Adaptation of Australian ley farming to Montana dryland cereal production
by Saidou Koala

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in SOILS
Montana State University

Abstract:
Sixteen annual legume/cereal rotations plus an alternate crop-fallow control were arranged in a randomized complete block design on an eroded field of Amsterdam var. of silt loam at Bozeman, Montana.

Results obtained during the legume phase (1979-1980) of the rotations showed that high dry matter yielding cultivars were Nungarin, 5268 Kg/ha, Geralton, 4960 Kg/ha, Northam, 4641 Kg/ha, Maral Schaftal, 4406 Kg/ha, Clare, 4353 Kg/ha and Jemalong, 4208 Kg/ha. The lupines were failures and these plots were considered to be double summer fallow treatments. Grain yields of faba bean were encouraging.

During the cereal phase of the rotations (1981), wheat grain yields, protein yields and N uptake were higher in all legume treatments compared to the alternate crop-fallow treatment and are attributed to the residual effect of the legumes. Medicado lupulina L., black medic was the most successful legume treatment.

Total water use and water use efficiency were higher for the legume treatments and support the hypothesis of their superiority over crop-fallow in terms of increased soil fertility and productivity.

NO-N values obtained after the legume phase and just before planting the spring wheat and total NO3-N used by the wheat crop were all significantly higher in the legume treatment.

These data have shown beyond any doubt that the Australian Ley system of farming is adaptable to Montana, can increase soil fertility and has some potential use for saline-seep control.

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Date August 6 1982

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TABLE OF CONTENTS

TABLE OF CONTENTS, Continued.

LIST OF TABLES

LIST OF TABLES, Continued.

LIST OF TABLES, Continued.

LIST OF APPENDIX TABLES, Continued.

LIST OF FIGURES

LIST OF PLATES

ABSTRACT

Sixteen annual legume/cereal rotations plus an alternate crop-fallow control were arranged in a randomized complete block design on an eroded field of Amsterdam var. of silt loam at Bozeman, Montana.

Results obtained during the legume phase (1979-1980) of the rotations showed that high dry matter yielding cultivars were Nungarin, 5268 Kg/ha, Geralton, 4960 Kg/ha, Northam, 4641 Kg/ha, Maral Schaftal, 4406 Kg/ha, Clare, 4353 Kg/ha and Jemalong, 4208 Kg/ha. The lupines were failures and these plots were considered to be double summer fallow treatments. Grain yields of faba bean were encouraging.

During the cereal phase of the rotations (1981), wheat grain yields, protein yields and N uptake were higher in all legume treatments compared to the alternate crop-fallow treatment and are attributed to the residual effect of the legumes. *Medicago lupulina L.*, black medic was the most successful legume treatment.

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Chapter 1

INTRODUCTION

The fertility of Montana soils has become a major constraint to the production of small grains and other crops. The increased needs for fertilizer N to achieve maximum yields compared to 30 to 50 years ago reflects a substantial decline in soil organic matter and available N content. Secondary adverse effects of the declining soil fertility are the inefficient use of water resources, leaching of nutrients (especially nitrate - N), formation of saline seeps, and increased susceptibility to both wind and water erosion. Additionally, some areas such as the Sudan Savanna zone of Africa are experiencing a general decline in soil fertility, especially organic matter.

The primary objectives of this study were to test the adaptability of the Australian ley system of farming to Montana and its potential to alleviate the declining fertility and productivity of these soils.

A secondary objective was to develop an understanding of the ley system in order to test it in the Sudan Savanna of Africa.

Chapter 2

REVIEW OF LITERATURE

Dryland Rotations in Montana and the Great Plains

There has been little research on dryland legume-cereal rotations in Montana since the early 1950's.

As early as 1917, Pieters reviewed American experiment station literature relative to the value of legumes as measured by yields of succeeding crops. Data from 28 states and Canada showed that the legume value as green manures decreased from the southeastern to northwestern United States. In South Dakota and North Dakota and in the Canadian Northwest, the use of leguminous green-manure crops was not profitable. Green-manure crops were found to use the moisture needed for the main crops.

Chilcott (1931), Mathews and Cole (1938) stated that the use of biennial and perennial hay and forage crops in rotation was not of major importance in the Great Plains. Maintenance or increase of the organic-matter content of the soil through the application of manures or green manures did not pay for the cost where crops are grown for grain.

In 1955, Duley and Coyle discussed dryland farming problems in the U.S. They reported that the use of green manures was not effective in improving growth of the succeeding crops.

In Montana, green-manure experiments were started at Moccasin in 1909, Huntley in 1913, and Havre 1917 (Hansen et al. 1933, Bell 1937, Army and Hide 1959 and Brown 1964).

Bell reported in 1937 that winter rye, pea and sweetclover green manures had a depressing effect on small grain yields the following year as compared to ordinary fallow. Army and Hide (1959) also found a decrease in yields of spring wheat at Havre, Huntley, and Moccasin of 3.2, 3.6, and 3.8 bushels per acre, respectively. However, at Moccasin winter wheat following a green manure crop outyielded wheat following ordinary fallow 50 percent of the time from 1914 to 1951 (Army and Hide 1959, Krall, et al. 1965).

These conclusions on the negative response of cereal yields following a green manure crop partially resulted from failure to consider that it required two years to grow a crop using the alternate crop-fallow rotations. Other factors leading to these conclusions were probably inefficient storage of winter precipitation and a poor management of the legume. Often the green-manure legume was plowed down too early in the season (Krall et al. 1965). They reported that the green manure crops actually were grown during the latter part of June or early July. An example of mismanagement was also pointed out by Bell (1937) who stated that "when green-manure crops were not established, there was invariably a good crop of Russian thistle (*Salsola kali L.*) to plow under." Possible other factors were poor selection of legume species, a lack of nodulation for a variety of reasons, and sufficient release of nitrogen from soil organic matter.

It appears then that summer-fallow has given good results in Montana. The State has been known for producing high quality hard red spring and winter wheats (Sims and Jackson 1974). Even if the recent increases in per acre yields have been the result of improved varieties and increased use of fertilizer, it is also the result of efficient summer-fallowing. However, the increased needs for fertilizer N to achieve maximum yields and appropriate protein levels of dryland cereals as compared to 30 to 50 years ago reflect the substantial decline in organic matter and available N contents of these soils (Sims and Jackson 1974, Jackson and Sims 1977).

Additionally, improvements in cultural practices, more timely tillage and seeding operations, and the availability of high yielding disease-resistant varieties have greatly increased crop yields in recent years. These and other factors have resulted in a greater need for fertilizer N for dryland crop production (Jackson and Sims 1974). The same authors estimated that fertilizer use on Montana wheat appeared to be just sufficient to boost per acre yields enough to result in dilution of protein content and hence lower wheat protein percentages.

These data point out an increased need for fertilizers for Montana agriculture. However, the cost of fossil-fuel derived energy and fertilizers, particularly N fertilizer, has risen sharply in recent years. An alternative to chemical fertilizer N to supply these needs would be advantageous.

Secondary adverse effects of declining fertility are the inefficient use of water resource, leaching of nutrients (especially nitrate-N), formation of saline seeps, and increased susceptibility to both wind and water erosion.

Salinity is on the increase in the states and provinces of the Great Plains (Miller et al. 1976). Bahls and Miller (1973) estimated that about 590,000 square kilometers of the Northern Great Plains of the United States and Canada are favorable for saline seep development. Unpublished statistics at the Montana State Soil Testing Laboratory operated by Montana Agricultural Experiment Station indicate that approximately 15 percent of the samples from irrigated soils east of the Continental Divide express some degree of salinization. Doering and Sandoval (1976) consider that saline seeps are recent ground water discharges on hillside locations in semiarid regions. Their principal visible characteristics are:

1. Intermittent or continual surface wetness sometimes accompanied by flow of free water down the slope,
2. reduced plant growth, and
3. quite often the development of a salt crust.

The premises that seeps are caused by a combination of geologic, climatic, and cultural conditions (Doering et al. 1976) and that seeps are sustained by local recharge have also been widely accepted (Ferguson et al. 1972, Halvorson et al. 1974, Brun and Worcester 1976 and 1975, Doering et al. 1976).

Excessive nitrate-N leaching below the root zone has also been associated with saline seep (Custer 1976). Summer fallow plays a great role in soil salinity. It aggravates the salinity problem (Miller et al. 1976) and appears to be the major contributor to saline seep development. Fallowing the soil facilitates percolation of water and leaching of salts below the root zone. Eventually, much of the salts resurface downslope as saline seep spots.

Thus a system that can replace summer fallow while improving the soil fertility level would be desirable.

Agriculture in West Africa

In many parts of the semi-arid tropics, arable land is fast becoming a limiting agricultural resource due to the ever increasing socio-economic pressures (Lombi 1981). Consequently, the traditional bush-fallowing system is being replaced by semi-intensive and continuous cultivation. This system lowers the equilibrium level of soil organic matter and fertility and invariably necessitates continuous fertilization to sustain good crop yields.

This problem has acquired considerable urgency in the heavily populated Sudan Savanna zone of West Africa (north of latitude 11°30'

N) where low annual rainfall (800 to 900 mm, restricted to 3 to 4 months annually) has further compounded the fertility problem of these light, sandy, poorly buffered soils (Kadeba 1977, Lombi 1981). One approach is increased use of fertilizers. Even though farmers and authorities may recognize this need for fertilizers in sustaining the fertility of continuously cultivated soils, an inefficient distributive system, poor communication, and especially lack of capital and other socio-economic factors severely limit the consumption of fertilizers. It is imperative that cheaper means of improving soil fertility and productivity be explored in order to supplement the use of mineral fertilizers.

Many researchers (Birch et al. 1956, Jones 1971, Kabdba 1977) recognize the importance of organic matter as a buffering agent and suggest that management practices in future intensive agricultural operations take account of the need to conserve and increase its level in these soils. However, under the climatic conditions of the Sudan Savanna zone of high temperature, an intensive dry season and of low topsoil clay content (Jones 1971), levels of soil organic matter can never be very high (Kabeda 1977). Jones (1971) estimated the maximum practicable topsoil organic-matter content to be 1 percent. This can be maintained either by an annual application of 7 - 8 tons of farmyard manure per hectare or by using grass fallow three years out of every six. However, the supply of farmyard manure under the actual cropping system will never be sufficient for more than a small fraction of the cultivated land. The proposed grass fallow system, although an effective restorer of soil organic matter, is unproductive. Economic pressures seem bound to tell against a practice which effectively produces a crop only once in two years. Jones (1971) suggested that some form of productive fallow or ley may be the eventual answer.

Ley Farming System

In areas of declining soil fertility, increased soil erosion and increased saline seep, an alternative to chemical fertilizer nitrogen would be advantageous. Legume-cereal rotations may offer such an alternative. The few instances of success with such rotations in central Montana in the first one-half of this century (Brown 1964) and the success of these rotations in other parts of the world such as Australian "Ley farming" (Webber et al. 1976, Webber et al. 1977, Ellington 1977) suggest that legume-cereal rotations should be reevaluated for Montana.

Also in semiarid areas such as the Sudan Savanna zones of low annual rainfall and decreasing soil organic matter, legume-cereal rotations may offer some possibilities.

Ley farming is a system in which crops and pasture are alternated on the same field (Doolette 1977). It may be considered a type of fallow system in which small grains are alternated with a short-season annual legume grown for pasture during the fallow year (Oram 1977).

Ley farming, a legume pasture-cereal crop rotation has revolutionized agricultural production in the cereal zone of South Australia since the late 1930s (Webber et al. 1977). It is based on growing annual legumes including forage and grain species between cereal crops.

In South Australia, soil fertility was depleted by continuous cropping of the initially fertile soils (Cornish 1949, Woodroffe 1949) and the introduction of fallowing and fertilizer gave only temporary relief. When the legume based pasture was introduced, however, the improvement in soil fertility was so marked that wheat yields were raised above the yield obtained on the virgin soils (Webber et al. 1976, Webber et al. 1977, Ellington 1977).

Measurements taken in the wheat belt of South Australia indicate that an average medic stand increases soil nitrogen by at least 60 to 70 kg/ha in one season. This is the equivalent of about 300 kg/ha of sulphate of ammonium (Webber et al. 1976). An increase of 200 Kg N/ha per year has been recorded on a sandy soil after a vigorous sward of Harbinger medic (*Medicago littoralis* L.) and Subterranean clover (*Trifolium subterraneum* L.) pastures have also been shown to build up soil fertility on a light textured soil (Watson 1963).

Elliott et al. (1972) studied the influence of rotation systems on long-term trends in wheat yields over a 29 year period. All the rotation systems examined showed positive, almost linear, yield increases over the first 19 years (1940-1958). Over the final ten years (1959-1968) those systems including a pasture phase continued to show a linear yield increase; other three-course systems (fallow, wheat, stubble crops) showed a less than linear increase while the two-course system (fallow-wheat) showed a 22 percent yield decline.

In general, ley farming in South Australia has given best results on the alkaline soils (the solonized brown soils and black earth) and has been less successful on the neutral to slightly acid soils (solodized solonetz and solodic soils).

The key to successful ley farming lies in the pasture phase of the rotation (Webber et al. 1976, Webber et al, 1976, Ellington 1977). A legume is needed which increases soil fertility, improves soil structure, and regenerates naturally after a crop. Some legumes can do this.

In South Australia, the main medics used are:

- Barrel medic (*Medicago truncatula* Gaertn) cv. Jemalong, Hannaford, Cyprus, and Borung.
- Strand medic (*Medicago littoralis* L.) cv. Harbinger
- Gama medic (*Medicago rugosa* L.) cv. Paragosa
- Snail medic (*Medicago scutellata* Mill.)

- Disc medic (*Medicago tornata L.*)

and the main subterranean clovers include the following cultivars: Clare, Geralton, Woogenelup and Daliak. The reason for their success is that they produce many hard seeds. Hard seeds are seeds with seed coats resistant to the entry of water, thus retarding germination (Doolette 1977). Where the medics are well adapted, most of their seeds are hard after seed-set at the end of the growing season. This means that in the following summer, they can resist germination after rains. During summer, extreme heat cracks the coats of some seeds so that by autumn they have become "soft", water can now penetrate allowing germination to begin.

Most seeds remain hard for longer than one summer and do not germinate with the first rains. Their seed coats remain hard for maybe a year or more. This means that the species can survive for years when it sets no seed, such as when a cereal crop is grown.

Clearly, the presence of hard seeds has important implications in ley farming.

Effects of Nitrogen

Legumes can derive N from the soil, applied fertilizers, and through symbiotic N_2-fixation. Each of these three sources can presumably supply the N requirements of the legumes.

As early as 1924, Perkins (1924) reported a study conducted in the greenhouse of the effect upon nodulation of the four essential elements most likely to be limiting factors. His results indicated that small applications of mineral N increased nodulation to a slight degree. However mineral N was not essential for good nodulation and that high applications inhibited nodulation of the host.

Fred, Baldwin and McCoy (1932) demonstrated that nodulation and thus fixation can be inhibited by a concentration of available inorganic N.

Burk and Lineweaver (1930) and later Wilson, Hull and Burris (1943), showed that fixation by azobacter could be prevented by the presence of sufficient inorganic N.

More recently, utilizing ^{15}N as a tracer, studies have been performed to evaluate the influence of varying quantities of available N on the fixation process in legumes. Norman and Krampitz (1946) reported investigations with soybeans (*Glycine max L.*) and lespedeza (*Lespedeza sp*), and Thornton and Broadbent (1948) worked with peanuts (*Arachis hypogaea L.*). Allos and Bartholomew (1955) reported studies with soybeans, peanuts, alfalfa (*Medicago sativa L.*), lespedeza, ladino clover (*Trifolium repens L.*) and birdsfoot trefoil (*Lotus corniculatus L.*). In all cases, negative effects of the presence of available inorganic N on N_2-fixation was noted. The effects varied among the legumes studied and among other experimental conditions, including the soil or substrate in which the legumes were grown. Other physical and environmental conditions also had an influence on the inhibition of fixation by inorganic N.

Allos and Bartholomew (1959) reported on the influence of increasing increments of available inorganic N on N_2-fixation by a number of legumes. Plants were grown in gravel culture in the greenhouse and supplied at weekly intervals with varying amounts of tracer nitrogen. Subsequent analyses of plant N permitted calculations of the N coming from the fertilizer and symbiotic fixation. All legumes responded in growth and in N uptake to the addition of inorganic N. In some instances, the increased growth resulting from fertilization caused increases in fixation of N. When N was applied in excess for growth, it tended to replace the fixation process. They found that fixation processes never supplied sufficient N for maximum growth under the conditions of their experiment. Each species exhibited an apparent capacity to fix about one-half to three-fourths of the total N which could be used by the plant.

The discrepancies in the results of Allos-Bartholomew (1959) and Thornton (1948) may be due to differences between nutrient solution and soil cultures, initial soil N level, and availability of the N.

Most of the data in the literature support a reduction in nodulation from any application of mineral N. Weber (1966) found that nodule numbers were reduced by about 33 percent, nodule fresh weight by 50 percent, and nodule size by 25 percent when 168 Kg N/ha was applied. A stronger reduction occurred when 672 Kg N/ha was applied on soil that had part of its available N immobilized by incorporation of corn cobs.

More recently, the acetylene reduction assay (Hardy et al. 1968) has been developed as a reliable measurement of N_2-fixation. The assay makes possible the rapid evaluation of the effects of cultural practices and environmental factors on N_2-fixation. Following this, reliable *in situ* methods for sample preparation and assay of nitrogenase activity were developed as described by Lockerman (1974).

Using these new techniques, Johnson and Hume (1972) reported the results conducted on low fertility soils in Ontario, Canada, with soybeans in newly introduced areas. N_2-fixation was progressively increased by treatments:

1) M_1 (88 T/ha of liquid cattle manure),
2) M_2 (176 T/ha of liquid cattle manure) + O.M (1.4 T/ha (dry weight) of ground corn cobs as an organic matter source),
3) M_1 + O.M. and
4) O.M.

Addition of 14 T (dry weight)/ha of ground corn cobs increased N_2-fixation seven times as much as the control.

The soybean plant has been extensively studied since the acetylene reduction assay. It has been reported that soybean is generally capable of growth and seed production with symbiotic N_2-fixation as the only N source. However, a marked decrease in seed yields has been observed and strongly suggests that the soybean plant must have an N source other than atmospheric N for optimum yield production. Harper (1972) reported maximum nitrate utilization at the full-bloom growth stage, with symbiotic N_2 (C_2H_2) fixation peaking three weeks later during pod fill. Seed yield of plants totally dependent on atmospheric N was less than one-half the yield of plants utilizing both nitrate and atmospheric N under hydroponic growth conditions. He concluded that both symbiotic N_2-fixation and nitrate utilization are essential for maximum yield of soybean.

Semu and Hume (1979), however, reported different results. They found that fertilizer N applications at planting time did not increase yields in areas where soybean had been grown several times, indicating that N_2-fixation may support maximum yields. Nodule number and mass, and N_2 (C_2H_2) fixation rates were decreased by fertilizer N. Yield responses to N fertilizer applied at planting will usually indicate that N_2-fixation is less than optimal.

In cases where inhibition has been obtained, nitrate has been reported to be the causal factor. Wong (1980) reported that lentils grown in a nutrient solution containing 15 mM nitrate had 84 percent fewer nodules than lentils grown in nitrate free nutrient solution. Nodules weighed 71 percent less and N_2-fixation was reduced. Addition of sugars alleviated the inhibitory effects of nitrate on symbiotic N_2-fixation. This not only increased the carbohydrate supply so lentils could support both N_2-fixation and nitrate reduction but also inhibited the accumulation of nitrate.

Obviously different results from supplying inorganic N to legumes have been reported. Many of them supporting that N fertilizer is beneficial to the plant at early stage with later inhibition of nodulation and N_2-fixation. Some reports indicated that N fertilizer is either beneficial or detrimental at all growth stages. Most of these discrepancies are probably due to differences in procedure. *Rhizobium* strain effectiveness, species and cultivar differences, nutrient solution versus soil cultures, initial soil N levels and availability of the N.

Chapter 3

METHODS AND MATERIALS

Description of site

Field plots were established May 22 and 23, 1979 on an eroded field of Amsterdam var. of silt loam (fine-silty, mixed family of Typic Haploborolls) located at the Montana State University Arthur H. Post Field Research Laboratory and which had been fallowed the previous season (Appendix Table 1).

Cultivars

Seed of sixteen annual legumes were utilized. Fourteen accessions were from the South Australia Department of Agriculture, including:

Five *Medicago sp*; annual medics,

- *Medicago truncatula* Gaertn. cv. Ghor (barrel medic)
- *M. truncatula* Gaertn.cv. Jemalong (barrel medic)
- *M. littoralis* L. cv. Harbinger (strand medic)
- *M. scutellata* Mill. cv. Robinson (snail medic)
- *M. truncatula* Gaertn. cv. Cyprus (barrel medic)

Seven *trifolium sp*.

- *Trifolium subterraneum* L. cv. Nangeela (subterranean clover)
- *T. subterraneum* L. cv. Clare (subterranean clover)
- *T. subterraneum* L. cv. Nungarin (subterranean clover)
- *T. subterraneum* L. cv. Northam (subterranean clover)

- *T. subterraneum L.* cv. Geralton (subterranean clover)
- *T. subterraneum L.* cv. Daliak (subterranean clover)
- *T. resupinatum L.* cv. Maral Schaftal.

Two *Lupinus sp.* sweet lupines

- *Lupinus angustifolius, L.* cv. Unicrop (narrow-leafed lupine)
- *L. albus, L.* cv. Ultra (white lupine).

One faba bean cultivar from the Egyptian Ministry of Agriculture

- Giza III,

and one *Medicago* species from Montana

- *Medicago lupulina L.* Montana common, Black medic.

Conventional alternate crop-fallow (spring wheat/summer fallow) plots were included as the control.

Experimental design

These sixteen annual legumes plus the conventional alternate crop-fallow were arranged in a randomized complete block design. The plots were 4 x 7 m wide with each cultivar replicated three times.

In the spring of 1979, the plots were seeded with a "Planet Jr." hand seeder at the rate of 10 Kg/ha for forage legumes, 100 Kg/ha for grain legumes and 60 Kg/ha for the Newana spring wheat control plots. Row spacings were 45 cm for forage legumes, 80 cm for grain legumes and 30 cm for spring wheat. For the first year, no fertilizer treatments were applied. In 1979, soil samples were taken at 0-15 cm and 15-30 cm from plots 1-17 on 15 May, 18 to 34 cm on 16 May and

35 to 51 on May 17.

Observation on growth pattern of legumes

Seed were planted on May 22 and 23 and the first observation on percent ground cover was recorded August 30. Flowering was recorded July 6, 12 and 24. In 1979, the mature crops were harvested 25 September.

Dry matter and seed production were measured by harvesting 1 m^2 areas in each plot except for seed yields of the grain legumes for which the grain from each entire plot was harvested. The control plot wheat yields were determined by harvesting a 10 m^2 swath down the middle of each plot with a small-plot combine.

Dry material were analyzed for total nitrogen and the seeds from faba bean were analyzed for total protein and amino-acids by the amino acid analyzer.

During the 1980 season, the annual forage legumes except Nangeela subclover were allowed to re-establish themselves from residual hard seeds and from seeds produced during the 1979 season. The Nangeela subclover which did not flower well in 1979, the Maral Schaffal clover and the grain legumes were reseeded and the control plots were summer fallowed. All dry matter produced during the 1980 season was incorporated into the surface 10 cm of soil by rototilling during late September. The faba bean plots were harvested for grain yield.

Observation on growth pattern of spring wheat

All plots were seeded to Pondera spring wheat on 5 May 1981 after soil samples were taken in each plot to a depth of 120 cm for total N, percent O.M., NO_3-N, P and soil water determinations. Phosphorus fertilizer at a rate of 100 Kg/ha was uniformly spread over all plots.

During the growing season, the plots were kept weed free by spraying with a chemical herbicide, Bromate, at 0.5 kg a. i per ha and by hand weeding. Growth stages based on Feekes scale adapted by Large (1954) were recorded on July 2 and 3. Plant heights were recorded using a meter stick and plant canopy color was estimated by visual observations.

Wheat samples, based on the entire plant cut at crown level were taken on July 15 for yield estimation and total N analysis. In each plot, three (3) sub-samples were taken on 30 cm x 15 cm and oven-dried at 80° C with forced air for 48 hours. Prior to harvesting, average tiller numbers and tiller density were also recorded.

On September 11, grain yields were determined after harvesting with a small plot combine as described above. Again soil samples were taken on each plot to a depth of 120 cm with a hydraulic soil sampler for total N, O.M., NO_3-N and soil water determinations. Following the soil sampling, the stubble was incorporated by cultivation to a depth of 10 cm with an off-set disc.

During the 1982 season, the annual forage legumes were allowed to re-establish from residual seed produced in 1979 and 1980. The Nangeela subclover, Maral Schaffal clover, and the grain legumes were reseeded as in 1980. The control plots were summer fallowed as in 1980. In early summer, percent ground cover and density were recorded to evaluate the degree of re-establishment.

Laboratory analysis

Laboratory analysis of soil samples and stored soil moisture obtained prior to fertilization include pH (2:1 water:soil), electrical conductivity (EC in mmhos/cm), NH_4OA_c extractable Ca, Mg, Na and K as described by Chapman (1965) and as used by the Montana State University Soil Testing Laboratory and P by the modified Bray and Olsen tests (Smith, et al., 1957; Olsen and Dean, 1965).

Soil NO_3-N was determined by the "chromotropic acid" procedure as developed by Sims and Jackson (1971) and as modified by Haby and Larson (1976) and soil organic matter was measured by the colorimetric method of Sims and Haby (1971). Grain, straw and soil samples were analyzed for total N by a semi-micro Kjeldahl method (Bremmer 1965). Wheat grain samples were analyzed for total protein using a near-infrared analyzer.

Faba bean grain samples were anlayzed for total protein and amino acids with an amino acid analyzer. Available soil water was estimated by drying the samples at 105° C for 48 hours in a forced-air oven.

Meteorological observations

Precipitation, evaporation and average temperatures were recorded daily approximately 300 m from the plots by the Weather Service Climatological Station and are summarized in Appendix Tables 2 and 3.

Statistical methods

Statistical analyses were performed on the Montana State University Honeywell Computer, GP6. Analyses of variance and correlation were calculated using MSUSTAT developed by Dr. Richard E. Lund. Multiple regression analyses were performed by the SPSS stepwise regression analysis program (Nie, et al., 1975). The stepwise forward procedure was used to select the first best five variables that entered the equation. This approach inserts variable in turn until the regression equation is satisfactory. The order of insertion is determined by using the partial correlation coefficient as a measure of the importance of variables not yet in the equation.

Chapter 4

RESULTS AND DISCUSSION

Legume phase, 1979-1980

Legume dry matter yields

Legume dry matter yields for the 1979 season are reported in Table 1 and Figure 1. Yield differences were statistically significant (p = 0.01). The highest dry matter yield was obtained with *Trifolium subterraneum L.* cv. Nungarin with 5268 Kg/ha compared to an average yield of 3113 Kg/ha. This represents a 69 percent yield increase over the average yield.

An average yield of 2254 Kg/ha of dry matter (straw) was produced on the cereal-fallow control plots planted with Newana spring wheat. This yield represents only 42.7 percent of the yield of Nungarin and 72 percent of the average yield.

Treatments which resulted in significantly high dry matter yield (p = 0.05) compared to the control plot and their percent yield increases include:

Nungarin	133.7 percent
Geralton	120.1 percent
Northam	105.9 percent
Maral Schaftal	95.5 percent
Clare	93.1 percent