions may result in premature soil moisture depletion and reduced cereal grain yield (Brown and Campbell, 1966; Chapman and Carter, 1976). Brown and Campbell (1966) reported that premature soil moisture depletion induced by excessive nitrogen levels reduced wheat yield by 70 percent at Huntley, Montana.

Differences in 1983 barley grain protein percent at the Post Research Farm (Fig. 5) may also be due to differential soil nitrogen and moisture levels (Briggs, 1978; McGuire et al., 1979; Walker, 1975; Wells and Dubetz, 1966). Test weight (Fig. 3) and percent plump (Fig. 4) differences suggest available soil moisture differences during the barley kernel fill period (Aspinall, 1965; Chapman and Carter, 1976).

These data suggest that soil moisture was limiting barley grain yield at higher nitrogen fertility levels. High nitrogen fertility following legume crops plus applied nitrogen fertilizer may have resulted in premature soil moisture depletion occurring during the barley kernel fill period. A more thorough analysis of soil moisture depletion could have been obtained using a neutron moisture meter during the barley growing season. Optimum performance of an annual legume-cereal grain rotation may depend on careful monitoring of available soil moisture and nitrogen.

CHAPTER V

SUMMARY AND CONCLUSIONS

Nitrogen is the most limiting essential nutrient element for cereal grain production in many Montana soils. An annual legume may supply residual soil nitrogen to a subsequent cereal crop while providing an alternative cash crop.

Nitrogen economy and agronomic characteristics of fababean, lentil, fieldpea, chickpea, fieldbean, and Austrian winter fieldpea hay and green manure, respectively, in rotation with barley were compared to wheat-barley, barley-barley, and fallow-barley cropping systems.

First Year Rotation

Early planting date, high initial soil $\text{NO}_3\text{-N}$ levels, and high precipitation resulted in higher biomass and seed yields for all crops at the Schutter Farm compared to the Post Farm. High fababean and fieldpea biomass yields indicate potential use as hay, silage, or green manure. Seed yield when planted early was high enough for each legume crop to merit consideration for commercial production.

Fababean and fieldpea's high biomass water use efficiency under diverse environments may have contributed to biomass yield stability. Fieldpea and chickpea's high seed production water use efficiency under diverse environments may have contributed to seed yield stability.

Fababean, lentil, and fieldpea had the highest seed protein percentage at both locations. High protein yield for fieldpea and fababean suggests potential use as an on-farm livestock feed supplement.

Fababean's low harvest index suggests more advantageous utilization as a hay, silage, or green manure crop than as a seed crop.

Fallow moisture conservation was inefficient. High post-harvest 0-120 cm available soil moisture following fieldbean and Austrian winter fieldpea hay indicates high potential for rotation with cereal grains under limited moisture conditions. Low post-harvest 0-120 cm available soil moisture following fababean and chickpea indicates efficient soil moisture extraction and suggests a potential problem for dry land cereal rotations if precipitation is not adequate for subsequent cereal production. Winter and spring precipitation resulted in non-differential available soil moisture prior to planting the second year rotation crop at the Post Farm.

Spring soil $\text{NO}_3\text{-N}$ levels prior to planting the second year rotation crop were highest following Austrian winter fieldpea green manure, fallow, and lentil; and lowest following barley and wheat. Legumes may contribute more available nitrogen to a succeeding crop than fallow due to residue mineralization during the second year rotation.

Second Year Rotation

Differential barley biomass and grain yields are primarily attributed to nitrogen and available soil moisture. Nitrogen was the most limiting factor for barley biomass and grain yield following fallow, barley, and wheat. Available soil moisture was the most limiting factor for barley biomass and grain yield following legumes. Barley biomass and grain yields were lower following wheat and barley than following legumes and fallow at each corresponding applied N rate.

Harvest index showed no differences due to previous crop or applied N, indicating that N fertility levels were not high enough to upset the vegetative-reproductive balance in any treatment.

Test weight differences may be primarily attributed to moisture stress during kernel fill. Test weight following wheat and Austrian winter fieldpea green manure were below acceptable limits for malting barley at all applied N rates.

Percent plump differences may be due to both nitrogen and available moisture. Percent plump following fallow, barley, wheat, and Austrian winter fieldpea green manure were below acceptable limits for malting barley at all applied N rates.

Barley grain protein percentage differences are attributed to N availability during the growing season and moisture stress. Protein percentage was highest following Austrian winter fieldpea green manure. Grain protein percentages and protein yield was higher following all legumes than following wheat or barley at corresponding applied N rates.

Nitrogen uptake by the barley crop plus other fates such as immobilization, leaching, etc., resulted in non-differential post-harvest soil $\text{NO}_3\text{-N}$ levels.

Post-harvest available soil moisture showed differences due to previous crop and applied N fertilizer at the 60-120 cm depth. Available soil moisture at the 0 applied N rate was highest for barley following barley, and lowest for barley following Austrian winter fieldpea green manure.

Legume nitrogen contribution to the cropping system was greatest for Austrian winter fieldpea and least for fieldbean. Additional N may become available for a second barley crop as legume residue mineralization continues.

High nitrogen fertility levels from legume N plus applied fertilizer N may have resulted in premature available soil moisture depletion during the barley kernel fill period. Optimum rotation performance will require N fertility levels to be balanced with expected available moisture.

Overall, barley performance following legumes was comparable to barley following fallow and superior to barley following barley and wheat. Nitrogen contribution to the cropping system, except for fieldbean, was greater for legumes than fallow.

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