124

AGRONOMIC PRACTICES FOR ALFALFA SEED PRODUCTION AND NITROGEN FIXATION IN THE ESTABLISHMENT YEAR

A Thesis

submitted to the Faculty

of

Graduate Studies

The University of Manitoba

by

MOLU DIKA SORA

In Partial Fulfilment of the

Requirements for the Degree

of

Master of Science

Department of Plant Science

September 1994

ISBN 0-612-13512-8

Name ____________________

Dissertation Abstracts International is arranged by broad, general subject categories. Please select the one subject which most nearly describes the content of your dissertation. Enter the corresponding four-digit code in the spaces provided.

____________________ | 0 2 8 5 | U·M·I

SUBJECT TERM | SUBJECT CODE

Subject Categories

THE HUMANITIES AND SOCIAL SCIENCES

COMMUNICATIONS AND THE ARTS
- Architecture 0729
- Art History 0377
- Cinema 0900
- Dance 0378
- Fine Arts 0357
- Information Science 0723
- Journalism 0391
- Library Science 0399
- Mass Communications 0708
- Music 0413
- Speech Communication 0459
- Theater 0465

EDUCATION
- General 0515
- Administration 0514
- Adult and Continuing 0516
- Agricultural 0517
- Art 0273
- Bilingual and Multicultural 0282
- Business 0688
- Community College 0275
- Curriculum and Instruction 0727
- Early Childhood 0518
- Elementary 0524
- Finance 0277
- Guidance and Counseling 0519
- Health 0680
- Higher 0745
- History of 0520
- Home Economics 0278
- Industrial 0521
- Language and Literature 0279
- Mathematics 0280
- Music 0522
- Philosophy of 0998
- Physical 0523
- Psychology 0525
- Reading 0535
- Religious 0527
- Sciences 0714
- Secondary 0533
- Social Sciences 0534
- Sociology of 0340
- Special 0529
- Teacher Training 0530
- Technology 0710
- Tests and Measurements 0288
- Vocational 0747

LANGUAGE, LITERATURE AND LINGUISTICS
- Language
  - General 0679
  - Ancient 0289
  - Linguistics 0290
  - Modern 0291
- Literature
  - General 0401
  - Classical 0294
  - Comparative 0295
  - Medieval 0297
  - Modern 0298
  - African 0316
  - American 0591
  - Asian 0305
  - Canadian (English) 0352
  - Canadian (French) 0355
  - English 0593
  - Germanic 0311
  - Latin American 0312
  - Middle Eastern 0315
  - Romance 0313
  - Slavic and East European 0314

PHILOSOPHY, RELIGION AND THEOLOGY
- Philosophy 0422
- Religion
  - General 0318
  - Biblical Studies 0321
  - Clergy 0319
  - History of 0320
  - Philosophy of 0322
- Theology 0469

SOCIAL SCIENCES
- American Studies 0323
- Anthropology
  - Archaeology 0324
  - Cultural 0326
  - Physical 0327
- Business Administration
  - General 0310
  - Accounting 0272
  - Banking 0770
  - Management 0454
  - Marketing 0338
- Canadian Studies 0385
- Economics
  - General 0501
  - Agricultural 0503
  - Commerce-Business 0505
  - Finance 0508
  - History 0509
  - Labor 0510
  - Theory 0511
- Folklore 0358
- Geography 0366
- Gerontology 0351
- History
  - General 0578
  - Ancient 0579
  - Medieval 0581
  - Modern 0582
  - Black 0328
  - African 0331
  - Asia, Australia and Oceania 0332
  - Canadian 0334
  - European 0335
  - Latin American 0336
  - Middle Eastern 0333
  - United States 0337
- History of Science 0585
- Law 0398
- Political Science
  - General 0615
  - International Law and Relations 0616
  - Public Administration 0617
- Recreation 0814
- Social Work 0452
- Sociology
  - General 0626
  - Criminology and Penology 0627
  - Demography 0938
  - Ethnic and Racial Studies 0631
  - Individual and Family Studies 0628
  - Industrial and Labor Relations 0629
  - Public and Social Welfare 0630
  - Social Structure and Development 0700
  - Theory and Methods 0344
- Transportation 0709
- Urban and Regional Planning 0999
- Women's Studies 0453

THE SCIENCES AND ENGINEERING

BIOLOGICAL SCIENCES
- Agriculture
  - General 0473
  - Agronomy 0285
  - Animal Culture and Nutrition 0475
  - Animal Pathology 0476
  - Food Science and Technology 0359
  - Forestry and Wildlife 0478
  - Plant Culture 0479
  - Plant Pathology 0480
  - Plant Physiology 0817
  - Range Management 0777
  - Wood Technology 0746
- Biology
  - General 0306
  - Anatomy 0287
  - Biostatistics 0308
  - Botany 0309
  - Cell 0379
  - Ecology 0329
  - Entomology 0353
  - Genetics 0369
  - Limnology 0793
  - Microbiology 0410
  - Molecular 0307
  - Neuroscience 0317
  - Oceanography 0416
  - Physiology 0433
  - Radiation 0821
  - Veterinary Science 0778
  - Zoology 0472
- Biophysics
  - General 0786
  - Medical 0760

EARTH SCIENCES
- Biogeochemistry 0425
- Geochemistry 0996
- Geodesy 0370
- Geology 0372
- Geophysics 0373
- Hydrology 0388
- Mineralogy 0411
- Paleobotany 0345
- Paleoecology 0426
- Paleontology 0418
- Paleozoology 0985
- Palynology 0427
- Physical Geography 0368
- Physical Oceanography 0415

HEALTH AND ENVIRONMENTAL SCIENCES
- Environmental Sciences 0768
- Health Sciences
  - General 0566
  - Audiology 0300
  - Chemotherapy 0992
  - Dentistry 0567
  - Education 0350
  - Hospital Management 0769
  - Human Development 0758
  - Immunology 0982
  - Medicine and Surgery 0564
  - Mental Health 0347
  - Nursing 0569
  - Nutrition 0570
  - Obstetrics and Gynecology 0380
  - Occupational Health and Therapy 0354
  - Ophthalmology 0381
  - Pathology 0571
  - Pharmacology 0419
  - Pharmacy 0572
  - Physical Therapy 0382
  - Public Health 0573
  - Radiology 0574
  - Recreation 0575
  - Speech Pathology 0460
  - Toxicology 0383
- Home Economics 0386

PHYSICAL SCIENCES

Pure Sciences
- Chemistry
  - General 0485
  - Agricultural 0749
  - Analytical 0486
  - Biochemistry 0487
  - Inorganic 0488
  - Nuclear 0738
  - Organic 0490
  - Pharmaceutical 0491
  - Physical 0494
  - Polymer 0495
  - Radiation 0754
- Mathematics 0405
- Physics
  - General 0605
  - Acoustics 0986
  - Astronomy and Astrophysics 0606
  - Atmospheric Science 0608
  - Atomic 0748
  - Electronics and Electricity 0607
  - Elementary Particles and High Energy 0798
  - Fluid and Plasma 0759
  - Molecular 0609
  - Nuclear 0610
  - Optics 0752
  - Radiation 0756
  - Solid State 0611
- Statistics 0463

Applied Sciences
- Applied Mechanics 0346
- Computer Science 0984
- Engineering
  - General 0537
  - Aerospace 0538
  - Agricultural 0539
  - Automotive 0540
  - Biomedical 0541
  - Chemical 0542
  - Civil 0543
  - Electronics and Electrical 0544
  - Heat and Thermodynamics 0348
  - Hydraulic 0545
  - Industrial 0546
  - Marine 0547
  - Materials Science 0794
  - Mechanical 0548
  - Metallurgy 0743
  - Mining 0551
  - Nuclear 0552
  - Packaging 0549
  - Petroleum 0765
  - Sanitary and Municipal 0554
  - System Science 0790
- Geotechnology 0428
- Operations Research 0796
- Plastics Technology 0795
- Textile Technology 0994

PSYCHOLOGY
- General 0621
- Behavioral 0384
- Clinical 0622
- Developmental 0620
- Experimental 0623
- Industrial 0624
- Personality 0625
- Physiological 0989
- Psychobiology 0349
- Psychometrics 0632
- Social 0451

AGRONOMIC PRACTICES FOR ALFALFA SEED PRODUCTION AND

NITROGEN FIXATION IN THE ESTABLISHMENT YEAR

BY

MOLU DIKA SORA

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

ABSTRACT

Sora, Molu Dika. M.Sc., The University of Manitoba, October, 1994. **Agronomic practices for alfalfa seed production and nitrogen fixation in the establishment year.** Major Professor: Dr. S. Ray Smith, Jr., Department of Plant Science.

Alfalfa (*Medicago sativa* L.) seed production in western Canada involves establishing the crop during the first year and harvesting seed during the subsequent years. Therefore, seed production has been restricted almost exclusively to winterhardy, fall dormant cultivars. Moderately dormant and non-dormant cultivars rarely survive the winter in western Canada, therefore seed production from these cultivars may not be possible under current management practices. The development of a production system that allows seed production during the year of establishment is required if these cultivars are to be grown for commercial seed production in western Canada. There is a lack of information on N_2-fixation and the agronomic practices for establishment year seed production. Field experiments were conducted in 1992 and 1993 to determine how cultivar, seeding rate and stage of plant development affect seed yield, dry matter production and N_2-fixation. An additional experiment was designed to determine the effect of cultivar, seeding rate and clipping management on alfalfa seed yield components when managed for establishment year seed production.

The first experiment was established in a split plot design with five alfalfa cultivars: Algonquin, Saranac, Saranac-In, Nitro and CUF 101 at two seeding rates (3.36 kg ha^{-1} and 16.8 kg ha^{-1}). N_2-fixation was determined using the difference method on

intact excavated plants at different stage of plant development. A wheat crop was seeded over the 1992 experimental plots to estimate the actual N contribution to subsequent crops. Results from the first experiment showed that the high seeding rate showed better agronomic production than the low seeding rate for most of the traits measured including seed yield. The dormant cultivar, Algonquin, and the moderately dormant cultivar, Saranac, had the highest seed yield. The total N yield ranged from 97 to 139 kg N ha^{-1} and root plus crown N yield ranged from 42 to 60 kg N ha^{-1} during the mature seed stage. During both years all cultivars had an equivalent quantity of N_2-fixed. Furthermore, depending upon stage of growth, N_2-fixed comprised 37% to 59% of the total N in the crop, corresponding to 23 kg N ha^{-1} to 74 kg N ha^{-1}. The average biomass in the root plus crown portion at the mature seed stage ranged from 1,841 to 2,485 kg ha^{-1} dry matter, and the root plus crown N yield available for fall incorporation was 44 to 66 kg N ha^{-1}. Wheat yield was not increased by planting it following any of the alfalfa cultivars at either seeding rate.

The second experiment was established with three cultivars (CUF 101, Cimarron VR, and Algonquin) at two seeding rates, 1.12 kg ha^{-1} and 3.36 kg ha^{-1} and subjected to two clipping treatments (clipped and unclipped). This experiment showed that flowering percentage and racemes per metre of row were highest for Cimarron VR. Furthermore, there was no influence of clipping treatment or seeding rate on plant height, number of racemes per metre of row and number of pods per raceme and seed yield. Clipping reduced lodging, but also delayed flowering. Cultivars produced similar seed yields, but the overall yield was much lower than long term averages in Manitoba. Seed yield components are predictors of the potential seed yield. Measurements of seed yield components was important in both years of this study because adverse environmental conditions directly influenced pollination, seed set, seed development, seed maturation and final seed yield.

In conclusion, the adverse environmental conditions during 1992 and 1993 affected N_2-fixation and seed production. N_2-fixation continued during alfalfa seed production and provided supplemental nitrogen to subsequent crops. Although establishment year seed production was low in this research, actual yields were equivalent to the provincial average on established stands in 1992 and 1993. Therefore, further research should be conducted to determine if establishment year seed production is possible in western Canada.

ACKNOWLEDGEMENT

I wish to express my appreciation to Dr. S. Ray Smith Jr for his guidance and patience throughout my course of study. I would also like to extend a special thanks to Drs. E. Stobbe, K. Vessey and R. Currie for their assistance and advise.

I would like to thank Drs. Felicita Katepa-Mupondwa and P. Bulman for their assistance. I would also like to extend my thanks to Radisa Gjuric (Rale) for his assistance throughout my course of study. I wish to express my sincere appreciation to Matt Fruehm and Doug Cattani for their technical assistance. I would also like to thank all the members of the Forage and Turfgrass Breeding and Seed Production research team with whom I worked during the past three years.

I also wish to thank Kenya Agricultural Research Institute and Canadian International Development Agency for the scholarship provided in support of this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Alfalfa (*Medicago sativa* L.) is a perennial forage legume that is grown for stored feed, pasture and seed production. In addition, it is an important component of many crop rotations, where it is known to increase soil nitrogen (N) and organic matter (Sheaffer *et al.*, 1989). In the western Canadian provinces of Manitoba, Saskatchewan, and Alberta alfalfa seed production is an important enterprise (Fairey and Lefkovitch, 1992: Smith, 1992) worth 25 million dollars annually.

Alfalfa seed production in western Canada involves establishing the crop during the first year and harvesting seed during the subsequent years. Therefore, seed production has been restricted almost exclusively to winterhardy, fall dormant cultivars (Fairey and Lefkovitch., 1991, 1992). Moderately dormant and non-dormant cultivars rarely survive the winter in western Canada, therefore seed production from these cultivars may not be possible under current management practices. The development of a production system that allows seed production during the year of establishment is required if these cultivars are to be grown for commercial seed production in western Canada. There is a need for research to determine the optimal agronomic practices for such a production system.

Traditional farming systems in western Canadian prairies are mainly directed towards grain production. Alfalfa seed production has became a important cropping option in recent years with 22,516 ha in Manitoba in 1991. Successful establishment year alfalfa seed production would allow alfalfa to be used as an "annual" in rotations with other cereal and oilseed crops.

Although alfalfa seed stands are a potential source of N and form a part of many crop rotations, previous research on N_2-fixation in the USA and Canada has focused exclusively on alfalfa grown for forage (Vance *et al.*, 1988). Therefore, there is a lack of information on N_2 fixation during seed production and a need for estimates of the N contribution from a alfalfa seed stands.

Information on the effect of planting density on N_2 fixation is also limited. Alfalfa hay and seed stands differ significantly in their population density. Alfalfa stands for hay production are normally established using high seeding rates (11.2 to 22.4 kg ha^{-1}), whereas, stands grown for seed are normally established at much lower seeding rates (1.12 kg ha^{-1}) to maximize seed yield (Rincker *et al.*, 1988). Plant density is positively correlated with dry matter yield (Porter and Reynolds, 1975), which is positively correlated to N yield and N_2-fixation (Heichel *et al.*, 1984). Therefore, the influence of alfalfa stand density on amount of N_2 fixation should be investigated.

Two separate studies were conducted in 1992 and 1993 growing season in southern Manitoba. The first study was initiated with the working hypothesis that substantial quantities of N_2 are fixed by alfalfa during the reproductive phase in the year of establishment. The hypothesis is based on results obtained from other non-harvested forage stands that have entered the reproductive phase (Groya and Sheaffer, 1985; Sparrow *et al.*, 1991). The second study was initiated with the working hypothesis that alfalfa seed production during the establishment year is possible in western Canada. This hypothesis is based on an assessment of the average environmental conditions in the primary alfalfa seed producing regions including growing degree days, growing season, temperature, solar irradiance and precipitation.

The specific objectives of these research were as follows: 1) to compare seed yield and dry matter production of non-dormant, moderately dormant and early fall dormant cultivars during the establishment year, 2) to determine the effect of seeding rate and clipping management on alfalfa seed yield and seed yield components during the establishment year, 3) to determine how cultivar, plant density and stage of plant development affect N_2 fixation in a seedling year stand of alfalfa.

Literature Review

2.1. USE AND ADAPTATION OF ALFALFA

Alfalfa (*Medicago sativa* L.) is often referred to as the "Queen of forage crops" because of its unrivalled adaptability, forage yield, and nutritional quality for livestock. Alfalfa is well adapted to marginal land, maintains productivity for several years, fixes atmospheric nitrogen, and fits well in crop rotations (Richards, 1984; Olson *et al.*, 1991; Hesterman *et al.*, 1986a).

Alfalfa has a wide geographical distribution due to its good tolerance to drought, moderate tolerance to salinity and its remarkable adaptability to a wide range of climatic conditions (Pederson and McAllister, 1955). Gist and Mott (1956) attributed alfalfa's drought tolerance to its deep and extensive root system.

Alfalfa originates from the Near East and Central Asia with its geographical center most probably occurring in Iran. Alfalfa was first introduced into Canada in 1871 in the province of Ontario. However, successful alfalfa culture in western Canada, with its severely cold winters, began with the introduction of the cultivar 'Grimm' in 1908 (Bolton *et al.*, 1972). Alfalfa is now grown in every province of Canada. Although there is no reliable estimate of total acreage, its probably grown on 4-5 million ha in Canada (Goplen *et al.*, 1982). Most of this area is used for hay and pasture. In addition, a substantial area of the crop is devoted to silage, dehydration products, green manure and seed production. According to 1991 Statistics Canada Census data alfalfa is grown for seed production on about 60,284 ha in Canada, of which 22,516 ha is grown in Manitoba.

In western Canada alfalfa cultivars must be very winterhardy to survive the long, cold winters, variable snow cover, and often dry conditions. The ability of alfalfa to become dormant in the fall is an important adaption that enables the crop to succeed as a perennial in temperate climates. Fall dormancy refers to the ability of an alfalfa plant to reduce above-ground growth during the later part of the growing season in order to increase carbohydrate storage in the roots for overwintering. The alfalfa seed trade uses a 1 to 9 rating system describing fall dormancy, with "1" designating those cultivars that produce the least amount of growth during the fall and "9" those cultivars that produce the most (Barnes et al., 1991). Fall dormancy is influenced by a number of environmental factors, primarily temperature and day length. Although there is a positive correlation between early fall dormancy and increased winter survival, this association is not absolute for all cultivars.

2.2. AGRONOMY OF ALFALFA SEED PRODUCTION

Alfalfa seed production is an important enterprise in western Canada and has increased dramatically in importance in recent years (Fairey and Lefkovitch, 1991, 1992; Smith, 1992). Successful seed production is the product of a complex interrelationship among climatic, genetic and agronomic variables (Pederson and Mcallister, 1955; Pederson *et al.*, 1959) and consequently requires fairly intensive management (Bolton,1956; Goplen *et al.*, 1982). Although climatic factors can not be modified to any major extent, excellent alfalfa seed production can be obtained through adequate pollination, the use of high-yielding cultivars, and by adjusting management practices for local conditions (Pederson and Mcallister, 1955; Pederson *et al.*, 1959; Rincker *et al.*, 1988).

Alfalfa seed production in western Canada has been restricted almost exclusively to the use of early fall-dormanct, winterhardy cultivars (Fairey and Lefkovitch., 1991, 1992). Less winterhardy, non-dormant cultivars have been virtually excluded since only winterhardy cultivars can survive the three or more production seasons that are generally accepted as required for economical for seed production (Bolton, 1956; Goplen *et al.*, 1982; Beacon *et al.*, 1991). Current seed production practices on the Canadian prairies involve two distinct phases: proper crop establishment in the first year and harvesting of the seed in subsequent years (Plews, 1973; Goplen *et al.*, 1982; Fairey and Lefkovitch, 1992). Seed production during the establishment year, though not common, is possible for all fall dormancy classes, but requires different management practices (Smith, 1992).

The potential to grow less winterhardy cultivars (semi-dormant and non-dormant cultivars) in western Canada is realistic using shorter-term stands (Fairey and Lefkovitch, 1992). Short-term production systems (1 to 3 years) may provide opportunities for alfalfa seed production from cultivars not adapted for longterm winter survival in western Canada.

The development of a system that allows seed production during the establishment year from all alfalfa cultivars would be beneficial. Development of such a system would allow western Canada to participate in the multi-million dollar seed multiplication industry for non-dormant alfalfa cultivars. Although these cultivars do not dependably survive western Canadian winters they comprise over 50% of the cultivars grown on a worldwide basis.

2.2.1. STAND ESTABLISHMENT

2.2.1.1. Time of Planting

The appropriate seeding date for alfalfa establishment varies with location, management, and with environmental conditions (Bolton, 1956; Goplen *et al.*, 1982). In western Canada, establishment practices for alfalfa are influenced by the need to increase winter survival. As a general rule, at least sixty days of good growing conditions prior to the first killing frost (-4°C) are required for winter survival following establishment (Huebner, 1992). The best stands are usually obtained from early spring seeding as soon as the seed bed can be prepared. Early planting takes advantage of spring moisture and allows alfalfa seedlings to emerge and establish themselves before the first flush of weed growth (Goplen *et al.*, 1982). In addition, Goplen *et al.* (1982) noted that seeding in late summer (mid-August) in the Prairie Provinces gives less than a 50% chance of a successful stand establishment. They attributed poor stand establishment to lack of adequate moisture and possible killing frosts in early September. Arakeri and Schmid (1949) reported that seeding too early in the spring or too late in the fall can be hazardous, since alfalfa seedlings are susceptible to frost injury.

Alfalfa grown for establishment year seed production should be planted as early as possible in the spring to ensure seed maturation before fall frost. Pedersen and McAlister (1955) concluded that in Utah (U.S.A.), spring planting was best, and that should be early enough to take advantage of the residual winter moisture and spring rains. In Washington (U.S.A), Rincker (1976) reported that late spring planting resulted in lower seed yields in the establishment year.

2.2.1.2. Soil Nutrients

Soil conditions are seldom ideal at seeding. Many factors affect the germination and growth of legume seedlings (Bass *et al.*, 1988). These include soil moisture and temperature, soil nutrients, depth of seeding, and time of seeding. Adequate levels of soil phosphorus (P), potassium (K), and sulphur (S), and other micronutrients at planting are essential in establishing productive alfalfa stands (Bolton, 1956; Goplen *et al.*, 1982; Beacon *et al.*, 1991). Potassium and sulphur enhance N_2 fixation and increase protein content of the forage (Goplen *et al.*, 1982). Sanderson and Jones (1993) observed that without adequate levels of P, root mass is concentrated in the upper 20 cm of soil, whereas under adequate to high levels of P, root mass is distributed throughout the upper 50 cm. They further noted that P incorporated prior to crop establishment increases alfalfa dry matter yields to a greater extent than by broadcasting.

During its establishment year, alfalfa can obtain a significant portion of its N requirements from mineralizable soil N (Heichel *et al.*, 1981). Residual N from the soil, fertilizer, and animal manure often makes establishment year alfalfa less dependent on N_2 fixation than older stands (Heichel *et al.*, 1984a). Although small levels of soil N may be good for alfalfa crop establishment, high levels may reduce nodulation. Like other legume species, alfalfa uses available soil N before nodulating and fixing N_2 symbiotically (Stewart *et al.*, 1968; Heichel *et al.*, 1984a). Heichel *et al.* (1979) reported that nitrate-N could depress nodule formation in alfalfa and reduce symbiotic N_2 fixation.

Alfalfa seeds require inoculation, which is the process of applying bacteria to leguminous seeds or to soils (Vance *et al.*, 1988). Soils may contain *Rhizobium spp.* from previous crop, but seed inoculation ensures nodulation (*Vance et al., 1988*). Inoculation in alfalfa is done by coating the seed with a prepared culture of the appropriate strain of *Rhizobium meliloti* (Dang) bacteria. Seed should be inoculated immediately before sowing to avoid drying and re-refrigerated if not immediately planted (Goplen *et al.*, 1982; Vance *et al.*, 1988)

2.2.1.3. Seeding Depth

Beveridge and Wilsie (1959) reported that percent seedling emergence of three varieties of alfalfa decreased as seeding depth increased beyond 2.5 cm. Alfalfa has small seedlings that have difficulty emerging through the soil if seeds are planted deep to reach moisture. Beveridge and Wilson (1959) recommended seeding at 1.25 cm (0.5 inch), although under poor moisture conditions a 2.5 cm (1.0 inch) could be more satisfactory. Also, Goplen *et al.* (1982) recommended a seeding depth of 1 to 2 cm, because shallow seeding ensures good stands. Lack of adequate soil moisture conditions, improper seedbed preparation and seeding too deep are some of the factors that may cause poor emergence.

2.2.1.4. Plant Density

Plant density is one of the few management practices that has a great impact on seed yield. Rincker *et al.* (1988) reported that optimum seeding rates vary considerably among cultivars, type of pollinator, soil types, soil moisture conditions, and number of frost-free days.

Engelke and Moutray (1980) noted that seed production is favoured by lower plant populations that allow for maximum plant development and seed production. They reported that seeding rates averaging 10% to 20% of the recommended forage production rates produce the highest seed yields for both grasses and legumes. Pedersen *et al.* (1959) in Utah (U.S.A) found that a low seeding rate (33 seeds per metre of row or 0.7 kg ha^{-1}) produced more seed than a high seeding rate (133 seeds per metre or 2.7 kg ha^{-1}) in all row spacings. In contrast, Moyer *et al.* (1991) reported that alfalfa plant densities slightly higher (3 kg ha^{-1}) than the currently recommended ones (1.7 to 2.2 kg ha^{-1}) usually produce the largest seed yields and the lowest weed infestations.

Cooper *et al.* (1979) reported that as seeding density within a row increases, more seedlings are lost due to competition.

They also observed that the number of seeds planted and the number of seedlings emerging per metre of row length are positively correlated. Suzuki (1991) observed large seedling losses during establishment of alfalfa in eastern Canada. Plant density declined from 600 plants m^{-2} after planting in May to 300 plants m^{-2} by late fall. Plews (1973) found that at plant densities of 22,000 plants $acre^{-1}$, plants had the highest number stems, racemes, pods per stem and flowers per square foot than plants at either higher or lower plant densities. Seed yields were also higher at this density than either the lower or higher plant populations.

The appropriate row spacing for alfalfa seed production is influenced by soil depth, texture and salinity, total water availability, length of growing season, desired length of stand, pollinator type, and cultivar (Rincker *et al.*, 1988). Mueller (1992) reported that in California (U.S.A.) hill plantings of alfalfa improves seed yields during the establishment year, compared to solid or thinned plantings. Pederson and McAllister (1955) reported that the crowding of alfalfa plants is harmful to seed production because the reproductive processes involving pollination and seed development are inhibited in dense stands. They indicated that the best practice for Californian conditions included 60-cm row spacing and a seeding rate of 1.12 kg ha^{-1}. The low seed production on dense hay-type stands is probably due to low nectar production, unattractiveness to pollinating bees and increased ovary abortion (Pederson and McAllister, 1955).

The seed yield of alfalfa grown under irrigation is also affected by within-row spacing (Abu-Shakra *et al.*(1969). In a study conducted at Tilley and Lethbridge, Alberta, Moyer *et al.* (1991) obtained maximum alfalfa seed yields with either a 36-cm row spacing or with a 3.0 kg ha^{-1} broadcast seeding rate. Seed yields were similar in row-seeded and broadcast-seeded alfalfa.

Although recommended seeding rates vary according to management practices and among geographic regions, researchers generally agree that a relatively low seeding rate (0.5 kg ha^{-1} to 1.12 kg ha^{-1}) is required for maximum alfalfa seed production. Additionally, seeding alfalfa in rows facilitates the application of herbicides, insecticides and drying agents.

2.2.1.5. Companion Crop

In the north central and northeastern U.S.A., spring established alfalfa is often sown with a small grain companion crop, primarily oats, (Goplen *et al.*, 1982; Tesar and Marble, 1988). Companion crops are used to provide some crop return in the year of alfalfa establishment (Goplen *et al.*, 1982; Fairey and Lefkovitch, 1992), to help suppress weeds and to reduce the risk of soil erosion (Tesar and Marble, 1998). However, since companion crops compete with alfalfa seedlings for light, soil nutrients and moisture they can be detrimental to alfalfa growth during establishment (Schmid and Behrens, 1992; Hansen and Krueger, 1993). In western Canada, companion crops are associated with alfalfa stands grown for seed. In Manitoba, the most prevalent companion crops are flax and wheat, although barley, oats, and canola are occasionally used (Smith *et al.*, 1993).

2.2.1.6. Clear Seeding

Clear seeding of alfalfa involves herbicide incorporation into the soil prior to planting, thereby eliminating the need for a companion crop to reduce weeds (Curran *et al.*, 1993). During the establishment year, alfalfa forage yields are usually greater for clear seeding than for companion crop establishment systems (Schmid and Behrens, 1972; Genest and Steppler, 1973; Sheaffer *et al.*, 1988a). The primary limitation to clear seeding, however, is the greater risk of soil erosion (Curran *et al.*, 1993). Curran *et al.* (1993) suggested that the selection of an establishment technique should be based upon the unique environmental constraints in a particular field and the intended use of the crop during the establishment year. Clear seeding has been the preferred technique for maximizing establishment year alfalfa forage production in California. This is because alfalfa seed yield is harvested during the year of establishment.

2.2.2. STAND MANAGEMENT

2.2.2.1. Clipping Management

Cutting alfalfa to a stubble height in early spring to equalize any uneven plant growth resulting from irregular planting or frost injury is not uncommon in Utah (U.S.A) (Taylor *et al.*, 1959). This practice also aids in weed control since annual weeds are clipped before they set seed (Person and Mcallister, 1955; Goplen *et al.*, 1982). Perennial weeds are also disadvantaged since the rapid alfalfa regrowth allows the stand to out-compete most weeds.

Clipping stimulates stem production and can make flowering more uniform by allowing all stems to develop at the same rate. Clipping also reduces the potential for lodging since mid-summer regrowth is typically not as tall as spring growth (Pedersen *et al.*, 1955).

2.2.2.2. Weed Control

Early weed control is essential for successful stand establishment and subsequent seed production (Beacon *et al.*, 1991). Annual weeds can strongly compete with seedling stands, and are especially difficult to control at low seeding rates. Moyer *et al.* (1991) reported that weed dry matter yields decreased as row spacing decreased or as broadcast seeding rates increased for alfalfa seed crops. Mowing, cultivation, and chemical controls are recommended for weeds under the low seeding rates (Pederson and McAllister, 1955; Goplen *et al.*, 1982). Moyer *et al.* (1991) related Canada thistle densities to alfalfa seed yield. Compared to stands in which thistles were controlled, average yield losses were more than 34% and 48% when thistle densities reached 10 and 20 shoots m^{-2}, respectively. The control of annual weeds and sweet clover in alfalfa is also important in terms of seed quality. A high weed seed content in harvested alfalfa seed may result in the seed being degraded or rejected (Bolton, 1956).

2.2.2.3. Insect Control

Many insects can cause reductions in alfalfa seed yields. The most common and generally destructive are the pea aphid (*Acyrthosiphon pisum*) [Harris], the alfalfa plant bug (*Adelphocoris lineolatus*, Goeze), lygus bug (*Lygus spp.*), and grasshoppers (Bolton, 1956, Goplen *et al.*, 1982). Insecticides should be used on seed crops only when insect populations are high enough to cause economic levels of damage. Bees are very sensitive to most insecticides, and so caution must be exercised in the timing and rates of insecticide application (Richards, 1984). Dylox [dimethyl (2,2,2-trichloro-1-hydroxyethyl) phosphonate] and Dimethoate [o,o-dimethyl s-(methylcarbamoylmethyl) phosphorodithioate] are recommended for insect control in alfalfa seed stands that are being pollinated.

2.2.3. POLLINATION

2.2.3.1. Mode of Pollination

The successful production of alfalfa seed depends on cross-pollination by bees (Bolton, 1956; Goplen *et al.*, 1982; Richards, 1984). Self-pollination is rare in alfalfa. Its unique flower morphology requires "tripping" for pollen release (Bolton, 1956) which occurs with the release of the staminal column from within the keel petals. When self-fertilization occurs the resulting seed often shows poorer germination (Palmer and Foster, 1965) and lower seedling vigour than with cross pollination (Poehlman, 1959; Bolton, 1962).

2.2.3.2. Pollination by Bees

Several bee species, including honey (*Apis mellifera* L.), alkali (*Nomia melanderi* Cockerell) and leafcutting (*Megachile rotunda* Fabricus) bees, are used as pollinators for alfalfa seed production (Pederson *et al.*, 1955, 1959; Goplen *et al.*, 1982). There are generally not enough native pollinators to ensure adequate pollination for maximum seed yields (Richards, 1984). Alfalfa plants flower over a period of approximately 7 weeks, and if pollination occurs, seed pods are set throughout this period (Ahring *et al.*, 1984).

Honey bees frequently visit alfalfa flowers to collect nectar, but seldom cause the release of pollen that ensures successful pollination. Seed production is greater with leafcutting bees because they almost always "trip" flowers and cause pollen release (Pederson, 1967). Alfalfa leafcutting bees (*Megachile rotunda* (Fabricius), of Eurasian origin, are the principal pollinators for seed production in the Pacific northwest of the U.S. (Rincker *et al.*, 1988).

The introduction of alfalfa leafcutting bees has revived the alfalfa seed industry in Canada (Goplen *et al.*, 1982; Richards, 1984). Besides increasing seed yields, the bees themselves are a valuable commodity particularly when the incidence of chalkbrood disease is kept low. Under favourable conditions, bee populations can be increased, and there is generally a ready market for surplus bees (Goplen *et al.*, 1982; Richards, 1984).

Row spacing, seeding rate, and the resultant flower density influence the foraging behaviour of the alfalfa leaf cutting bee (Richards, 1984). Large row spacings together with low seeding rates lead to less dense, more open, erect plants that favour light penetration, higher soil and air temperatures and lower relative humidities, all of which favour nectar secretion and increased pollinator activity.

2.2.4. GROWTH AND ENVIRONMENT

2.2.4.1. Seedling Vigour

Seedling vigour in alfalfa is difficult to define or measure. As a consequence, several criteria have been used in an attempt to measure it. Walter and Jensen (1970) used seedling weight (mg per plant), root and shoot length (cm), plant volume, rate of emergence, and day of appearance of cotyledons, unifoliate leaf, and first trifoliate leaf. High seedling vigour increases the competitive ability of alfalfa relative to weeds.

2.2.4.2. Lodging

Lodging is a problem in alfalfa stands as it interferes with seed set. Photoassimilates are not translocated in lodged stems, and, therefore are not utilized for seed yield. Lodging potential can be reduced by low seeding rates that promote large plants with strong stems (Bolton, 1956; Pederson and McAllister, 1955). Abu-Shakra *et al.* (1969) reported that plants spaced 25 cm apart within a row were taller than those spaced at 50 cm. Reduced lodging makes alfalfa plants more open and erect and the flowers more exposed and accessible to bees for pollination (Pederson and McAllister, 1955). Tysdal (1946) attributed the reduction in seed yield of frequently irrigated plots to the greater regrowth and inter-plant competition in the lodged crop.

Regrowth following lodging diverts resources from seed development reducing carbohydrate reserves which, in turn, reduces winter survival and stand longetivity.

2.2.4.3. Environmental Factors

Alfalfa produces higher seed yields when temperatures are higher, relative humidity is lower, and soil moisture is less than what is regarded as optimal for hay production (Pendersen *et al.*, 1955, 1959). Pederson and Nye (1962) observed reduction in nectar secretion, honey bee populations and seed yield in stands subjected to high soil moisture, low temperatures and high precipitation.

Changes in the relative humidity, temperature, and light penetration associated with thin stands were beneficial to alfalfa seed production (Pederson *et al.*, 1959; Pederson and Nye, 1962). In thin stands air movement and light penetration into the canopy is increased, and the stand becomes more attractive to pollinators since blooms are abundant and more accessible (Pedersen *et al.*, 1955, 1959; George and Mott, 1956; Plews, 1973).

2.2.5. SEED YIELD COMPONENTS AND SEED YIELD

Seed yield components in alfalfa tend to be compensatory. For example, if there are fewer stems per unit area, the stems have more racemes. Cowett and Sprague (1962) reported that increasing stand density of alfalfa from 11 plants m^{-2} to 89 plants m^{-2} decreased the number of stems per plant. Pedersen and Nye (1962) found that cultural practices did not significantly affect the number of racemes or flowers per hectare, and that there was a compensating effect between racemes per stem and stems per hectare.

Liang and Riedel (1964) reported that seed size, fertility, and number of tillers per plant were positively correlated with seed yield in alfalfa. Fertility showed the largest direct effect upon seed yield versus number of tillers. Seed size had a small negative effect.

Alfalfa seed crops must produce sufficient seed yield per acre to ensure economic competitiveness with other annual crops. Rincker *et al.* (1988) reported alfalfa seed yields ranging from 0 (crop failure) to 2,110 kg ha^{-1} of clean seed. In the southern prairie region of Canada, seed yields of 300 to 900 kg ha^{-1} can be attained under irrigation, whereas, without irrigation, seed yields of 150 to 300 kg ha^{-1} may be considered satisfactory (Goplen et al., 1982). Experiments conducted at Glenlea, Manitoba involving eight alfalfa cultivars representing the full range of fall dormancy classes had an establishment year alfalfa seed yield ranging from 197 to 418 kg ha^{-1} (Smith, 1992).

2.2.6. SEED HARVEST

Alfalfa seed crops are harvested when most of the seed pods have changed to dark brown and before the pods have begun to open. This process can be accelerated with the use of chemical desiccant such as Diquat (Reglone), Dinoseb, Endothall or Harvest. Complete foliar coverage by the desiccant is essential, as incomplete coverage in a dense, green stand will only kill parts of the plants contacted and regrowth will occur (Pedersen *et al.*, 1972). Swathing is not economical in many seed-growing areas because of the problems caused by high winds. Usually straight combining occurs one week after desiccation (Goplen *et al.*, 1982). Careful attention to adjustment of settings on the combine is important, as seed can be lost in the harvesting operation.

2.3. SYMBIOTIC N_2-FIXATION

2.3.1. IMPORTANCE

Smith (1992) reported that establishment year seed production is possible in Manitoba from cultivars covering the range of dormancy types. This provides a feasible alternative management system for introducing alfalfa as an "annual" in rotations while allowing the production of an alfalfa seed crop in one year. Growing a perennial legume as an "annual" crop in rotations reduces fossil fuel consumption by returning N to the soil for succeeding grain crops in a short amount of time (Heichel, 1978; Sheaffer *et al.*, 1989). Alfalfa has been recognized as being one of the most important soil-improving crops, yet it is seldom used exclusively as a cover or green manure crop (Goplen *et al.*, 1982).

Alfalfa, with its symbiont bacterium *Rhizobium meliloti* (Dang), has the potential to fix more N_2 per season than other legumes species. This superior N_2 fixing ability makes it an energy efficient crop (Sheaffer *et al.*, 1989; Heichel and Barnes, 1984). The net amount of symbiotically fixed-N that is returned to the soil in the legume residue depends on the degree of symbiotic activity, the amount and type of residue left in the soil, and the availability of soil-N (Heichel and Barnes, 1984). It is important to note that only the percentage of N in the plant that results from symbiotic N_2 fixation represents a net input into the soil-plant system. The soil N contribution to alfalfa N content represents a temporary storage until it is recycled to the soil N pool. Symbiotic N_2-fixation represents a net gain beyond that needed for alfalfa growth, and it represents an "energy credit" that can be allocated to a subsequent crop (Heichel, 1978).

Soil N and symbiotically fixed N_2 may be partitioned differently in the plant. In alfalfa, a large proportion of biologically fixed N remains in the roots and shoots, while in grain legumes such as soybean, symbiotically fixed N is preferentially partitioned to developing pods and shoot meristems (Henson and Heichel, 1984a). This is mainly because the alfalfa pods are smaller than the grain pods and therefore probably have less demand for N.

The amount of plant N derived from biological N_2- fixation is influenced by environmental and crop management factors (Gibson, 1977). Heichel and Barnes (1984) reported that the proportion of available N derived from symbiosis varies with legume species, stage of growth and environment, and that the proportion of symbiotic N_2-fixation may vary from 28% to 81% of total N. Heichel *et al.* (1981) initiated field experiments using ^{15}N as a tracer of N metabolism to determine the N_2-fixation capabilities of two alfalfa populations in the seeding year. Both populations obtained about 43% of their N needs from symbiosis and fixed an average of 148 kg ha^{-1} of N during the growing season.

Alfalfa has been reported to fix 160kg N ha^{-1} to 177 kg N ha^{-1} during the year of establishment, and as much as 224 kg N ha^{-1} in the best year of a four-year stand managed for hay (Heichel *et al.*, 1984a). The corresponding proportion of N derived from symbiosis was 55.9% to 62.4% of the total plant N for the year of establishment, and 78.2% for the best year of the four-year stand managed for hay. Depending upon stage of growth and the age of the stand, fixed N_2 comprised 33 to 78 % of the total N in the crop.

The amount of N_2 fixation in a perennial legume crop varies with the herbage yield, the yield of roots plus crown, and the concentration of total N in the above-and below-ground phytomass (Heichel *et al.*, 1984b; Heichel *et al.*, 1985).

The rate of N_2-fixation has seldom been a factor in the choice of legume species for use in rotation or on set-aside cropland, although knowledge of N_2-fixation capability is important when estimating the replacement of fertilizer N by legume N (Baldock *et al.*, 1981; Heichel and Barnes, 1984b). The potential exists to reduce N fertilizer requirements in cropping systems through soil improvement by legumes (Heichel, 1979).

2.3.2. BENEFITS OF LEGUMES TO SUBSEQUENT CROPS

The introduction of a legume crop into a continuous cropping system reduces financial risk and uncertainty (Campbell *et al.*, 1990). Alfalfa rotated with shallow-rooted crops helps prevent much of the nitrate leached below the root zone of shallow rooted crops from reaching the water table (Stewart *et al.*, 1968). The benefit of alfalfa-derived N in a crop rotation depends on the rate of N mineralization and its recovery by the subsequent crop. Residual N remaining in the soil after alfalfa decreases the levels of fertilizer N required for a succeeding non-legume crop (Heichel, 1978; Peterson and Barnes, 1981). It is important that producers recognize the fact that N is supplied to the soil by legumes and that they must reduce fertilizer N application rates accordingly for a succeeding crop (Peterson and Russelle, 1991).

Hesterman *et al.* (1986) reported that over a range of soil and climatic conditions an alfalfa-corn rotation with alfalfa grown and harvested during the establishment year was a more profitable cropping practice than continuous corn and soybean-corn systems. In their research, they used a non-dormant alfalfa cultivar that was established yearly because of excessive winterkill. They further suggested that if these non-dormant cultivars were grown in environments with milder winters and managed as a perennial crop, the profitability of these rotations would be increased because alfalfa production could be allowed for an additional one to three years thereby distributing the cost of establishment over a longer period of time.

The contribution of N by legumes in a rotation can be measured using the fertilizer N replacement value. This method determines the amount of inorganic fertilizer that would be required to produce an equivalent yield under otherwise comparable test conditions. Fox and Piekielek (1988) estimated the three-year total fertilizer N equivalence (fertilizer N required to achieve the same yield in continuous non-legume crop as was attained by non-fertilized non-legume crop that followed a legume) of alfalfa, birdsfoot trefoil, and red clover to be 187, 169, and 147 kg ha^{-1}, respectively. The proportion of N contributed each year to subsequent crops averaged 70% in the first, 20% in the second and 10% in the third year for alfalfa and red clover, and 55%, 30%, and 15% for birdsfoot trefoil in those same years, respectively. Bruulsema and Christie (1987) reported fertilizer N replacement values of 90 to 125 kg N ha^{-1} from a seeding year legume for a succeeding corn crop. Research on legume-corn rotations by Hesterman *et al.* (1987) in Minnesota (U.S.A) established that the uptake of fixed N_2 by corn was greater following alfalfa than soybean.

Typical values of incorporated alfalfa N range from 52 to 78 kg N ha^{-1} when only fall regrowth, roots, and crowns are incorporated (Fribourg and Johnson, 1955 ; Smith, 1956; Stickler and Johnson, 1959; Groya and Sheaffer, 1985) to 300 kg N ha^{-1} when herbage is harvested several times during the season and retained on the soil surface for fall incorporation (Groya and Sheaffer, 1985). In Ontario, Canada, direct-seeded alfalfa and red clover harvested in late July during the establishment year and allowed to regrow until fall plowdown can furnish a plowdown N yield of 140 kg N ha^{-1} (Bruulsema and Christie, 1987)

Yield enhancing effects, not directly associated with the N contributions of previous crops are referred to as rotation effects. As much as 25% of yield increases in rotations can been attributed to rotation effects (Baldock *et al.*, 1981). Sheaffer *et al.* (1989) attributed a number of benefits from alfalfa to subsequent crops in addition to extra N. These included the rotational benefits of disease and weed control, reduced soil erosion, and improved soil tilth and soil water holding capacity.

The proportion of legume N that is mineralized and made available to a succeeding crop has not yet been established with certainty. Incorporation of alfalfa residues in the spring prior to corn planting allowed a better synchronization of N mineralization and uptake by plants and led to a greater recovery of alfalfa residual N than did residue incorporation in the preceeding fall (Harris and Hesterman, 1990). The recovery of N from legume residues in the first year by succeeding non-legume crops has been surprisingly low (15% to 43%) when estimated using ^{15}N isotope techniques (Hesterman *et al.*, 1987; Harris and Hesterman, 1990).

Kroonje and Kehr (1956) measured N uptake in barley crops that were preceeded by a number of non-dormant and dormant alfalfa cultivars subjected to three different harvest schedules. The average N uptake was numerically higher for barley preceded by non-dormant cultivars. Grain yield of corn following red clover plowdown was 7% greater than that following alfalfa plowdown. However, the whole plant N concentration of corn was 7% higher following alfalfa (Bruelsema and Christie, 1987). These results differ from those of Groya and Sheaffer (1985) who reported no differences in dry matter yield or in N uptake of sorghum-sudangrass mixtures following alfalfa compared to that following red clover plowdown. However, neither yield nor N uptake responded to fertilizer N, indicating that soil N supply was less limiting. The response of crops following alfalfa and other legumes in crop rotations constitutes an important aspect of the N dynamics of cropping systems.

Alfalfa can average 50% more N_2-fixation in the establishment year than birdsfoot trefoil, and 26% more than red clover (Heichel *et al.*, 1984a; Heichel *et al.*, 1985). Research evaluating the influence of time and number of harvests on the dry matter and N production of legumes in the seeding year has demonstrated that harvesting decreases the total dry matter yields of sweet clover, but increases the dry matter and N yields of alfalfa, red clover, and ladino white clover (Stickler and Johnson, 1959). Harvesting for hay can change individual plant development by eliminating weed competition.

Groya and Sheaffer (1985) reported that in the establishment year, alfalfa and red clover contributed 68% more N at fall plowdown when they were not harvested than when they were subjected to a two-cut conventional management system with herbage regrowth and roots incorporated. Direct-seeded alfalfa and red clover not harvested during the establishment year will produce a plowdown N yield of 198 kg N ha^{-1} and 129 kg N ha^{-1}, respectively (Bruulsema and Christie, 1987). In a three-year study using ^{15}N, Heichel *et al.* (1984, 1985), observed that alfalfa, red clover, and birdsfoot trefoil fixed an average of 155 kg ha^{-1} $year^{-1}$, 96 kg ha^{-1} $year^{-1}$, 86 kg ha^{-1} $year^{-1}$, respectively. This suggests a greater potential of residual N from alfalfa than from the other two species.

2.3.3. FACTORS AFFECTING AMOUNT OF N_2-FIXED IN THE FIELD

2.3.3.1. Plant Density and Dry Matter Production

Many experiments, including those conducted in the field, give results only as mg N per plant, percentage N of yield, or percentage plant N derived from fixation. In the absence of information about yield per unit area or planting density, it is impossible to calculate the amount of N_2-fixed on a per unit area basis.

Alfalfa dry matter is known to be influenced by plant density which is a function of seeding rate. A seeding rate of 6.7 kg ha^{-1} gives lower forage yields than rates of 13.4 kg ha^{-1} (Belzie and Rioux, 1984; Belzie, 1984). Moyer *et al.* (1991) observed that in the establishment year alfalfa dry matter yield decreases as the row spacing increases or the rate of broadcast seeding decreases. In Knoxville, Tennessee (U.S.A), plant density of a second-year alfalfa stand was positively correlated with dry matter yield among cultivars when averaged over all harvests (Porter and Reynolds, 1975). Friborg and Johnson (1955) evaluated the relationship between the herbage and root dry matter and N yields of alfalfa, sweetclover, and red and ladino clovers, in the fall of seeding year. When species were combined, they found a significant linear relationship (r=0.98) between total (herbage and root) dry matter yield and total N yield.

Heichel *et al.* (1984b) reported that N_2-fixation on a per plant basis is highly correlated with mean herbage yield within and across years. Farnham and George (1993) observed that N_2

fixed per unit area of land of red clover decreases as the amount of dry matter yield decreases.

2.3.3.2. Fall Dormancy and Cultivar Effect

Heichel *et al.* (1981) reported that changing field environmental conditions and the onset of fall dormancy affect the rates of N_2-fixation of field-grown plants. Nitrogen fixation varies among fall-dormant and non-dormant cultivars during the growing season because of different growth patterns, regrowth ability, and spring and fall dormancy (Hoffman and Melton, 1981). Varietal dormancy characteristics influence the N contributions to a subsequent crop (Sheafer *et al.*, 1989; Heichel *et al.*, 1989).

The advantages of using non-dormant alfalfa include more vigorous seedling growth, faster regrowth after harvest, and greater herbage production and N_2-fixation in the fall (Heichel *et al.*, 1989). The cultivar 'Nitro' is an example of a non-dormant cultivar that can be used in short rotations, because of its greater N_2-fixation capability compared to other alfalfa varieties (Sheafer *et al.*, 1989). Research results from Iowa (U.S.A) indicate that two southern, non-dormant alfalfa cultivars, 'Indian' and 'African', are superior in dry matter and N yielding ability than the hardier variety 'Ranger' (Stickler and Johnson, 1959). Total N yields obtained for Indian, African, and Ranger were 90 kg ha^{-1}, 84 kg ha^{-1}, and 62 kg ha^{-1}, respectively. Differences in dry matter and N yields were attributed to a more rapid growth rate and lack of hardening among the southern cultivars in late fall prior to harvest.

Sheaffer *et al.* (1989) have suggested that non-dormant alfalfa cultivars are superior to dormant alfalfa cultivars in short-term rotations.

Fall dry matter and N yields are higher for moderately dormant and non-dormant cultivars than for dormant cultivars (Sheaffer *et al.*, 1988b; 1989). Sheaffer *et al.* (1988b) measured average fall plowdown N values of 144 kg ha^{-1} and 132 kg ha^{-1} , for Nitro (non-dormant) and 'Saranac AR' (dormant), respectively, when these cultivars were allowed to accumulate *in situ* until the fall. Experiments with non-dormant ('CUF 101' and 'Ardiente') and dormant ('Saranac' and 'Agate') alfalfa cultivars revealed plowdown averages of 184 kg ha^{-1} and 207 kg N ha^{-1} for the non-dormant and dormant cultivars, respectively, when the forage was allowed to accumulate over the growing season (Groya and Sheaffer, 1985). The root mass of Nitro and other non-dormant cultivars is greater than that of the dormant cultivars (Heichel *et al.*, 1989).

2.3.3.3. Stage of Plant Development

The proportion of fixed N_2 to total N yield in alfalfa is highest during midseason (Heichel *et al.*, 1981; Henson and Heichel, 1984a). Heichel *et al.* (1981) reported that the N_2-fixation of alfalfa stands increases in the seeding year from the first to the second or third harvest, but declines in the fourth harvest. Alfalfa grown for seed develops through the seedling, vegetative, bud, flower, pod, and seed maturation stages. Alfalfa grown for hay is harvested when the crop reaches the late vegetative or early bloom stage. Root and herbage samples taken from the late vegetative to seed maturity stages will show variation of N_2-fixation over these developmental stages.

2.3.3.4. Environmental Effects

2.3.3.4.1. Soil N

The most important environmental factor affecting N_2-fixation under field conditions is likely soil N level and water logged conditions. Like other legume species, alfalfa uses available soil N before nodulating and fixing N_2 symbiotically (Stewart *et al.*, 1968; Heichel *et al.*, 1984a). During its establishment year, alfalfa can obtain a significant portion of its N requirements from mineralizable soil N (Heichel *et al.*, 1981). Residual N from the soil, fertilizer, and animal manure often make establishment year alfalfa less dependent on N_2-fixation than older stands (Heichel *et al.*, 1984a). The contribution of symbiotically fixed N_2 to the soil by alfalfa can come either directly through mineralization of plant residues and accretion from growing plants or indirectly through the recycling of manure from animals fed alfalfa (Peterson and Russelle, 1991).

Heichel and Barnes (1984) reported that a substantial amount of the total N in legume plants often comes from soil N, but that selection for increased N_2-fixation increases the proportion of plant N derived from fixation and decreases the N derived from the soil. Alfalfa and soybean derive significantly more N from fixation under conditions of low soil N than under high soil N (Henson and Heichel, 1984b). Trimble *et al.* (1987) reported that soil N levels influences herbage and root yield, root morphology, and nodule mass score of alfalfa. They observed that under high soil N conditions herbage yield was increased during the establishment year, root yield is reduced, nodulation is limited and roots become more branched or fibrous. Heichel *et al.* (1979) reported that nitrate-N could depress nodule formation in alfalfa and reduce symbiotic N_2-fixation.

2.3.3.4.2. Other environmental factors

The physiological and biochemical processes involved in plant growth and development exhibit coordinated responses in N_2-fixation in response to many biotic and abiotic environmental factors (Barnes *et al.*, 1984). For example, N_2-fixation capacity is influenced by temperature (Viands *et al.*, 1981), dormancy caused by daylength fluctuations (Heichel *et al.*, 1983) and soil moisture (Carter and Sheaffer, 1983). The ability of alfalfa to fix N is further influenced by growth stage (Vance, 1979; Heichel *et al.*, 1981), and is strongly dependent upon specific host-rhizobial combinations (Hardarson *et al.*, 1982). The genomes of both the host plant and the *Rhizobium meliloti* (Dang) symbiont determine the effectiveness of symbiotic N_2-fixation in alfalfa (Barnes *et al.*, 1984).

2.3.3.5. Management Effect

The potential benefit of using a perennial legume in rotation to help replace inorganic fertilizers strongly depends on the manner in which the legume is managed. In Minnesota (U.S.A), when alfalfa is managed for maximum hay production with upto three to four harvests, there is little net N input into the soil during the seeding year (Heichel and Barnes, 1984).

However, if seed production from an establishment year is desired, then more net N input should be expected since plant material is not harvested.

Herbage management of legumes affects the quantity of N returned to the soil and consequently influences subsequent crop yields (Hesterman *et al.*, 1986b). Sheaffer *et al.* (1991) reported that not harvesting forages until fall consistently results in greater amounts of dry matter and N for fall incorporation than a conventional harvest management which removes a significant amount of forage each year.

The accumulation of alfalfa forage *in situ* gives greater fall herbage and root N yields than when alfalfa is cut during the seeding year (Groya and Sheaffer, 1985; Sheaffer *et al.*, 1988b). Sparrow *et al.* (1993) estimated the amount of fixed N_2 in the herbage of cultivar Nitro when the forage was allowed to accumulate over the season in a subarctic environment during establishment year. Over the growing season Nitro fixed an average of 45 kg N ha^{-1} (measured in the herbage only). This ranked lowest among all of the other green manures examined. Harvest management has a greater effect than cultivar on fall N available for incorporation (Hesterman *et al.*, 1986; Sheaffer *et al.*, 1988c). Research has indicated that there is a relatively low partitioning of alfalfa dry matter to roots plus crown and a low N concentration in the roots in comparison to foliage. Adoption of management practices that allow the fall plowdown of a large amount of the alfalfa herbage in addition to the incorporation of roots and crowns is necessary for the greatest net return of N to the soil (Heichel *et al.*, 1984a).

Generally, the straw coming out of combine is physically removed after seed harvestor subjected to a spring burn in Manitoba. Therefore, only the roots plus crown (including stubble) dry matter and N yield are available in the fall for plowdown from an alfalfa seed stand. However, where farmers burn the straw, the mineral N is made available to the plants. Under such circumstance the herbage N nitrogen does contribute to subsequent year crop.

2.3.6. METHODOLOGY OF MEASURING NITROGEN FIXATION

The assessment of N_2-fixation in artificial environments such as glasshouses may be an unreliable indicator of field performance (Viands *et al.*, 1981). Larue and Patterson (1981) have suggested that most estimates of N_2-fixation are excessive because they were obtained from controlled conditions on small experimental plots.

The difference method has been used extensively to estimate N_2-fixation (Larue and Patterson, 1981). This method is based on the assumption that the fixing and non-fixing systems assimilate identical amounts of soil and fertilizer N. The difference method of estimating N_2-fixation (William *et al.*, 1977) uses fewer materials and has lower analytical costs than the isotope dilution technique that uses ^{15}N (Talbot *et al.*, 1982; Heichel *et al.*, 1989).

Measurements of N_2-fixation using the isotope dilution or the difference method are often done on aerial plant parts but reported as 'whole plant' values (Talbot *et al.*, 1982; Wagner and Zapata, 1982) on the assumption that excluding root systems introduces inconsequential error. However, observations of differential allocation of fixed N_2 between shoots and roots (Ruschel *et al.*, 1979; Henson and Heichel, 1984b) suggest that whole plants should be analyzed to accurately measure total N_2-fixation. In a study comparing the ^{15}N isotope dilution technique and the difference method, the ^{15}N technique measured more N_2-fixation than the latter in all treatments (Henson and Heichel, 1984b). This suggests that the non-fixing controls may recover disproportionably more soil N resulting in an underestimation of N_2-fixation by the difference method.

The discovery and release of non-N_2-fixing strains of fall-dormant alfalfa (Viands *et al.*, 1979; Peterson and Barnes, 1981; Barnes *et al.*, 1988) has provided a means of measuring N_2-fixation in alfalfa germplasm under field conditions using the inexpensive difference method. 'Ineffective Saranac', a non-N_2-fixing alfalfa germplasm (Barnes *et al.*, 1990), was developed from Saranac (Peterson and Barnes, 1991) and provides a suitable control for both the isotope dilution technique and the difference method (Henson and Heichel 1984b). The difference between the total N content of effective and ineffective N_2-fixing cultivars is assumed to be the amount of N_2 fixed (Henson and Heichel 1984b). The accumulation of dry matter and photosynthate in above-ground organs is similar for the symbiotically dependent alfalfa Saranac and the ineffectively nodulated Ineffective Saranac supplied with combined N (Cralle and Heichel, 1986). Peterson and Barnes (1981) reported that non-fixing plants were small and chlorotic with white nodules, while plants with effective nodules were vigorous, dark green and bore pink nodules.

3. N_2-FIXATION AND DRY MATTER PRODUCTION DURING ALFALFA SEED PRODUCTION

3.1. ABSTRACT

Alfalfa (*Medicago sativa* L.) grown for seed production forms part of the crop rotation for many producers in western Canada. Although alfalfa seed stands are an important source of N, there is an absence of information on N_2-fixation during seed production. This research was designed to determine how seed yield, dry matter production and N_2-fixation were affected by cultivar, seeding rate and stage of plant development. Seed production experiments were conducted at Glenlea and Homewood in southern Manitoba in 1992 and 1993. The experiments were established in a split plot design at two seeding rates (3.36 kg ha^{-1} and 16.8 kg ha^{-1}) with five alfalfa cultivars: Algonquin, Saranac, Saranac-In, Nitro and CUF 101. N_2-fixation was determined using the difference method with intact excavated plants at different stage of plant development during establishment year. A wheat crop was seeded over the 1992 experiment to provide an estimate of the actual N contribution to subsequent crops. The results suggested that the stand established at the higher seeding rate performed better than at the low seeding rate for most of the traits measured including seed yield. The dormant cultivar, Algonquin, and the moderately dormant cultivar, Saranac, had the highest seed yield. The total N yield for all cultivars ranged from 97 to 139 kg N ha^{-1} and root plus crown N yield ranged from 42 to 60 kg ha^{-1} during the mature

seed stage. During both years cultivars produced an equivalent quantity of N_2-fixed. Depending upon stage of growth, N_2-fixed comprised 37% to 59% of the total N in the crop, corresponding to 23 kg N ha^{-1} to 74 kg N ha^{-1}. The average phytomass in root plus crown at the mature seed stage was about 1841 to 2485 kg ha^{-1} dry matter, and root plus crown N yield available for fall incorporation ranged from 44 to 66 kg N ha^{-1}. Wheat yield was not influenced by previous year cultivar or seeding rate effects. In summary, this research indicated that N_2-fixation continues during alfalfa seed production and would provide only a supplemental amount of nitrogen for subsequent crops. Seed production was not practical from establishment year stands in 1992 and 1993, but was similar to that from established fields in Manitoba suggesting that the environmental conditions were the primary factor influencing seed production.

3.2. INTRODUCTION

Alfalfa (*Medicago sativa* L.) is a perennial forage legume that is grown for stored feed, pasture and seed production. Alfalfa acreage is limited by the economic return and end use of the crop, but alfalfa is also an important component of rotations that include cereal and oilseed crops.

Traditional farming systems in western Canadian prairies are directed towards grain production. Alfalfa seed production has became an increasingly important cropping option in recent years with 22,516 ha in Manitoba in 1991. Alfalfa seed in western Canada has a major limitation in that it is restricted almost exclusively to winter hardy, early fall dormant cultivars (Fairey and Lefkovitch, 1991, 1992), since seed is normally not harvested during the establishment year. Successful establishment-year alfalfa seed production would allow alfalfa to be used as an "annual" in rotations with other cereals and oilseed crops. This type of rotation system would provide the additional benefit of increased soil N and organic matter (Sheaffer *et al.*, 1984).

Although alfalfa seed stands are a potential source of N and form a part of many crop rotations, previous research on N_2-fixation in the USA and Canada has focused exclusively on alfalfa grown for forage (Vance *et al.*, 1988). Therefore, there is an absence of information on N_2 fixation during seed production. The literature also contains a limited amount of information on the effect of varied planting densities on N_2 fixation. Alfalfa hay and seed stand differs significantly in their population density. Alfalfa for hay is normally established at high seeding rates (11.2 to 22.4 kg ha^{-1}) while seed crops are normally established at much lower seeding rates (1.12 kg ha^{-1}) to maximize seed yield (Rincker *et al.*, 1988). Plant density has been closely associated with dry matter yield (Porter and Reynolds, 1975), which has been correlated to N yield and N_2-fixation (Heichel *et al.*, 1984). Therefore, since N_2 fixation is a affected by dry matter yield, alfalfa stands established at different planting densities would be expected to differ in the amount of N_2 fixation.

A study was conducted in the 1992 and 1993 growing seasons at two locations, Homewood and Glenlea, in southern Manitoba. This research was initiated with the working hypothesis that substantial quantities of N_2 are fixed by alfalfa during reproductive phase in the year of establishment. The hypothesis is based on results obtained from non-harvested forage stands that have entered the reproductive phase. The specific objectives of this research were as follows:1) to compare seed yield and dry matter production of non-dormant, moderately dormant and dormant alfalfa cultivars during the establishment year; 2) to compare how cultivar, plant density and stage of plant development affect nitrogen fixation of alfalfa and 3) to estimate N contribution to subsequent crops.

3.3. MATERIALS AND METHODS

A series of field experiments were conducted to study the effects of seeding rate and cultivar on dry matter and N yield of alfalfa. The experiments were established in the spring of 1992 and 1993 at two sites in Manitoba: Homewood (56 km southwest of Winnipeg) and Glenlea (15 km south of Winnipeg). The soil type at Homewood was Sperling mixed loam and at Glenlea was Red River clay (lacustrine fine clay). Soil tests were conducted at each experimental site during fall 1991 and 1992 to determine the nutrient requirements of an alfalfa seed crop. Phosphorus was applied as 0-46-0 fertilizer at a rate of 20 kg ha^{-1} of P_2O_5 . In addition sulphur was also applied at soil test recommendations.

The alfalfa seed industry uses a 1-9 rating system to differentiate the fall dormancy of individual cultivars with 1 designating those cultivars that show the least growth during the fall and 9 those cultivars that show the most fall growth (Barnes *et al.*, 1991). The term fall dormancy refers to the tendency of alfalfa plants to enter a state of dormancy during the later part of the growing season and has been related to winter survival. For the purpose of this experiment cultivars with fall dormancy ratings from 1-3 were considered dormant, 4-5 moderately dormant and 6-9 non-dormant.

The experiments were established on 7 May at Homewood and 13 May, 1992 at Glenlea, and at the same sites on 12 May and 5 May 1993, respectively. These plots were established at two seeding rates, 3.36 kg ha^{-1} and 16.8 kg ha^{-1} with five alfalfa (*Medicago sativa* L) cultivars representing a range of fall-dormancy classes. The cultivars and their fall dormancy classes (in brackets) are as follows: 'CUF 101' (9), a non-dormant cultivar of Indian and African origin (Gilchrist *et al.*, 1982); 'Algonquin' (2), a winterhardy, dormant, 16-clone synthetic developed at the Agriculture Canada Research Station, Ottawa, Ontario (Baenziger, 1975); 'Nitro' (8), a non-dormant cultivar, selected for high root N accumulation (Barnes *et al.*, 1988); 'Saranac' (4), a moderately dormant cultivar (Peterson and Barnes, 1991); and 'Ineffective Saranac'(4), an ineffectively nodulating, moderately dormant cultivar developed from Saranac (Barnes *et al.*, 1990).

The experimental design was a randomized complete block design with a split-plot treatment arrangement and four replications. Seeding rates were assigned to the main plot and cultivars assigned to the sub-plot. Each sub-plot was 1.8 m * 7 m, with 30 cm row spacing. Seeding rates of 3.36 kg ha^{-1} and 16.8 kg ha^{-1} were included in this study to evaluate the N_2-fixation from an alfalfa seed stand seeded at a low rate in comparison to traditional forage crop establishment where seeding rates are much higher. The seeds were inoculated before planting with *Rhizobium meliloti* L. Dang.

In this experiment, weed control was accomplished using a combination of chemicals, cultivation and hand weeding. Specific herbicides included: 1) Pre-emergence herbicides: Edge 50 DF (Ethalfluralin) or [N-ethyl-N-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl)benzenamine] and Treflan (Trifluralin) or {2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine}; 2) Post-emergence: Pursuit (Imazethapyr) or {2-[4,5-dihydro-4-methyl-4-(1-methylenthyl)-5-oxo-1H-imididazol-2-yl]-3-pyridinecarboxylic acid}, Poast (Sethoxydim) or {2-[1-(ethoxyimino)]-5-[2-(ethylthio)propyl]-3-hydroxy-2 cyclohexen-1-one} and Roundup (Glyphosate) or {isopropylamine salt of N-(phosphono-methyl) glycine}. These herbicides were used to control annual grassy and broadleaf weeds with exception of Roundup, which was spot applied in both years to control Canada thistle. Ethalfluralin and Trifluralin are applied in the spring and incorporated with a bidirectional cultivation one week before planting. Pursuit was applied on 2 June and 11 June, 1992 at Homewood and Glenlea, respectively. Poast was applied on 7 July and 9 July, 1993. The herbicides were applied at recommended rates, except in 1993, where Pursuit was accidentally applied at ten times the recommended rate.

Scouting for insects was done frequently to check for any alfalfa pests. Lygus bug, alfalfa plant bug, pea aphid, and other insect control was achieved with Dimethoate [o,o-dimethyl S-(methylcarbamoylmethyl) phosphorodithioate] and Dylox (trichlorfon) or [dimethyl (2,2,2-trichloro-1-hydroxyethyl) phosphonate]. Many insecticides are harmful to alfalfa leafcutting bees, therefore Dimethoate was sprayed one week before bee release and Dylox was applied at night when the bees were dormant in their shelters. Dimethoate was applied on 26 July, 1992 at both sites and 5 July and 9 July, 1993 at Homewood and Glenlea, respectively and Dylox was applied on 29 July, 1993. The control of these insects was effective and insect damage had no influence on seed production, as subsequent scouting showed that the insects were below the threshold level that may cause any substantial damage.

Alfalfa leafcutting bees were used for pollination in both years. Six leafcutter shelters were placed around the periphery and in the centre of the entire area which included two other experiments. Incubation trays containing recently emerged bees were placed in each shelter when the flowering averaged 25% across experiments. Additional leafcutter bees were placed on the experiments at the 100% flowering stage. In both years adverse weather delayed bee release and bee mortality occurred during these holding periods.

Morphological traits associated with alfalfa seed yield were measured and included: seedling vigour score, plant height, % flowering, lodging, height of vegetative regrowth following lodging and plant counts. Seedling vigour scores were taken twice on 10 June and 22 June, 1992 and on 10 June, 1993 at both locations. Scoring was based on a 1 to 5 scale with "1" corresponding to least vegetative growth and "5" corresponding to the greatest vegetative growth. Plant height was measured at approximately 7, 9, 11 and 14 weeks after planting beginning 28

June, 1992 and 29 June, 1993. Fifteen stems were randomly selected from each sub-plot for plant height measurements in 1992, and ten stems per sub-plot in 1993.

Starting in mid-July in 1992 flowering percentage (number of stems with flowers) was recorded at weekly intervals until plants reached 100 % bloom. In 1993, flowering percentage was not recorded due to the destructive sampling procedure used for the whole plant harvest. In 1992, cool temperatures and adequate moisture provided ideal growing conditions, which resulted in lodging at both locations. Lodging was scored in mid-September with scores ranging from 1 to 5, with: "1"= 0%-20% of stem lodged in horizontal position, "2"= 21% to 40% of stem lodged in horizontal position, "3"=41% to 60% of stem lodged in horizontal position, "4"= 61% to 80% of stem lodged in horizontal position and "5" indicating that over 80% of stems were lodged in a horizontal position. In 1993, there was very little lodging and lodging score was not recorded.

The desiccant Harvest [2-amino-4-(hydroxymethylphosphinyl) butanoic acid] was sprayed at Homewood and Glenlea on 28 and 30 September, 1992, respectively. Two inner rows from each plot were direct-harvested with a Hege-plot combine in Homewood and Glenlea on 7 October and 9 October 1992, respectively, to determine total seed yield. In 1993, dry matter and nitrogen fixation determination involved destructive sampling. Seed yield for 1993 was obtained from the plants removed during the last sampling period by removing pods to provide a seed sample. The pods were dried, threshed and screened to obtain a clean seed sample. The harvested seed was measured and both seeds and pods were then returned to their original sample to be include in the dry matter yield and N_2-fixation measurements.

During the 1992 season N_2-fixation was determined from whole plant samples which were harvested at 3-to 4-week intervals. The first harvest was taken during the bud stage of growth and subsequent harvests occurred at the 10% bloom to 20% bloom, 50 % bloom to full bloom and the mature seed stage. This corresponded to 13 July, 5 August, 25 August and 30 September in 1992 and 15 July, 10 August, 31 August and 23 September in 1993. In 1992, two 0.5 m row sections were excavated from each plot at each sampling date. In 1993, a mechanical harvester (Dean's Vibra Digger) was used to remove 0.6 m from each of the four inner rows from each plot. Individual plant counts were made from the harvested plants and roots were carefully washed for subsequent dry matter and N_2-fixation measurements.

During both years the samples were separated into two fractions: 1) shoots cut 7 cm above the soil surface and 2) crown and roots trimmed 12 cm below the soil surface. Dry weight was determined from each fraction after drying at 80 °C for 48 hours. Each sample was ground in a Wiley mill, passed through a 2 mm screen, then thoroughly mixed and a sub-sample was taken for determination of N concentration using a LECO N determinator (Model FT 428, Mississauga, Ontario).

The amount of N_2-fixation was determined using the simple technique called "the difference method" (Weber, 1966; Ham *et al.*, 1975; Talbott *et al.*, 1982; Barnes *et al.*, 1990; Hensen *et al.*, 1984). The amount of N_2-fixed through symbiosis is the difference between the total N content of a fixing ('effective') cultivar and the total N content of a non-N_2-fixing ('ineffective') cultivar of the same species (Hensen and Heichel, 1984).

'Ineffective' Saranac was used as the non-N_2-fixing control to estimate N_2-fixation by the difference method (Henson and Heichel, 1984). The apparent symbiotically fixed N_2 was calculated by subtracting the N yield for 'Ineffective Saranac' (non-fixing reference crop) from the N yield of each fixing cultivar within a subplot. Dry matter, total nitrogen content and nitrogen fixed by symbiosis were presented on land area basis (Tabolt et al., 1982; Rennie, 1984). The percentage of N derived from atmosphere (%NDFA) was determined following the equation: $\%NDFA = \{[\%N_c \times DM_c) - (\%N_n \times DM_n)] \div (\%N_c * DM_c)\} \times 100\%$, where: $\%N_c$= N concentration in N_2-fixing alfalfa cultivar, DM_c= dry matter yield of N_2-fixing alfalfa cultivar, $\%N_n$= N concentration in non-N_2-fixing alfalfa cultivar (Saranac-In) and DM_n= dry matter yield of non-N_2-fixing alfalfa cultivar. The amount of N fixed was determined by the equation: amount N_2 fixed=$(\%N_c \times DM_c) - (\%N_n \times DM_n)$ or N yield (fixing alfalfa cultivar) - N yield (non-fixing alfalfa cultivar).

Wheat was included in the experiments in both years as a second non-fixing control crop. On 26 May 1993, a wheat crop was grown across the entire 1992 experimental areas to determine if the previous year's treatments (cultivars and seeding rate) had any influence on the wheat straw dry matter, N and grain yield. Nitrogen was mistakenly applied at 70 kg ha_{-1} at Homewood by the producer cooperator in 1993. This applied N raises questions about the validity of the wheat data from this site. At both sites all other nutrients were applied at the recommended rate. At Glenlea, there was regrowth of some alfalfa despite tillage and Canada thistle was a problem weed in some plots. Both the alfalfa regrowth and Canada thistle were controlled by the herbicide, clopyralid (Lontrel) or [3,6-dichloro-2-pyridinecarboxylic acid].

Wheat straw dry matter yield and grain yield were taken from the subsequent year wheat crop experiment in mid-September, 1993. A hand sickle was used to harvest an area of 1 m × 0.5 m from the centre of each plot on 15 September and 16 September, 1993 at Homewood and Glenlea, respectively. The 1 m length was parallel to the length of the plot. Each sample was dried at 80°C and weighed to obtain total dry matter (straw and grain) yield. Each sample was threshed using a Vogel thresher to separate the grain which was cleaned using a small clipper weighed. Straw dry matter weight was determined by the difference between total (straw and grain) and grain dry weight yield. All straw sub-samples were ground in a Wiley mill, passed through a 2-mm screen and grain samples were ground in a Udy cyclone mill to pass through a 1-mm screen. The samples were then analyzed using a LECO N Determinator (Model FT428, Mississauga, Ontario) to measure N concentration in each sample. Straw and grain N yield were then calculated on land area basis as function of dry matter yield.

Analysis of variance (ANOVA) was conducted by GLM procedure using the Statistical Analysis Systems procedure (SAS Institute, 1988) with all treatments considered fixed effects. Bartlett's Chi-square test (Steel and Torrie, 1960) was used to determine homogeneity of variance across years and locations. In all cases variances did not meet the criteria for homogeneity across years, and data transformation did not solve the problem, therefore data analysis was conducted within each year. Data variances were homogeneous over locations within years, therefore the data was pooled over locations in each year. However, in 1993 there were location*cultivar interactions between some traits (dry matter and N yield) and hence separate analysis were conducted for each location. Analyzes were conducted with block, seeding rate, and cultivars considered fixed effects and location considered a random effect. Treatment means were compared using Fisher's protected least significant difference procedure ($P \leq 0.05$).

3.4. RESULTS

3.4.1. GROWTH HABIT AND SEASONAL DEVELOPMENT

3.4.1.1. Seedling Vigour

Seedling vigour was measured across alfalfa cultivars and treatments as an indication of the relative rate of establishment and ability to compete with weeds. Although there were no differences for seedling vigour, cultivar ranking from most vigorous (5) to least vigorous (1) was as follows: CUF 101 (3.8), Nitro (3.8), Saranac (3.3), Saranac-In (2.9) and Algonquin (2.9) in 1992 and CUF 101 (4.3), Nitro (3.9), Saranac-In (3.9), Saranac (3.6) and Algonquin (3.6) in 1993. Location and seeding rate also did not influence seedling vigour (data not shown).

3.4.1.2. Plant Height

In 1992, plant height was not influenced by seeding rate nor were there location*cultivar, rate*cultivar and location*rate*cultivar interactions (data not shown). However, there were differences in plant height ($P \leq 0.05$) at 7 and 9 weeks after planting (Figure 1). Average plant height was higher ($P \leq 0.05$) at Homewood (37 cm and 58 cm) than Glenlea (26 cm and 44 cm) at the 7 and 9 week measurement dates, respectively. At 11 and 14 weeks after planting plant height was similar between the two sites (data not shown). At 7 weeks after planting, the plant height of the two non-dormant cultivars, Nitro and CUF 101, was equivalent, but higher than Saranac (Figure 1). The height of Algonquin and Saranac-In was equivalent, but lower than all other cultivars. At 9 weeks after planting Nitro, CUF 101 and Saranac showed equivalent plant height, but were higher than both Algonquin and Saranac-In. There were no plant height differences among cultivars at 11 and 14 weeks after planting.

In 1993, there was a location*cultivar interaction for plant height at the 9 and 11 week growth stages, therefore each location was analyzed separately. At Glenlea and Homewood, plant height was influenced ($P \leq 0.05$) by seeding rate (Table 1). At Glenlea, both 11 and 14 weeks after planting, plant height was higher for the low seeding rate than the high seeding rate. Plant height was similar for the two seeding rates at 7 and 9 weeks after planting. There were cultivar differences ($P \leq 0.05$) at 11 and 14 weeks after planting (Figure 2). Plant height measurements showed that Saranac, Algonquin, CUF 101 and Nitro had equivalent height at 11 weeks after planting and Saranac-In had the lowest plant height, but equivalent to Nitro. At 14 weeks after planting, Saranac had the highest plant height of all cultivars, with the exception of Nitro. Nitro, CUF 101 and Algonquin had equivalent height, whereas Saranac-In had the lowest height. There were no rate*cultivar interactions at any measurement date.

At Homewood, seeding rate also influenced ($P \leq 0.05$) plant height at 9 and 14 weeks after planting (Table 1). At 9 weeks after planting, plant height was higher for the high seeding rate than the low seeding rate. However, at 14 weeks after planting, plant height was higher for the low seeding rate than the high seeding rate. Plant height was similar for the two seeding rates at 7 and 9 weeks after planting. Cultivar differences ($P \leq 0.05$) were observed at 9 and 11 weeks after planting at Homewood (Figure 3). At 9 weeks after planting, CUF 101 and Nitro had equivalent height, but CUF 101 had a higher plant height than Saranac-In, Saranac and Algonquin. Nitro and Saranac-In had equivalent plant height, as did Saranac-In and Saranac. Algonquin had lowest plant height, but equivalent to Saranac. Plant height measurements showed that CUF 101, Nitro, Saranac, Saranac-In had equivalent height at 11 weeks after planting and Algonquin had lowest plant height (Figure 3). There were no rate*cultivar interactions at any measurement period.

3.4.1.3. Flowering

Flowering percentage was measured to determine the relative rate of maturation between alfalfa cultivars, and to assess the effect that profuseness of flowering had on seed yield potential.

Location and seeding rate did not influence flowering percentage and there were no interactions between the treatments for flowering percentage (data not shown). Flowering percentage tended to be higher at Homewood verses Glenlea and higher for the low seeding rate versus the high seeding rate at all measurement dates (data not shown). There were cultivar differences ($P \leq 0.05$) for flowering percentage when measurements were taken on 24 July and 29 July, but not on 21 July and 5 August (Table 2). Saranac-In had a higher flowering percentage than Nitro, CUF 101 and Saranac which had equivalent flowering percentages at both dates (July 24 and 29). Algonquin had the lowest flowering percentage at both dates.

3.4.1.4. Lodging and Regrowth

There was no influence of location or seeding rate (data not shown) on lodging, but there were cultivar differences ($P \leq 0.05$). Nitro (4) and CUF 101 (3.3) showed the most lodging followed by Algonquin (2.6) and Saranac (2.5) whereas Saranac-In (1.2) had the least lodging. As result of lodging, plant crowns were exposed to sunlight, which in turn stimulated and new shoot growth from the crown. However, there were no differences between cultivars in the height of these new shoots. The height of the newly developed shoots was 50, 49, 43, 41, 31 cm for CUF 101, Nitro, Saranac, Algonquin, and Saranac-In, respectively. In 1993, there was very little lodging and virtually no secondary regrowth.

3.4.1.5. Seed Yield

Seed yield was harvested at Glenlea in 1992, but not in Homewood, because the two inner rows harvested were sampled for determination of dry matter yield and N_2-fixation. Seeding rate and cultivar both influenced ($P \leq 0.05$) seed yield. The low seeding rate produced 47 kg ha^{-1} of seed and the high seeding rate produced 28 kg ha^{-1} of seed. In 1992, Saranac and Algonquin produced higher seed yields than Nitro, CUF 101 and Saranac-In (Table 3). In 1993, there were no cultivar differences for seed yield (Table 3). Overall seed yield was considerably lower in 1993 than in 1992, but there was a similar ranking among cultivars. Location (data not shown) and seeding rate did not influence seed yield in 1993. Averaged over locations and cultivars, the seed yield obtained were 12.3 kg ha^{-1} and 4.4 kg ha^{-1} for the low and high seeding rates, respectively.

3.4.2. DRY MATTER PRODUCTION AND NITROGEN FIXATION

3.4.2.1. Total dry matter yield

There was no effect of location (Table 1, Appendix) on total (herbage and root plus crown) dry matter yield across all growth stages in 1992 nor were there significant interactions between any of the treatments. Seeding rate had an effect ($P \leq 0.05$) on total dry matter yield at the mature seed stage (Table 4). At this stage the total dry matter was significantly higher for the high seeding rate than the low seeding rate.

There were differences ($P \leq 0.05$) between cultivars at the late vegetative stage (Table 5). At this stage Nitro produced the highest total dry matter yield, but equivalent to CUF 101 and

Saranac. Saranac-In yielded lowest, but equivalent to Saranac and Algonquin. CUF 101, Saranac and Algonquin all had equivalent yield. At all other growth stages there were no cultivar differences for total dry matter yield (Table 5).

In 1993 there was a location*cultivar interaction for total dry matter yield, therefore, separate analyzes were conducted for each location. At Glenlea there was no effect of seeding rate on total dry matter yield at any growth stage (Table 6). However, at all growth stages there were cultivar differences for total dry matter yield (Table 7). At the late vegetative and mature seed stages, Saranac-In produced lower total dry matter yield than all other cultivars. The other four cultivars had similar total dry matter yield at these two stages. At the 10% to 20% bloom stage the total dry matter yield (Table 7) was equivalent for Algonquin and Saranac, but higher than that of Nitro and CUF 101 which had equivalent yield. Saranac-In yielded significantly lower than all the cultivars. At 50% to full bloom stage the cultivars, Saranac, Algonquin, and Nitro had equivalent total dry matter yield followed by CUF 101. Nitro and CUF 101, had similar total dry matter yield and Saranac-In had the lowest total dry matter yield.

In 1993 at Homewood, there was no effect of seeding rate at any of the growth stages (Table 6). Cultivars showed differences for total dry matter yield at most growth stages with exception of late vegetative stage (Table 8). At the 10% to 20% bloom stage Saranac had significantly greater total dry matter yield than Algonquin, Saranac-In, and Nitro, but was similar to CUF 101. Nitro had the lowest total dry matter yield, but was similar to Algonquin and Saranac-In. Algonquin, Saranac-In and CUF 101 had similar yield. At the 50% to full bloom stage Saranac had significantly greater total dry matter yield, but was similar to CUF 101, and Algonquin. Saranac-In had the lowest total dry matter yield, but had similar yield to Algonquin and Nitro. CUF 101, Algonquin and Nitro had equivalent yield. At the mature seed stage the cultivars, Saranac, Algonquin, CUF 101 and Nitro had similar total dry matter yield. Saranac-In yielded significantly lower than all other cultivars with exception of Nitro.

When averaged over seeding rate and cultivar, the total (herbage and root plus crown) dry matter tended to be higher at Homewood than Glenlea at most growth stages in both years, with exception of late vegetative and 50% to full bloom stages in 1993 (Table 1, Appendix 1). Similarly, the total (herbage and root plus crown) dry matter yield tended to be higher at the high seeding rate (16.8 kg ha^{-1}) than the low seeding rate (3.36 kg ha^{-1}) (Table 6). However, this trend was not followed at Glenlea at the 50% to full bloom and mature seed stages.

Changes in total dry matter production over cultivars as affected by growth stages are shown for each year (Tables 5, 7, and 8). In both years dry matter production increased considerably as alfalfa matured during the growing season. As would be expected, total dry matter yield at each growth stage was increased for most cultivars from the late vegetative to the mature seed stage in 1992 (Table 5) and at Homewood, in 1993 (Table 8). However, this was not so for Saranac-In in 1992. The total dry matter yield of this cultivar decreased at mature seed stage relative to the 50% to full bloom stage. At Glenlea in 1993, there was a decline in the total dry matter yield of Algonquin and Saranac between 50% to full bloom and mature seed stage (Table 7).

Averaged over locations and treatments, the total (herbage and root plus crown) dry matter yield available for incorporation at fall (mature seed stage) was 5595 kg ha^{-1} in 1992. In 1993 the average total dry matter yield (herbage and root plus crown) available for incorporation in the fall was 3853 and 4235 kg ha^{-1}, at Glenlea and Homewood, respectively.

3.4.2.2. Root plus crown dry matter yield

In 1992, there was no effect of location (Table 1, Appendix) nor were there interactions between treatments for root plus crown dry matter (data not shown). Cultivar differences ($P \leq 0.05$) were apparent at the late vegetative growth stage (Table 10) and there was an effect ($P \leq 0.05$) of seeding rate at the 10%- to 20% bloom growth stage (Table 4). The root plus crown dry matter at the 10% to 20% bloom stage was higher at the high seeding rate than the low seeding rate (Table 4). At the late vegetative stage Nitro and CUF 101 had equivalent root plus crown dry matter yield followed by Saranac with Saranac-In and Algonquin producing the lowest dry matter yield (Table 9). At all other growth stages the cultivars had similar root plus crown dry matter yield.

In 1993 a location*cultivar interaction occurred for root plus crown dry matter yield, therefore separate analysis were conducted for each location. At Glenlea there was a seeding rate effect ($P \leq 0.05$) at the 10% to 20% bloom stage (Table 6). At this stage the high seeding rate had higher root plus crown dry matter yield than low seeding rate. At all other growth stages root plus crown dry matter yield was similar.

Cultivar differences were observed at Glenlea at all growth stages in 1993 (Table 10). At the late vegetative stage the root plus crown dry matter yield for the Nitro, Algonquin, CUF 101, and Saranac were equivalent. At this stage Saranac-In had significantly lower yield than all the other cultivars with exception of Saranac. At the 10% to 20% bloom and 50% to full bloom stages the root plus crown dry matter yield for the cultivars, Algonquin, Saranac, Nitro, and CUF 101 were equivalent. At these two stages Saranac-In had significantly lower yield than all the other cultivars. At the mature seed stage Nitro had significantly greater yield than Algonquin and Saranac-In, but had similar yield to CUF 101 and Saranac. Furthermore, at this stage, CUF 101 had significantly greater yield than Saranac-In, but had similar yield to Nitro, Saranac and Algonquin. There was no rate*cultivar interaction for roots plus crown dry matter yield at any growth stage at Glenlea in 1993.

In 1993 at Homewood, there was an effect of seeding rate ($P \leq 0.05$) at the 50% to full bloom stage (Table 6). At this stage the high seeding rate had higher root plus crown dry matter yield than low seeding rate. At all other growth stages root plus crown dry matter yield was similar.

In 1993 at Homewood, cultivar differences were present at all growth stages with the exception of the late vegetative stage

(Table 11). At the 10% to 20% bloom stage the root plus crown dry matter yield for the cultivars Saranac and CUF 101 were similar, but higher than those of Saranac-In, Algonquin, and Nitro. At the 50% to full bloom stage the root plus crown dry matter was significantly higher for Saranac in comparison to Nitro and Saranac-In. However, with exception of Saranac all other cultivars had similar root plus crown dry matter yield at this stage. At the mature seed stage the root plus crown dry matter yield was significantly higher for Algonquin and Saranac than CUF 101 and Saranac-In which had equivalent yield. Nitro had equivalent yield to all the cultivars.

There were obvious changes in alfalfa root plus crown dry matter production over the growth stages (Tables 9, 10, and 11). In both years root plus crown dry matter production increased considerably as alfalfa matured during the growing season. In 1992, root plus crown dry matter yield from the late vegetative to the seed maturity stage (Table 9) increased the most for CUF 101 followed in descending orders by Saranac, Nitro, Algonquin, and Saranac-In.

In 1993, the cultivars showing the greatest increase in root plus crown dry matter yield were not consistent between Glenlea and Homewood (Table 10 and 11). Averaged over locations and treatments, the root plus crown dry matter yield available for incorporation in the fall (mature seed stage) was 2,320 kg ha^{-1} in 1992, and 1,674 and 1,753 kg ha^{-1}, in 1993 at Glenlea and Homewood, respectively.

3.4.2.3. Dry matter partitioning

The proportion of plant dry matter yield accumulated in root plus crown increased from the late vegetative to the mature seed stage in both years (see below). In 1992, the proportion of root plus crown dry matter in comparison to total dry matter (herbage and root plus crown) shifted from 25% at the late vegetative stage to 42% at the mature seed stage. At Glenlea in 1993, there was a decrease in the proportion of root plus crown dry matter in the plants from the late vegetative (40%) to 50%-full bloom stage (35%). However, at the mature seed stage seed the proportion partitioned to the root plus crown increased to 43%. At Homewood in 1993, there was also a decrease in the proportion of root plus crown dry matter in the plants from the late vegetative (41%) to 50%-full bloom stage (35%) in 1993. However, at the mature seed stage, the proportion partitioned to the roots plus crown increased to 41%.

3.4.2.4. Total N yield

In 1992, total (herbage and roots plus crowns) N yield of alfalfa was not influenced by location (Table 2, Appendix) nor were there interactions between any of the treatments (data not shown). There was no effect of seeding rate on total N yield at any growth stage, but N yield tended to be higher for the high seeding rate than the low seeding rate (Table 12). Cultivar differences were present only at the late vegetative growth stage (Table 13). At this growth stage the total N yield for the cultivars, Nitro, CUF 101, Saranac, and Algonquin are equivalent, but higher than the that of Saranac-In. Averaged over locations, seeding rate treatments and cultivars, the total N available for plowdown in the fall (mature seed stage) was 139 kg N ha^{-1}.

In 1993, there was a location*cultivar interaction for total N yield, therefore a separate analysis was conducted for each location. At Glenlea, total N yield was affected by seeding rate at late vegetative stage (Table 14). At this stage the total dry matter yield was significantly higher ($P \leq 0.05$) for the high seeding rate than the low seeding rate. At all other growth stages there were no differences between seeding rates for total N yield. There was a seeding rate*cultivar interaction at Glenlea for total N yield during the late vegetative growth stage (Table 16). At low seeding rate cultivars had equivalent total N yield. However, at high seeding rate Algonquin and Nitro had total N yield equivalent to Saranac, but higher than CUF 101 and Saranac-In. Saranac-In had lowest total N yield. Generally, the total N yield tended to be lower for the low seeding rate than the high seeding rate.

Cultivar differences for total N yield were present at all growth stages at Glenlea in 1993 (Table 15). At the late vegetative and mature seed stage the total N yield for Nitro, Algonquin, Saranac, and CUF 101 were equivalent, but higher than Saranac-In. At the 10% to 20% bloom stage Algonquin had similar total N yield to Saranac and significantly greater total N yield than Nitro, CUF 101, and Saranac-In. Saranac had equivalent total N yield to Nitro, but had higher yield than CUF 101. Nitro had equivalent total N yield to CUF 101, but both had greater yield than Saranac-In. At the 50% to full bloom stage the total N yield for the cultivars Algonquin, Saranac, and Nitro were equivalent, but greater than CUF 101 and Saranac-In. Nitro and CUF 101 had equivalent total N yield, but had greater yield than Saranac-In.

In 1993 at Homewood, there was no effect of seeding rate (Table 14) nor was there a rate*cultivar interaction for total N yield (data not shown). However, cultivars showed differences for total N yield at all growth stages with the exception of the late vegetative growth stage (Table 17). At the 10% to 20% bloom stage Saranac had equivalent total N yield to CUF 101, but had significantly greater N yield than Algonquin, Nitro, and Saranac-In. CUF 101 had similar total N yield to Algonquin and Nitro, but higher than Saranac-In. Algonquin and Nitro had equivalent total N yield to Saranac-In. At the 50% to full bloom and mature seed stages the total N yield for the cultivars Saranac, CUF 101, Nitro and Algonquin were equivalent, but significantly higher than Saranac-In. Saranac-In was observed to have more N yield in 1992 than in 1993, and more at Homewood than at Glenlea (Tables 13, 15, 17).

In 1993, when averaged over treatments the total (herbage and roots plus crowns) N yield available for plowdown at fall (mature seed stage) was 97 kg N ha^{-1} and 101 kg N ha^{-1} for Glenlea and Homewood, respectively.

3.4.2.5. Root plus crown N yield

In 1992, root plus crown N yield of alfalfa was not influenced by location (Table 2, Appendix) nor were there interactions between treatments (data not shown). At all growth stages, root plus crown N yield tended to be higher for the high seeding rate than the low seeding rate, but seeding only had a significant effect ($P \leq 0.05$) on root plus crown N yield at the 10% to 20% bloom stage (Table 12). At this stage the root plus crown N yield was significantly higher for the high seeding rate in comparison to the low seeding rate.

Cultivar differences ($P \leq 0.05$) for root plus crown N yield were present at the late vegetative and the 10% to 20% bloom stages (Table 18). At the late vegetative growth stage Nitro had equivalent root plus crown N yield to CUF 101 and Saranac, but was higher than Algonquin and Saranac-In. CUF 101 and Saranac had equivalent root plus crown N yield, but were higher than Saranac-In. However, the root plus crown N yield of Algonquin and Saranac-In were similar. At the 10% to 20% bloom stage the root plus crown N yield for Nitro was higher than Algonquin and Saranac-In, but equivalent to CUF 101 and Saranac. Saranac-In yielded less than CUF 101, but had equivalent yield to Saranac and Algonquin. Whereas, the cultivars CUF 101, Saranac, and Algonquin had similar root plus crown N yield. Averaged over treatments, the amount of root plus crown N yield available for fall incorporation was 59.6 kg N ha^{-1} in 1992.

In 1993, there was a location*cultivar interaction for root plus crown N yield and therefore a separate analysis was conducted for each location. At Glenlea, the seeding rate influenced ($P \leq 0.05$) root N yield at the 10% to 20% bloom stage (Table 14). At this growth stage (10% to 20% bloom stage), the root plus crown N yield was higher for high seeding rate than the low seeding rate.

Cultivar differences for root plus crown N yield were evident at all growth stages at Glenlea in 1993 (Table 19). At the late vegetative stage the root plus crown N yield for Nitro, CUF 101, and Algonquin were equivalent, but higher than Saranac-In. Saranac produced equivalent yield to all other cultivars. At the 10% to 20% and 50% to full bloom stages the root plus crown N yield for all cultivars was equivalent with exception of Saranac-In which produced the least root plus crown N yield. At the mature seed stage Nitro had significantly greater root plus crown N yield than Algonquin, Saranac, and Saranac-In, but equivalent N yield to CUF 101. CUF 101 had equivalent root plus crown N to Algonquin and Saranac, but higher than Saranac-In. Saranac-In had the least yield.

At Homewood in 1993, seeding rate had an effect ($P \leq 0.05$) on root plus crown N yield only at the 50% to full bloom stage (Table 14). At this stage the root plus crown N yield was higher for the high seeding rate than the low seeding rate. Cultivar differences for root plus crown N yield were present at all growth stages with exception of the late vegetative stage at Homewood in 1993 (Table 20). At the 10% to 20% bloom stage the root plus crown N yield for CUF 101 and Saranac were equivalent, but significantly greater than Nitro, Algonquin, and Saranac-In. The later three cultivars also had equivalent root plus crown N yield. At the 50% to full bloom stage Saranac and CUF 101 had equivalent root plus crown N yield to Nitro and Algonquin, but were higher than Saranac-In. The yield of Saranac-In was equivalent to that of Nitro and Algonquin. At the mature seed stage the root plus crown N yield for Algonquin was similar to

Saranac and CUF 101, but higher than Nitro and Saranac-In. The yield of Nitro is equivalent to that of Saranac and Algonquin, whereas Saranac-In produced the lowest yield. In 1993 there was no interaction between seeding rates and cultivars at either site.

3.4.2.6. % N derived from atmosphere

The amount of root plus crown (including stubble at 7 cm) and total (herbage and root plus crown) percentage N derived from atmosphere (%Ndfa) were not influenced by seeding rate or cultivar (Table 3, Appendix) at any growth stage in either years. However, there was an effect of location ($P \leq 0.05$) in 1992 at the mature seed stage for root plus crown and total %Ndfa (Table 21). The %Ndfa was higher at Glenlea than at Homewood. There were no interactions between the variables in either year (data not shown).

In 1992, the total (herbage and roots plus crowns) %Ndfa was 37%, 42%, 37%, 43% for the late vegetative, 10% to 20% bloom, 50% to full bloom and mature seed stage, respectively. Whereas, in 1993, the total %Ndfa was 38%, 49%, 60%, 59% for late vegetative, 10% to 20% bloom, 50% to full bloom and mature seed stage, respectively. In 1992, the root plus crown %Ndfa was 40%, 52%, 40%, 44% for late vegetative, 10% to 20% bloom, 50% to full bloom and mature seed stage, respectively. Whereas, in 1993, the root plus crown %Ndfa was 39%, 50%, 55%, 57% for late vegetative, 10% to 20% bloom, 50% to full bloom and mature seed stage respectively. These results indicate that more N was derived from symbiosis in 1993 than in 1992.

3.4.2.7. Total dinitrogen fixation

The total (herbage and root plus crown) amount of N derived from symbiotic fixation tended to be higher at Glenlea than Homewood throughout the growing season in both years, but was only significant ($P \leq 0.05$) at the mature seed stage in 1992 (Table 22). At the mature seed stage, Glenlea had higher total N_2 fixed (107 kg ha^{-1}) than Homewood (38 kg ha^{-1}). In both years seeding rate had no effect on the amount of N_2-fixation with the exception of seeding rate at the late vegetative stage in 1992 (Table 4, Appendix). At the late vegetative stage the total N_2 fixed was significantly ($P \leq 0.05$) higher for the high seeding rate (28 kg N ha^{-1}) than the low seeding rate (17 kg ha^{-1}). At all other growth stages the N_2-fixed was similar between the seeding rates.

There were very few interactions between treatments for biological nitrogen fixation at all growth stages in both years with the exception of location*seeding rate at the late vegetative stage and location*cultivar at the 50% to full bloom stage in 1993. The location*seeding rate at the late vegetative stage, showed that the total N_2 fixed at the high seeding rate was 50 kg N ha^{-1} and at the low seeding rate was 19 kg N $ha^{-1.}$ at Glenlea. Whereas at Homewood, the total N fixed was 12 and 9 kg N ha^{-1} for high and low seeding rates, respectively. At either seeding rate it seems that N_2-fixation was greater at Glenlea. There was a location*cultivar interaction at 50% to full bloom growth stage. Therefore, when each location was analyzed separately in 1993, there were no cultivar differences at either location at the 50 % to full flowering stage (Table 23).

Averaged over all cultivars, there was higher total N_2 fixed at Glenlea. Cultivars showed differences in ranking at the different locations.

There were no cultivar differences for total amount of N_2 derived from symbiotic fixation at any growth stage in either year (Table 5, Appendix), though relative cultivar ranking varied between location in 1992, the total (herbage and roots plus crowns) symbiotic N_2 fixation was 23 kg N ha^{-1}, 64 kg N ha^{-1}, 54 kg N ha^{-1}, and 74 kg N ha^{-1} for late vegetative, 10% to 20% bloom, 50% to full bloom and mature seed stage, respectively. Whereas, in 1993, the total (herbage and roots plus crowns) symbiotic N_2 fixation was 23 kg N ha^{-1}, 35 kg N ha^{-1}, 67 kg N ha^{-1}, and 70 kg N ha^{-1} for late vegetative, 10% to 20% bloom, 50% to full bloom and mature seed stage, respectively. In 1992, the N derived from symbiosis was lower when plants were sampled at the 50%-full bloom stage than at 10 to 20% bloom stage.

3.4.2.8. Root quantities of fixed N_2

There was no influence of location (Table 22), seeding rate (Table 4, Appendix) and cultivars (Table 6, Appendix) for the amount of root plus crown N_2 derived from symbiosis at any growth stage in either year. However, in both years the root plus crown quantities of fixed N_2 tended to be higher at Glenlea than at Homewood (Table 22). There were no interactions between the variables in either year. Although there were no cultivar differences, CUF 101 and Nitro ranked highest in 1992 and Nitro highest in 1993 for the amount of symbiotic N_2 fixation by roots plus crown during the mature seed stage (Table 6, Appendix).

In 1992, the root plus crown symbiotic N_2 fixation was 4 kg N ha^{-1}, 23 kg N ha^{-1}, 23 kg N ha^{-1}, and 33 kg N ha^{-1} for late vegetative, 10% to 20% bloom, 50% to full bloom, and the mature seed stage, respectively. Whereas, in 1993, the root plus crown symbiotic N_2 fixation was 6 kg N ha^{-1}, 10 kg N ha^{-1}, 17 kg N ha^{-1}, 28 kg N ha^{-1} for late vegetative, 10% to 20% bloom, 50% to full bloom, and the mature seed stage, respectively.

3.4.3. SUBSEQUENT YEAR WHEAT CROP

Previous year seeding rate and cultivar had no effect ($P \leq 0.05$) on grain yield, straw yield or total N yield. However, there were location*cultivar interactions for grain yield and N yield and a rate*cultivar interaction for total N yield (Table 24). Grain yield, straw yield and total N yield were all higher at Homewood (Table 25). The site at Homewood had 70 kg ha of fertilizer N applied to it accidentally. The location*cultivar interaction for straw yield and N yield resulted from higher overall values at Homewood than Glenlea (Table 26). There were differences in ranking among cultivars for both straw and N yield between the locations. However, there were no differences between cultivars within each location. Alfalfa cultivar ranking for N yields changed with the previous year's seeding rate except for Algonquin and wheat (Table 27). Averaged over alfalfa cultivars the wheat straw yield was 5.1 tonnes ha^{-1}.

3.5. DISCUSSION

3.5.1. GROWTH HABIT AND SEASONAL DEVELOPMENT

3.5.1.1. Environmental conditions

The 1992 and 1993 growing season were characterised by extreme environment conditions, with 1992 being one of the coolest seasons on record and 1993 being one of the wettest (Table 7, Appendix). Higher than normal precipitation was recorded in both years. Moreover, in 1993 there was extremely high precipitation in the months of July and August when alfalfa grown for seed production is in the reproductive phase.

High rainfall events in July and early August (Table 7, Appendix) led to flooded fields at both sites in 1993. Although the experimental area at Glenlea had heavier soil it also had better surface drainage compared to Homewood. As a result water was left standing longer on experiment plots at Homewood than at Glenlea. Stress from flooding and saturated soil conditions in 1993 reduced overall plant growth and caused leaf and stem chlorosis. The flood damaged plants continued to lose leaves after the water receded and some plants were severely stressed after waters receeded. Later new leaves developed on the least damaged plants and stem elongation was re-initiated. Although lodging in 1992 led to similar leaf losses, the effect was less dramatic, with exception of mortality of some the lodged stems.

Soil flooding has been observed to stop alfalfa root growth, with prolonged flooding causing the deterioration of the root system (Thompson and Fick, 1981). Thompson and Fick (1981) further suggested that photosynthate normally used for alfalfa root growth is probably needed to sustain anaerobic respiration during flooding and they observed that tops of the plants did not always grow during the post flooding period.

In 1992 and 1993 adverse environmental conditions included high soil moisture, low temperatures, high precipitation and low solar irradiance and previous research has demonstrated that these conditions depress alfalfa seed yield (Pederson et al. (1972). These environmental stresses reduced seed yields by their effect on general plant health, reduced photosynthesis and seed maturation.

During the months of July and August, 1992 and 1993, average monthly temperatures were generally lower than long term averages (Table 7, Appendix). These are the primary months for pollinating by the alfalfa leafcutter bees. Lower temperature and high precipitation accompanied by cloudy conditions are unfavourable for bee activity. Alfalfa leafcutting bees are known to be most effective as pollinators during clear, sunny and warm days (〉18°C) with low rainfall and wind (Richards, 1984).

3.5.1.2. Seedling vigour

The seedling vigour of the non dormant cultivar, CUF 101 and Nitro, tended to rank higher than the other cultivars. Walter and Jensen (1970) reported that 'Moapa' (a non-dormant cultivar) seedlings emerged faster and were larger than 'Ranger' (a dormant cultivar), when grown under similar conditions. Other studies have also reported that non-dormant and moderately dormant cultivars show superior plant growth over dormant cultivars (Heichel et al., 1989).

However, the superior seedling vigour of the non-dormant cultivars may have been a disadvantage by actually promoting lodging through the vigorous growth. Nitro and CUF 101 actually showed severe lodging during 1992. During crop establishment it is known that species and cultivars with large, vigorous growing seedlings have an advantage in early weed competition and, consequently, initial stand establishment. In alfalfa, seedling vigour may be particularly important where seed production is intended from the establishment year crop. Research has shown that seedling growth and development are typically slower than regrowth from established plants because seedlings lack the crown, root, and nodule systems of older plants (Pearson and Hunt, 1972).

3.5.1.3. Plant height

Average plant height was higher in 1992 than in 1993 (Figure 1, 2, and 3). This probably resulted from the flooding stress that occurred in 1993. Cameroon (1973) reported that plant height was lower when alfalfa was maintained in the greenhouse under flooded conditions in comparisons to unflooded conditions.

In 1992, plant height was higher at Homewood than at Glenlea early in the growing season (7 and 9 weeks after planting) probably due to higher levels of initial soil N at Homewood (data not shown). This soil N was available for plant growth before the plants developed nodules and started fixing atmospheric N_2. Later during the growing season differences between locations disappeared as the plants actively produced symbiotically fixed N. At 14 weeks after planting for both locations in 1993

(Homewood and Glenlea), the plants established at the low seeding rate maintained a higher plant height (Table 1).

Generally, plant height was higher at lower seeding rate (Table 1), except for Homewood at 9 weeks after planting. This indicates that less crowded plants may have more light available than dense plants. This was not surprising since individual alfalfa stems are typically thicker and more lignified in thinner stands consequently leading to less lodging.

Earlier in the 1992 growing season the non-dormant (Nitro and CUF 101) and moderately dormant (Saranac) cultivars had higher plant height than a dormant cultivar Algonquin (Figure 1). Later in the season plant height measurements were confounded by lodging making the true height difficult to determine, as height measurement were restricted to upright stems. This means the older stems were not measured because they have lodged. This conditions led to measurements of canopy instead of stem length. In 1993, the cultivar differences for plant height were not expressed until later in the growing season (Figure 2 and 3). However, Algonquin still had lower height than the other cultivars, with exception of Saranac-In at Glenlea. Although Saranac-In is a moderately dormant cultivar, its lack of effective nodules probably curtailed its potential growth, except at Homewood in 1993 (Figure 3) where higher growth could be attributed to the high soil N.

3.5.1.4. Flowering

In 1992, the higher flowering percentage of Saranac-In, Nitro, and CUF 101 in comparison to Algonquin did not translate into a higher seed yields (Table 2 and 3). Algonquin had a higher seed yield in 1992 than most cultivars with exception of Saranac, despite having a lower flowering percentage early in the growing season than other cultivars. The higher lodging observed for Nitro and CUF 101 than Algonquin and Saranac may have contributed to these differences. However, alfalfa clones that flowered early produced highest seed yields in a study conducted at Kentucky and Washington, U.S (Dade *et al.*, 1967).

Interestingly, a higher flowering percentage (Table 2) and lack of lodging by Saranac-In did not translate into higher seed yield in 1992 (Table 3). This could have resulted from its inability to fix atmospheric N_2 leading to N limitations. This was evident later in the growing season as the plants became chlorotic.

Flower shedding and pod abortion was observed in both years as result of lodging in 1992 and heavy rain and flooding in 1993. This phenomenon had been observed in legumes by other researchers. Flowers and maturing pods in *Vicia faba* often abort because of competition for photoassimilate (McEwen, 1972). Photosynthate competition is also present in the annual medics, where the sink at each node apparently dictates flower and pod survival (Cocks, 1990).

3.5.1.5. Lodging and growth from crown

Alfalfa plants produced tall, dense vegetative growth and were prone to lodging as result of the cool moist conditions in 1992 (Table 7, Appendix). Higher lodging by Nitro and CUF 101 in 1992 could have resulted from the higher plant height of these cultivars (Figure 1). Lodging stimulated new shoot growth from the crown (see text above) by exposing the crown to light penetration. New shoot growth from the crown was consistent with the ranking for lodging scores among cultivars. These new shoots either flowered very late in the season or did not flower at all and they may have negatively affected seed development in existing pods by influencing nutrient partitioning within the plant.

Additionally, lodging may have led to decreased air movement, increased humidity, decreased accessibility for pollinating bees and decreased light penetration through canopy. These conditions negatively influence seed yield (Pederson et al., 1955, 1959; Plews, 1973). Tysdal (1946) and Taylor *et al.* (1959) suggested that excessive lodging of alfalfa plants causes low seed yields through its effect on the micro-environment around individual plants. Furthermore, Fick et al. (1988) reported that lodging can affect photosynthesis and photosynthate partitioning through shading and new regrowth. Stand lodging was not observed in 1993, therefore it was not a contributing factor to low seed yields during that year.

3.5.1.6. Seed Yield

Adverse environmental conditions influenced alfalfa seed production and also the expression of seed yield components that are associated with seed production. In addition, the depressing effect of environmental conditions on leafcutter bee activity was one of the most important limiting factors for seed yield. Another serious limitation for seed development was the subsequent shoot growth that occurred after lodging in 1992 which may have competed with the developing seed for photosynthate.

The high seeding rate was included in these experiment because all previous N_2-fixation research in alfalfa was conducted at high seeding rates typical of forage production. The lower seed yield of the high seeding rate (dense stand) in this experiment in comparison to the low seeding rate was not surprising. Previous research had shown that dense alfalfa forage stands do not produce optimum seed yields (Pederson and McAllister, 1955;Engelke and Moutray, 1980; Rincker et al., 1988). In 1992, the least lodged cultivars, Saranac and Algonquin produced higher seed yields than the most lodged cultivars, Nitro and CUF 101 (Table 3). In 1993 there were no differences between cultivars for seed yield, but still Saranac and Algonquin continued to rank higher than other cultivars (Table 3). These results suggest that a moderately dormant and dormant cultivars, such as Saranac and Algonquin may have been favoured under the adverse environmental conditions of these experiments.

The seed yield (kg ha^{-1}) from these experiments were much lower than yields reported by Ricker (1976) at Prosser, Washington, USA, of 214 kg ha^{-1} for an establishment year stand seeded at 1.12 kg ha^{-1}. Similarly, research in Manitoba (Smith, 1992) also reported yields that ranged from 197 kg ha^{-1} to 418 kg ha^{-1} for an establishment year stand seeded at 3.4 kg ha^{-1}. It is difficult to make seed yield comparisons with other studies conducted in western Canada because seed is traditionally not harvested during the year of establishment (Moyer et al, 1991, Fairey and Lefkovitch, 1992). However, our result was similar to seed yield obtained by commercial producers in Manitoba. A survey conducted by Smith *et al.* (1993 and 1994) showed that the corresponding longterm yield from commercial field under current management in southern Manitoba was 261 kg ha^{-1}, whereas a seed yield of 46 and 35 kg ha^{-1} was obtained in 1992 and 1993, respectively. Therefore, the prevailing environmental conditions during the growing season, rather than the production system might have affected the seed yield from our experiments.

3.5.2. DRY MATTER PRODUCTION AND NITROGEN FIXATION

3.5.2.1. Total (herbage and root plus crown) dry matter

Average total dry matter yield did not differ between the locations in either year, however, it was observed that the yield tended to be higher at Homewood than Glenlea (Table 1, Appendix). This was attributed to high initial soil N at Homewood as compared to Glenlea in both years (data not shown).

The high initial soil N at Homewood was further suggested by growth of Saranac-In. Saranac-In showed signs of N-deficiency during both growing seasons. The symptomatic smaller, chlorotic plants were more evident at Glenlea than Homewood. The initial soil N available for plant growth was higher at Homewood than Glenlea, which provided the alfalfa cultivars with sufficient N for initial good growth. Later in the growing season the plants relied more on symbiotically fixed N_2 at both locations and correspondingly Saranac-In expressed chlorotic symptoms at this period.

The total dry matter was not affected by seeding rate at most growth stages in both years, with the exception of the mature seed stage in 1992 (Table 4 and 6). The total dry matter was high for high seeding rate at this growth stage, but equivalent at the other growth stages. This was not surprising since dense stands normally produce the highest forage yields. These results were in agreement with other research (Belzie and Rioux, 1984), where a seeding rate of 6.7 kg ha^{-1} gave a lower dry matter yield than a rate of 13.4 kg ha^{-1}. However, later in the growing season the two seeding rates produced similar total dry matter yield because the less dense plants had a tendency to produce lateral branches with more yield.

When total dry matter yield was pooled across locations in 1992, cultivar differences were only evident at the late vegetative stage (Table 5). The non-dormant cultivars (Nitro and CUF 101) performed better than both moderately dormant and dormant cultivars. These higher yields may have resulted from superior seedling vigour of these of these two cultivars in 1992 (see above text: seedling vigour). At all other growth stages in 1992, cultivar had similar total dry matter yield (Table 5). During this year Saranac-In had a good total dry matter yield at Homewood (data not shown), such that its combined yield over sites did not differ much from other cultivars. The high variation that existed as indicated by higher CV (%) (Table 5) could have made it hard for cultivar differences to be detected. This high variation is mainly attributed to environmental effect.

Cultivar performance varied with location in 1993 (Table 7 and 8). At both sites cultivar differences were more evident during the 10% to 20% bloom and 50% bloom growth stages. During these growth stages flooding occurred at both locations as result of high precipitation (Table 7, Appendix). Apparently, alfalfa cultivars respond differently to the flooding stress. At Glenlea, Algonquin and Saranac consistently performed better during this period than Nitro, CUF 101 and Saranac-In (Table 7), suggesting that they are more flooding tolerant. However, at the mature seed stage the total dry matter of Algonquin and Saranac declined (Table 7). A similar decline was not observed at Homewood in 1993 (Table 8).

When, total dry matter yield was pooled over location in 1992, dry matter yield of Saranac-In decreased between the 50% to full bloom stage and the mature seed stage (Table 5). Flooding damage was probably a factor in the decline of total dry matter between the 50% to full bloom stage and the mature seed stage for these alfalfa cultivars in 1993. Saranac-In had the least lodging in 1992, however the resulting lose of leaves and death of stems may have had a more pronounced effect as plants are weaker. These conditions may have led to the lower total dry matter yield observed at the mature seed stage in comparison to the 50% to full bloom stage.

Reduction in growth, leaf chlorosis and leaf loss were observed at both locations in 1993 as result of flooding stress. Although lodging in 1992 led to a similar leaf losses, the effect was less dramatic. In Minnessota, (U.S.A.), Sheaffer *et al.* (1988) reported that alfalfa forage stands that were harvested only in the fall suffer from leaf loss, which affected the dry matter yield.

At Homewood, Saranac yielded higher than Nitro and Saranac-In at both 10% to 20% bloom and 50% to full bloom growth stages. The low yield of Nitro was surprising, however, these results suggest that Nitro was less tolerant to flooding stress than the other cultivars. The low dry matter yield of Saranac-In particularly at Glenlea as compared to Homewood (Table 7 and 8), evidently resulted from limited soil N. Under conditions of high soil N the total dry matter of Saranac and Saranac-In has been reported to be similar (Henson and Heichel, 1984).

The results indicate that the non-dormant cultivars (Nitro and CUF 101) had no higher fall dry matter yield than the other cultivars (Table 5, 7, and 8) in a stand managed for seed production during establishment year. Apparently, the superior fall growth potential of non-dormant cultivars is not fully expressed without a late summer cutting. When managed for forage production, non-dormant cultivars produced higher fall dry matter than the fall-dormant cultivar (Sheaffer *et al.*, 1988; Sheaffer *et al.*, 1989). The total dry matter yield harvested from these experiments at a mature seed stage is in the range obtained by Sheaffer *et al.* (1988)in Minnesota. They reported total dry matter yields (including roots to 30 cm) ranging from 3,268 to

8,548 kg ha^{-1} when alfalfa stand was harvested once in the fall. Similarly Kroonje and Kehr (1956) obtained an average of 4,829 kg ha^{-1} dry matter in the fall from a single fall harvest.

3.5.2.2. Root plus crown dry matter yield

Although total dry matter yield is important, from a practical standpoint only the root plus crown remains for incorporation after desiccation and seed harvest. In these experiments the average root dry matter yield was similar for the two locations in 1992 (Table 1, Appendix).

As with the total dry matter yield the dry matter of root plus crown was either similar between seeding rates or higher for high seeding rate than low seeding rate (Table 4 and 6). Field observations showed that the individual plant root was thicker and likely heavier for the lower seeding rate. However, the high seeding rate plots had more numerous plants which compensated for the smaller individual root sizes.

Cultivar differences were observed only at late vegetative stage in 1992 (Table 9). These results suggest that the non-dormant cultivars were better at developing roots. Cultivar performance seemed to vary with location (there was an interaction) in 1993 (Table 10 and 11). Although there were no cultivar differences at late vegetative growth stage at Homewood (Table 11), there were differences at Glenlea (Table 10). The lower yield of Saranac-In for this stage at Glenlea could be attributed to low soil N at this site (Saranac-In more chlorotic). Saranac-In had either the lowest yield or was among the cultivars with the lowest yield at all growth stages at either site. This was not surprising since Saranac-In was not capable of fixing N_2 through symbiosis (Barnes et al., 1990).

Nitro, CUF 101 and Saranac seemed to rank high for root plus crown dry matter yield (Table 9 and 10). One of the main criteria in developing Nitro was selection for large root mass (Barnes et al., 1988). The root dry matter yields measured were within the range obtained by Sheaffer *et al.* (1989). They reported a root yields of 1,760, 1,760, and 1,760 kg ha^{-1} for Nitro and representative non-dormant and dormant cultivars respectively. However, Sheaffer *et al.* (1989) harvested the crop three times during summer before harvesting the roots in the fall. The result from this experiment is also similar to that of Kroonje and Kehr (1956). They reported an average root yield of 1510 kg ha^{-1} when no summer harvest was taken and roots excavated to a depth of 15 cm. Similarly, Sheaffer *et al.* (1988) reported a root dry matter yield ranging from 2,011 kg ha^{-1} to 3,520 kg ha^{-1}. However, they excavated the roots to a depth of 30 cm and recovered more roots.

3.5.2.3. Dry matter partitioning

The proportion of plant dry matter partitioned to roots plus crown was about 40% of the total dry matter yield. This proportion was higher than that reported by Trimble *et al.* (1987), where they observed dry matter partitioning to roots plus crown at 31%, when they sampled to a depth of 25 cm. Although we only sampled to a depth of 12 cm, because our measurements included 7 cm of stubble our proportion partitioned to roots plus crown is higher. Trimble *et al.* (1987) only included 5 cm of stubble. A decrease in the proportion of the roots plus crown dry matter yield was observed in 1993. This resulted from high precipitation and flooding. Flood stress curtails plant growth particularly the root growth (Thompson and Fick, 1991; Ficks *et al.*, 1988). At the late vegetative stage more photosynthate may go to herbage versus roots because the plants is establishing its photosynthesis capacity by developing more leaves. The regrowth occurring after floods receeded may have depleted root reserves at full flowering. At the mature seed stage the dry matter partitioned to roots increased as plants stored resources in preparation for winter.

3.5.2.4. Total (herbage and root plus crown) N yield

Total N yields consistently ranked higher at Homewood than at Glenlea, although differences between locations were not significant (Table 2, Appendix). Higher soil N levels at Homewood in comparison to Glenlea offer the most plausible explanation for this trend. The higher N uptake values for non-N_2-fixing reference crop (Saranac-In) at Homewood compared to Glenlea confirm this explanation (Table 16 and 18).

Seeding rate did not influence the total N yield, except during late vegetative growth stage at Glenlea in 1993 (Table 12 and 14). At this growth stage the denser stands yielded more total N. This is not surprising in that stand density relates to dry matter which, in turn, relates to N yield (Friborg and Johnson, 1975; Porter and Reynolds, 1975; Belzie and Rioux, 1984). Friborg and Johnson (1955) evaluated the relationship between the herbage and root dry matter and N yields of alfalfa, sweetclover, and red and ladino clovers, in the fall of the establishment year. Even when species were combined, they found a significant linear relationship (r=0.98) between total (herbage and root) dry matter yield and total N yield.

The amount of total N fixed by alfalfa in this study closely followed the amount of the dry matter yield at each growth stage. As alfalfa dry matter generally increased with the growth stage, it was also observed that N yield increased similarly. Heichel *et al.* (1984) reported that N-fixation on a per plant basis was highly correlated with mean herbage yield within each year and across years.

Cultivar differences for total N yield were only present the late vegetative stage in 1992 (Table 13). The lower N yield of Saranac-In presumably resulted from its low dry matter yield at this growth stage (Table 5). At all other growth stages in 1992, there were no cultivar differences for total nitrogen yield (Table 13) which in turn correspond to the lack of differences for total dry matter yield (Table 5).

Cultivar performance was variable across locations in 1993 (Table 15 and 17). At Glenlea cultivar differences were present for all growth stages (Table 15). These cultivar differences for total N yield closely followed the differences observed for total dry matter (Table 7). Among all cultivars Algonquin and Saranac tended to produce high N yields at all growth stages in 1993. This trend suggests that this cultivar had more tolerance to flooding stress and possibly shows less leaf loss as a result. The two non-dormant cultivars Nitro and CUF 101 tended to be most vulnerable to flooding damage.

At Homewood, cultivar differences were present for all growth stages with exception of the late vegetative stage (Table 18). These cultivar differences for total N yield were also closely related to observed differences for total dry matter yield (Table 8). Saranac performed exceptionally at most growth stages, particularly after flooding occurred (at 10% to 20% bloom stage). As expected, Saranac-In had the lowest total N yield at most growth stages, especially toward the end of the growing season. These results indicate that soil N was limiting at this time.

Non-dormant cultivars have been promoted for their high N yield potential during the fall, but their potential was not expressed in these experiments. It is critical to note that these experiments were managed for seed production in the establishment year, therefore no harvest was taken during the summer. Other research supported this finding in that in non-harvested (not harvested during summer) alfalfa stands, cultivars did not show differences for the total N yield (Fribourg and Johnson, 1955). The average total N yield over all treatments was 139 kg N ha^{-1} in 1992. In 1993 they were 97 kg N ha^{-1} and 101 kg N ha^{-1} at Glenlea and Homewood, respectively. Again, these results fall within the range reported for alfalfa stands that were not harvested in summer, but only once in the fall (Sheaffer *et al.*, 1988; Sparrow *et al.*, 1993).

In an experiment comparing different green manure crops in Alaska, Nitro accumulated an average of 127 kg N ha^{-1} (Sparrow et al., 1993), but root N yield was not included their results. Stickler and Johnson (1959) reported slightly higher fall N yields in two non-dormant alfalfa cultivars compared with a dormant cultivar, with measured N yields of 90 kg N ha^{-1}, 84 kg N ha^{-1} and 62 kg N ha^{-1} for Indian, African and Ranger alfalfas, respectively. However, the value in this experiment is lower than reported in an experiment with non-dormant (CUF 101 and 'Ardiente') and dormant (Saranac and 'Agate') alfalfa, which produced N yields of 184 kg N ha^{-1} and 207 kg N ha^{-1}, respectively, when forage was allowed to accumulate over the growing season (Groya and Sheaffer, 1985).

Other studies with one summer harvest also showed a variable N yields. In a study at Guelph, Ontario, Bruelsema and Christie (1987) reported a average plowdown N yield of 198 kg N ha^{-1} for 2 alfalfa cultivars. In a second experiment they reported a plowdown N yield of 140 kg N ha^{-1} for 20 alfalfa cultivars with varying levels of fall dormancy. They harvested once in late July and allowed the stand to regrow until early November for fall harvest. In other studies, Heichel *et al.* (1981) reported that during the seeding year two alfalfa populations (similar to 'Vernal' and 'Ranger' in fall dormancy and winter hardiness: that is dormant) had fixed an average of 148 kg ha^{-1} of N during the growing season.

The interaction between seeding rate and cultivar (Table 16) resulted from the fact that cultivar performed differently at the two seeding rates. Cultivars had equivalent total N yield at the low seeding rate, but at the higher seeding rate, Algonquin, Nitro and Saranac produced a higher total N yield than CUF 101 and Saranac-In. This suggests that performance by CUF 101 and Saranac-In is not fully expressed at higher seeding rates. The competition at the higher seeding rate among plants might have more detrimental effects on these two cultivars. In addition, all cultivars with exception of Saranac-In performed well when established at the high seeding rate as compared to the low seeding rate. This suggests that in order to maximize the total N yield of alfalfa the stand should be established at the high seeding rate. However, for a cultivars like Saranac-In with 'ineffective nodules' it is advisable to establish them at low seeding rate. This would limit competition for nutrients among plants. Alfalfa seed stands are always established at low seeding rates and therefore the above result suggests that alfalfa seed stands may not yield as high N as forage stand.

3.5.2.5. Root and crown N yield

Normally farmers remove or burn off the straw and chaff that remains after seed harvesting for ease of management and to control disease and insect pests (Rincker et al., 1988). Therefore, available dry matter and N for incorporation is restricted to the root plus crown (including any regrowth).

In 1992, the root plus crown N yield was similar between the two locations (Table 2, Appendix), however, N yield was higher for the high seeding rate than the low seeding rate at the late vegetative stage (Table 12). A higher N yield for the high seeding rate indicates the advantage of high stand density for a green manure crop that will be incorporated during the vegetative growth stage. Cultivars produced different yields at the two locations in 1993 (Table 20 and 22). At Glenlea, for example cultivar differences at the late vegetative and 10% to 20% bloom stages suggested a greater potential for the non-dormants (Nitro and CUF 101) as a green manure crop (Table 19). At Homewood, low N yields for Nitro and CUF 101 root plus crown N yield provided a further indication that the cultivars were more affected by flooding stress in 1993 (Table 20). N yield of Saranac-In was low because the contribution to the N yield is from soil N only.

In these experiments, we obtained a root plus crown N yield at fall harvest (mature seed stage) of 60 kg ha^{-1} in 1992 and 42 kg ha^{-1} in 1993. The root and crown N yield obtained in these experiment at the mature seed stage in both years was within the range obtained by Sheaffer *et al.* (1988), where herbage was accumulated in situ until fall harvest. However, Sheaffer *et al.* (1988) sampled the roots plus crown to a depth of 30 cm compared to 12 cm for our measurements. Stickler and Johnson (1959) reported a slightly higher fall nitrogen yields in two non-dormant alfalfa cultivars compared with a dormant cultivar, when they measured nitrogen yields of 90, 84, and 62 kg N ha^{-1} for Indian, African and Ranger alfalfa, respectively. They sampled the roots to a depth of 75 cm.

3.5.2.6. % N derived from atmosphere (%Ndfa)

In 1992, there was location effect on %Ndfa at the mature seed stage (Table 21). At this growth stage, the %Ndfa was higher at Glenlea than Homewood. At all other growth stages there were no differences for %Ndfa, although Glenlea consistently ranked numerically higher than Homewood at all growth stages in both years. However, it was not surprising to have high %Ndfa at Glenlea because of the apparent low soil N

(Saranac-In was more chlorotic). In this experiment the alfalfa N derived from symbiosis (%Ndfa) ranged from 25% to 65 % in 1992 and 18 % to 70% in 1993. The %Ndfa was not consistent over growth stages, suggesting that it was more affected by prevailing environmental conditions than by growth stage.

These results were similar to those reported in other studies. Heichel *et al.* (1981) reported that during the seeding year two alfalfa populations (similar to 'Vernal' and 'Ranger' in fall dormancy and winter hardiness) had 43 % of their N needs supplied from symbiosis during the growing season. Heichel and Barnes (1984) reported that alfalfa derived 30% to 60 % N from symbiosis. In 1992, %Ndfa was lower when plants were sampled at 50 % to full bloom stage than when plants were sampled at 10-20% bloom stage at Glenlea (Table 21). Similarly, at Homewood plants sampled at the 10% bloom and the 50% to full bloom stages had lower %Ndfa than at the late vegetative stage and mature seed stage, respectively (Table 21). Stress from lodging and resulting growth during the later part of growing seasons may have contributed to this decrease in %Ndfa or N_2-fixation efficiency. However, at the seed maturity stage the plants seemed to overcome this stress.

3.5.2.7. Total N_2-fixed

There was no influence of cultivar on total (herbage and root plus crown) N_2 fixed (Table 5, Appendix), but location and seeding rate influenced N_2-fixation at the late vegetative stage (Table 22, Table 4, Appendix). The total N_2-fixed was higher at Glenlea than at Homewood (Table 22), indicating that N was more limiting at the latter location. The high seeding rate stands also fixed more N_2 at the late vegetative stage (Table 4, Appendix), suggesting that dense stands are superior for total N_2 fixation on land area basis.

There was an interaction between the location and seeding rate at the late vegetative stage for total dinitrogen fixation (see result section). At Glenlea the two seeding rates fixed N_2 at quite different levels with the high seeding rate fixing higher N_2 than the low seeding rate. However, at Homewood the N_2-fixed was quite similar for the two seeding rates. Generally, the total N_2-fixed had the tendency to be higher at Glenlea than at Homewood for both seeding rates. These result suggest that higher total N_2 yield could be obtained from Glenlea if plants are established at high seeding rate. However, the problem is that it is hard to produce seed at higher seeding rates. The site at Glenlea has lower soil N (more chlorosis of Saranac-In observed here) than at Homewood. Therefore, it is not surprising to observe high N_2-fixation at Glenlea when plants were established at either seeding rates.

The interaction between location and cultivar (Table 23) for total N_2-fixation resulted from variable cultivar ranking over locations. In addition, all cultivars showed higher N_2-fixation at Glenlea than at Homewood. Obviously soil N was less limiting at Homewood which was confirmed by the less chlorosis of Saranac-In at Homewood.

Soil N is the single most important environmental factor which affects N_2 fixation under field conditions. Alfalfa is not unlike other legume species, in that it uses available soil N before nodulating and fixing N_2 symbiotically (Stewart *et al.*, 1968; Heichel *et al.*, 1984a). A serious stress on symbiotic N_2 fixation was the shoot regrowth that occurred from the crown following lodging. These new shoots may have negatively affected N_2 fixation during seed development by influencing nutrient partitioning within the plant. The most lodged cultivars (Nitro and CUF 101) also had the most vigorous seedling growth and regrowth. Previous research reported that non-dormant cultivars have good seedling vigour, faster regrowth after harvest, greater herbage production and good N_2 fixation ability during the fall (Heichel *et al.* 1989). Regrowth was not desirable because it affected seed yield by competing for nutrients with the pods and seeds. In 1992, total symbiotic N_2-fixation was lower when plants were sampled at the 50 % to full bloom stage than when plants were sampled at the 10-20% bloom stage (Table 22). These declines may have resulted from the excessive lodging that occurred and stimulation of new shoots growth from exposed crown. Later, by the mature seed stage, N_2-fixation capability had recovered because the new shoots had established themselves as the primary stems. The decline of total N_2-fixed that occurred in both years showed that N_2-fixation of alfalfa changes with prevailing climatic and plant growth conditions.

CUF 101 and Nitro showed the highest regrowth and consequently also ranked high for the amount of symbiotic N_2 fixation later at the mature seed stage (Table 5, Appendix). In 1993, with the influence of flooding, CUF 101 and Nitro ranked lower for the amount of dry matter and N yield during mature seed stage at Homewood (Table 8 and 17). Field observations showed that CUF 101 and Nitro were more affected by the 1993 flood than the other cultivars (Algonquin, Saranac, Saranac-In), with more leaf loss and plant mortality. Carter and Sheaffer (1983) reported that extreme soil moisture affects N_2-fixation. Patterns of N_2 fixation have been thought to be related to factors such as mineral soil N and availability and seasonal precipitation (Heichel *et al.*, 1984a).

In this study the adverse environmental conditions during the growing season may have made it difficult for proper estimation of N_2-fixation capacity. The lodging and new shoot growth from the crown in 1992, and extremely high precipitation and flooding stress in 1993 were major limiting factors to N_2-fixation.

3.5.2.8. Root quantities of fixed N_2

There was no influence of location or seeding rate or cultivar differences for root quantities of N_2-fixed in both years (Table 22, Table 3 and 5, Appendix). There was a high variation among the data as indicated by high C.V (%) that might have made difficult for cultivar differences to be detected (Table 6, Appendix). This high variation is caused by the environment effect. However, CUF 101 and Nitro ranked higher for root quantities of N_2-fixed.

The root quantities of fixed N_2 at the fall harvest (mature seed stage) was 28 kg N ha^{-1} and 33 kg N ha^{-1} in 1992 and 1993, respectively. Kelner (1994) reported that non-dormant cultivar (Nitro and CUF 101) had a higher quantity of fixed N_2 than 'Excalibur', Algonquin and Saranac. In his study, he cut the alfalfa stand twice for hay, sampled the upper 10 cm of the roots in fall and obtained the quantity of N_2-fixed ranging from 27.9 to 102.2 kg N ha^{-1}. These values are substantial considering that this N was fixed through symbiosis and is a net contribution to the soil N system from an alfalfa seed stand in an establishment year. The quantities of root N_2-fixed presented in this experiment are limited only to the upper 12 cm of the root and thus the actual contribution by roots system could be higher.

3.5.3. SUBSEQUENT YEAR WHEAT CROP

In this experiment, the average amount of root plus crown dry matter available for fall (mature seed stage) incorporation in 1992 was 2,320 kg ha^{-1} (Table 4, when averaged over seeding rate). Although higher N_2 fixation took place at Glenlea than Homewood at the mature seed stage (Table 22), the amount of available N during fall incorporation was similar between the sites (Table 12). The average root plus crown N yield available for fall incorporation was 60 kg N ha^{-1} at both sites (Table 12, when averaged over seeding rate). However, not all of the incorporated N will be recovered by a subsequent crop. Janzen *et al.* (1990) reported only 11-27% of annual legume green manure N was recovered by a subsequent year spring wheat crop grown on a dark brown Chernozemic soil. Bruelsema and Christie (1987) reported yield contribution to a succeeding corn crop to be between 90 and 125 kg N ha^{-1}. They suggested that N availability from red clover and alfalfa is 65% and 71%, respectively.

Wheat straw, grain, and N yield was influenced by location (Table 24). The Homewood location was more thoroughly tilled providing more complete control of the alfalfa regrowth and other weeds. Furthermore, the Homewood location was fertilized accidentally with N and obviously this biased the final wheat yields. In this experiment alfalfa regrowth was a major problem at Glenlea. The regrowth competed with wheat and caused a reduction in growth early in the season. However, the alfalfa regrowth was controlled effectively by herbicides later in the growing season. The straw yield, grain yield, and N yield at Glenlea were lower than Homewood (Table 25). This could be attributed to competition from alfalfa regrowth and Canada thistle early in the growing season at Glenlea and N fertilization of the plots at Homewood. Recurrence of alfalfa in the second cycle of rotation was a contributing factor to low straw yield of barley following alfalfa (Rice et al. (1993).

When the alfalfa stand field was well tilled and fertilized (Homewood) the grain yield ranked higher for all plots previously planted with alfalfa cultivars than those planted with wheat (Table 26). This might indicate that wheat following alfalfa had some advantages. At both locations alfalfa and wheat stubble were not incorporated until the early spring, therefore less mineralizable N was available for the wheat during the growing season.

In this experiment, previous year seeding rate (stand density) and cultivar had no effect on grain yield, straw yield or total N yield (Table 24). This was not surprising as there was no effect of seeding rate at the mature seed stage (fall period) the previous year for root dry matter, root N yield, and root quantities of symbiotic N_2-fixed (Table 4, 12 and Table 4, Appendix). The high subsequent year wheat yield on the plots cropped to wheat in Glenlea was probably due the absence of alfalfa regrowth in their plots. Although the symbiotically N_2-fixed (kg ha^{-1}) available for incorporation was higher at Glenlea than Homewood (Table 22), the fertilization and better tillage of the field at Homewood made it impossible to quantify any advantage from previous year symbiotically fixed nitrogen.

When the effect of previous year alfalfa cultivars and wheat were compared they showed similar effect on the yields of subsequent year wheat. This type of response of different cultivars belonging to different dormancy classes has not been uncommon. Kroonje and Kehr (1956) reported that barley grain yields following various alfalfa cultivars (2 non-dormant and 4 dormant) were similar. Hesterman *et al.* (1986) reported that yield of a subsequent corn crop was related to alfalfa N yield at only one out of four locations in Minnesota, despite differences in N yield among alfalfa cultivars and cutting managements. Furthermore, Bruulsema and Christie (1987) reported that although significant cultivar variation in plowdown N yield was observed, there was no apparent association with succeeding corn yield and N concentration. In this experiment, the previous year N yield of four alfalfa cultivars (Algonquin, Saranac, Nitro and CUF 101) were not different.

Significant yield and nitrogen response in subsequent crops has often been evident when the preceding alfalfa was compared to a non-leguminous crop (Bruelsema and Christie, 1987). However, the advantages of previous year non-dormant cultivars (Nitro and CUF 101) in comparison to the moderately dormant (Saranac and

Saranac-in) and dormant (Algonquin) cultivars and wheat was not apparent from this study (Table 24 and 26). These results indicate that further research should be conducted to evaluate the benefits of subsequent year grain crop following alfalfa managed for establishment year seed production.

3.6. CONCLUSIONS

Although seeding rate did not influence flowering percentage, lodging, and seedling vigour, the higher seeding rate led to decreased seed yield and plant height. The non-dormant cultivars (CUF 101 and Nitro) ranked highest for seedling vigour and lodging and were followed by Algonquin, Saranac, and Saranac-In. Lodging apparently contributed to decreased seed yields in 1992, as indicated by cultivar ranking for seed yield with Algonquin and Saranac yielding higher than Nitro, CUF 101 and Saranac-In.

Seeding rate only influenced dry matter, N yield, and symbiotic N_2-fixed at a few sampling dates. However, dry matter, N yield and symbiotic N_2-fixed tended to be higher for the high seeding rate than the low seeding rate at all growth stages. There were no consistent cultivar differences for measured traits over the growing season. Surprisingly, the non-dormant cultivars had no higher fall dry matter yield than other cultivars in a stand managed for seed production during establishment year. This is in contrast to stand managed for hay where non-dormants and moderately dormants cultivars fixed more N than the dormants cultivars.

In 1992, the total (herbage and roots plus crowns) %Ndfa was 37%, 42%, 37%, 43% for late vegetative, 10% to 20% bloom, 50% to full bloom and mature seed stage, respectively. Whereas, in 1993, the total %Ndfa was 38%, 49%, 60%, 59% for late vegetative, 10% to 20% bloom, 50% to full bloom and mature seed stage, respectively. In 1992, averaged over treatments the corresponding total symbiotic N_2-fixed was 23 kg N ha^{-1}, 64 kg N ha^{-1}, 54 kg N ha^{-1}, and 74 kg N ha^{-1} for late vegetative, 10% to 20% bloom, 50% to full bloom and mature seed stage, respectively. Whereas, in 1993, the total symbiotic N_2 fixed was 23 kg N ha^{-1}, 35 kg N ha^{-1}, 67 kg N ha^{-1}, and 70 kg N ha^{-1} for late vegetative, 10% to 20% bloom, 50% to full bloom and mature seed stage respectively.

Lodging, flooding stress and new shoot regrowth from the crown affected seed yield, dry matter yield, N yield, and symbiotic N_2-fixation in these experiments. The root plus crown dry matter yield and N yield are components of an alfalfa seed stand available for fall incorporation. Therefore, this research indicated that 1,674 to 2,320 kg ha^{-1} dry matter and 41 to 59.6 kg ha^{-1} of N (of which 28 to 33 kg ha^{-1} was from symbiotically fixed N_2) was available for fall incorporation and production of subsequent crops.

Generally, yield and nitrogen response are expected for crop in subsequent production when the preceding crop was alfalfa in comparison to a non-leguminous crop. However, these research results did not show differences in wheat straw, N, and grain yield when wheat was grown on plots following alfalfa grown for seed production.

This research will be the first published information on N_2-fixation in alfalfa during seed production. Alfalfa seed yields were disappointing during 1992 and 1993 in our research plots and for producers across western Canada. Therefore extrapolation of these results may be difficult, but this research will provide important basic information on N_2-fixation during seed development in alfalfa. This research will also be helpful in determining the N contribution of an alfalfa seed crop for rotations and in determining the influence of stand density and cultivar on N_2-fixation.

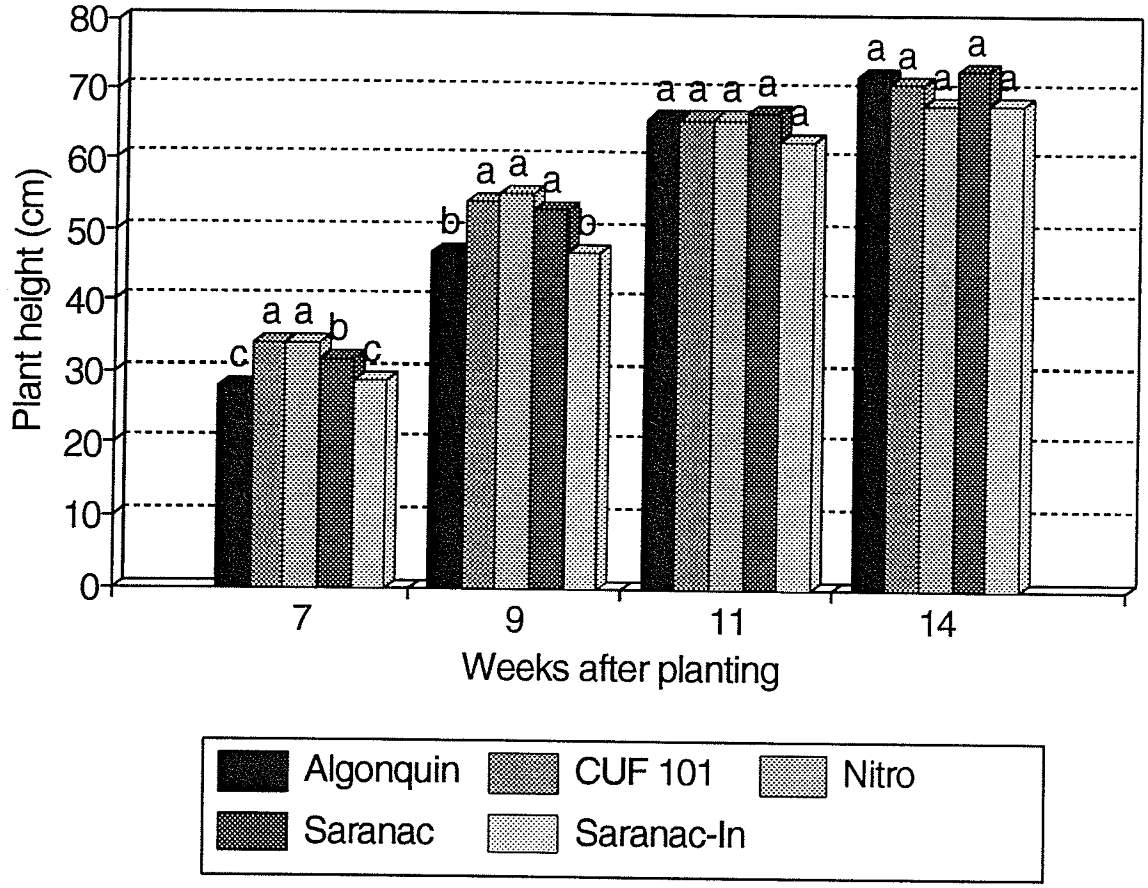

Figure 1. Plant height of five alfalfa cultivars at different weeks after planting (averaged over locations and seeding rates) when grown for establishment year seed production in southern Manitoba in 1992. Within series (weeks after planting), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

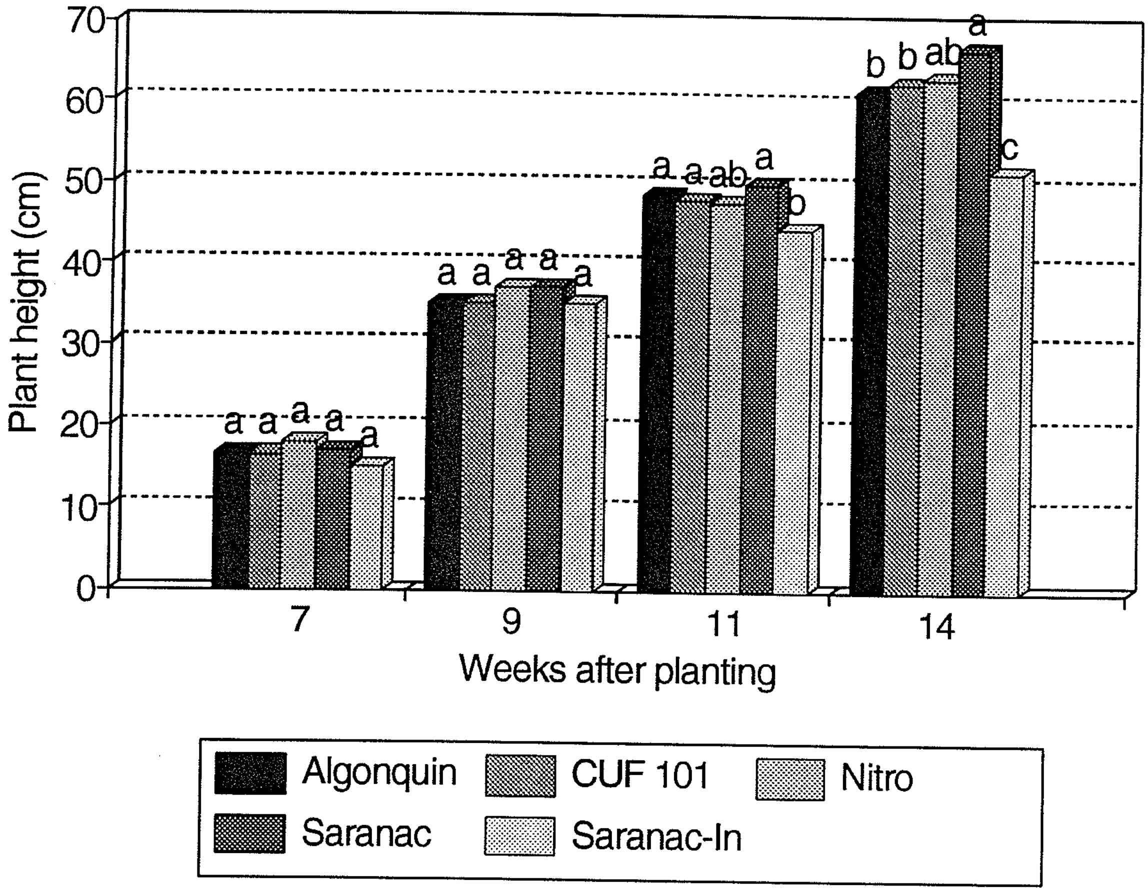

Figure 2. Plant height of five alfalfa cultivars at different weeks after planting (averaged over seeding rates) when grown for establishment year seed production at Glenlea in southern Manitoba in 1993. Within series (weeks after planting), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

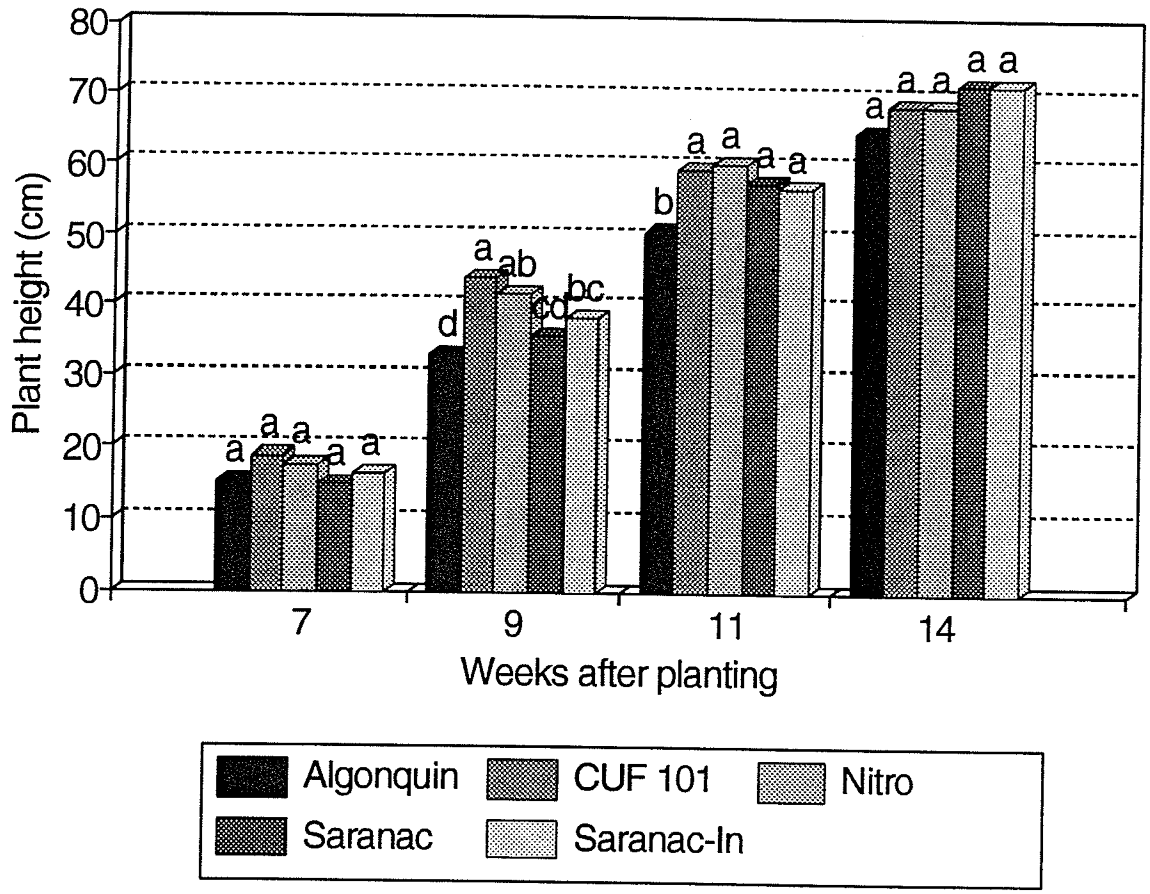

Figure 3. Plant height of five alfalfa cultivars at different weeks after planting (averaged over seeding rates) when grown for establishment year seed production at Homewood in Southern Manitoba in 1993. Within series (weeks after planting), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 1. Plant Height (cm) of alfalfa (averaged over locations and cultivars) at different dates when seeded at two seeding rates for establishment year seed production at Homewood and Glenlea in southern Manitoba in 1993.

	Weeks after planting			
Seeding rate‡	7	9	11	14
	Glenlea			
	---------- cm ----------			
High	16.4a‡	35.5a	44.7b	56.2b
Low	16.9a	36.3a	50.6a	66.0a
	Homewood			
	---------- cm ----------			
High	17.7a	41.5a	58.0a	67.0b
Low	15.5a	35.4b	55.6a	70.6a

† Seeding rates (SR) are: High (16.8 kg ha^{-1}) and Low (3.36 kg ha^{-1}).

‡ Within a column (weeks after planting), in each location, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 2. Flowering percentage of five alfalfa cultivars averaged over two locations and two seeding rates at different dates when grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992.

Cultivar	Scoring date			
	July 21	July 24	July 29	August 5
	------------------Flowering (%)†------------------			
Algonquin	7a‡	11c	18c	35a
CUF 101	14a	22b	32b	42a
Nitro	12a	24b	34b	46a
Saranac	10a	22b	35b	51a
Saranac-In	15a	40a	56a	55a

† Flowering percentage was determined as the percentage of the number of stems with at least one open flower within a sub-sub-plot.

‡ Within a column, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 3. Seed yield (kg ha^{-1}) of five alfalfa cultivars for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992 and 1993.

Year	Cultivar				
	Algonquin	CUF 101	Nitro	Saranac	Saranac-In
	kg ha^{-1}				
1992†	54a‡	22b	26b	57a	26b
1993	13a	2a	4a	21a	4a

† Seed was not harvested from Homewood in 1992.
‡ Within a row (year), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 4. Total (herbage and root plus crown) and root plus crown dry matter (DM) yield (kg ha^{-1}) of alfalfa for different growth stages when grown at two seeding rates during establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992.

Seeding rate‡	Growth stages†			
	LV	T%B	F%B	Seed
	Total (herbage and root plus crown) DM yield			
	--------------------kg ha^{-1}--------------------			
High	1788a§	4790a	5575a	5733a
Low	1592a	4173a	5039a	5439b
	Root plus crown DM yield			
	--------------------kg ha^{-1}--------------------			
High	454a	1468a	1966a	2471a
Low	382a	1179b	1752a	2170a

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Seeding rates are: High (16.8 kg ha^{-1}) and Low (3.36 kg ha^{-1}).
§ Within a column (growth stage), and for each trait measured, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 5. Total (herbage and root plus crown) dry matter yield of five alfalfa cultivars (averaged over locations and seeding rates) at different growth stages when grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992.

Cultivars	Growth stages†			
	LV	T%B	F%B	Seed
	kg ha^{-1}			
Algonquin	1426bc‡	4601a	5028a	5326a
Saranac	1760abc	4633a	6083a	6101a
Nitro	2116a	4889a	5589a	6438a
CUF 101	1854ab	4844a	5512a	6363a
Saranac-In	1294c	3440a	4322a	3748a
CV (%)§	26	28	27	31

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a row (growth stage), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Coefficient of variation (%).

Table 6. Total (herbage and root plus crown) and root plus crown dry matter (DM) yield (kg ha^{-1}) of alfalfa for different growth stages when grown at two seeding rates (SR) during establishment year seed production at Glenlea and Homewood in southern Manitoba in 1993.

Location	SR‡	Growth stages† LV	T%B	F%B	Seed
		Total (herbage and root plus crown) DM yield			
		---kg ha^{-1}---			
Glenlea	High	1722a§	2092a	3735a	3846a
	Low	1224a	1786a	3872a	4021a
Homewood	High	1739a	2777a	4033a	4372a
	Low	1064a	2509a	3177a	4075a
		Root plus crown DM yield			
		---kg ha^{-1}---			
Glenlea	High	692a	827a	1396a	1701a
	Low	488a	691b	1297a	1701a
Homewood	High	693a	1003a	1558b	1870a
	Low	444a	819a	1085a	1625a

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Seeding rates (SR) are: High (16.8 kg ha^{-1}) and Low (3.36 kg ha^{-1}).
§ Within a column (growth stage), and for each trait measured, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 7. Total (herbage and root plus crown) dry matter yield of five alfalfa cultivars (averaged over seeding rates) at different growth stages (GS) when grown for establishment year seed production at Glenlea in southern Manitoba in 1993.

Cultivars	Growth stages†			
	LV	T%B	F%B	Seed
	kg ha^{-1}			
Algonquin	1800a‡	2775a	4732a	4232a
Saranac	1440a	2634a	4805a	4189a
Nitro	1783a	2116b	4217ab	4360a
CUF 101	1386a	1806b	3682b	4490a
Saranac-In	848b	1041c	1678c	1992b
CV (%)§	31	18	24	26

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a column (growth stage), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Coefficient of variation (%).

Table 8. Total (herbage and root plus crown) dry matter yield of five alfalfa cultivars (averaged over seeding rates) at different growth stages (GS) when grown for establishment year seed production at Homewood in southern Manitoba in 1993.

Cultivars	Growth stages†			
	LV	T%B	F%B	Seed
	----------kg ha^{-1}----------			
Algonquin	1091a‡	2581bc	3646abc	4830a
Saranac	1255a	3279a	4626a	4837a
Nitro	1660a	2174c	3136bc	4152ab
CUF 101	1639a	2852ab	4061ab	4314a
Saranac-In	1438a	2403bc	2629c	3040b
CV (%)§	37	22	31	25

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a column (growth stage), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Coefficient of variation (%).

Table 9. Root plus crown dry matter yield of five alfalfa cultivars (averaged over locations and seeding rates treatment) at different growth stages when grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992.

Cultivars	Growth stages†			
	LV	T%B	F%B	Seed
	-------------	----------kg ha^{-1}	----------	-------------
Algonquin	337c‡	1148a	1662a	2184a
Saranac	427b	1321a	2042a	2517a
Nitro	504a	1547a	1966a	2472a
CUF 101	482a	1573a	2067a	2765a
Saranac-In	379c	1028a	1527a	1664a
CV (%)§	29	30	32	35

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a row (growth stage), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Coefficient of variation (%).

Table 10. Root plus crown dry matter yield of five alfalfa cultivars (averaged over locations and seeding rates treatment) at different growth stages when grown for establishment year seed production at Glenlea in southern Manitoba in 1993.

Cultivars	Growth stages†			
	LV	T%B	F%B	Seed
	---------kg ha^{-1}---------			
Algonquin	673a‡	916a	1548a	1622b
Saranac	548ab	900a	1547a	1707ab
Nitro	702a	806a	1533a	2059a
CUF 101	609a	729a	1367a	1957ab
Saranac-In	377b	467b	770b	1024c
CV (%)§	32	23	27	23

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a column (growth stage), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Coefficient of variation (%).

Table 11. Root plus crown dry matter yield of five alfalfa cultivars (averaged over locations and seeding rates treatment) at different growth stages when grown for establishment year seed production at Homewood in southern Manitoba in 1993.

Cultivars	Growth stages†			
	LV	T%B	F%B	Seed
	------------------kg ha^{-1}-------------------			
Algonquin	460a‡	806b	1184ab	2081a
Saranac	537a	1108a	1660a	2019a
Nitro	648a	768b	1114b	1737ab
CUF 101	638a	1097a	1528ab	1532b
Saranac-In	585a	830b	1134b	1397b
CV (%)§	30	23	35	25

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a column (growth stage), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Coefficient of variation (%).

Table 12. Total (herbage and root plus crown) and root plus crown N yield (Kg ha^{-1}) of alfalfa for different growth stages when grown at two seeding rates for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992.

	Growth stages†			
Seeding rate‡	LV	T%B	F%B	Seed
	Total (herbage and root plus crown) N yield			
	---------------kg N ha^{-1}---------------			
High	54.5a§	145.6a	141.8a	142.5a
Low	50.6a	115.0a	134.1a	134.3a
	Root plus crown N yield			
	---------------kg N ha^{-1}---------------			
High	19.4a	39.3a	51.7a	64.0a
Low	8.1a	31.8a	48.8a	55.1a

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Seeding rates (SR) are: High (16.8 kg ha^{-1}) and Low (3.36 kg ha^{-1}).
§ Within a column (growth stage), and for each measured trait, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 13. Total (herbage and root plus crown) N yield of five alfalfa cultivars (averaged over seeding rates) at different growth stages (GS) when grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992.

Cultivars	Growth stages†			
	LV	T%B	F%B	Seed
	kg N ha^{-1}			
Algonquin	48a‡	143a	137a	132a
Saranac	57a	135a	154a	150a
Nitro	66a	150a	142a	168a
CUF 101	57a	143a	147a	161a
Saranac-In	36b	82a	110a	83a
CV (%)§	28	30	33	33

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a column (growth stage), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Coefficient of variation (%).

Table 14. Total (herbage and root plus crown) and root plus crown N yield (Kg ha^{-1}) of alfalfa for different growth stages when grown at two seeding rates (SR) for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1993.

		Growth stages†			
Location	SR‡	LV	T%B	F%B	Seed
		Total (herbage and root plus crown) N yield			
		---kg N ha^{-1}---			
Glenlea	High	58a§	60a	96a	97a
	Low	41b	54a	103a	103a
Homewood	High	53a	64a	86a	103a
	Low	35a	61b	74a	101a
		Root plus crown N yield			
		---kg N ha^{-1}---			
Glenlea	High	15.7a	18.7a	26.1a	40.2a
	Low	11.3a	14.0b	25.3a	44.7a
Homewood	High	15.5a	17.0a	27.8a	42.5a
	Low	10.3a	14.3a	20.7b	40.6a

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Seeding rates (SR) are: High (16.8 kg ha^{-1}) and Low (3.36 kg ha^{-1}).
§ Within a column (growth stage), and for each trait measured, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 15. Total (herbage and root plus crown) N yield of five alfalfa cultivars (averaged over seeding rates) at different growth stages (GS) when grown for establishment year seed production at Glenlea in southern Manitoba in 1993.

Cultivars	Growth stages†			
	LV	T%B	F%B	Seed
	---------------------kg N ha^{-1}	---------------------		
Algonquin	61a‡	80a	130a	115a
Saranac	49a	73ab	125a	110a
Nitro	62a	65bc	114ab	113a
CUF 101	48a	53c	97b	114a
Saranac-In	24b	21d	34c	34b
CV (%)§	29	18	25	31

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a column (growth stage), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Coefficient of variation (%).

Table 16. Total (herbage and root plus crown) N yield of five alfalfa cultivars at two seeding rates (SR) for the late vegetative growth stage when grown for establishment year seed production at Glenlea in southern Manitoba in 1993.

	Cultivar				
SR†	Algonquin	CUF 101	Nitro	Saranac	Saranac-In
	-------------------------kg ha^{-1}-------------------------				
High	75a	53b	74a	63ab	15c
Low	48a	43a	50a	36a	30a

† Seeding rates (SR) were as follows: High (16.8 kg ha^{-1}) and Low (3.36 kg ha^{-1}).
‡ Within a row, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 17. Total (herbage and root plus crown) N yield of five alfalfa cultivars (averaged over seeding rates) at different growth stages when grown for establishment year seed production at Homewood in southern Manitoba in 1993.

Cultivars	Growth stages†			
	LV	T%B	F%B	Seed
	kg N ha^{-1}			
Algonquin	37a‡	61bc	87a	124a
Saranac	41a	83a	100a	118a
Nitro	53a	54bc	79a	107a
CUF 101	50a	72ab	96a	108a
Saranac-In	39a	46c	42b	49b
CV (%)§	35	26	39	25

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a column (growth stage), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Coefficient of variation (%).

Table 18. Root plus crown N yield of five alfalfa cultivars (averaged over seeding rates) at different growth stages when grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992.

Cultivars	Growth stages†			
	LV	T%B	F%B	Seed
	----------kg N ha^{-1}----------			
Algonquin	7.8bc‡	30.3bc	46.6a	58.9a
Saranac	9.9ab	34.2abc	53.9a	66.1a
Nitro	12.3a	49.2a	55.9a	68.8a
CUF 101	10.7ab	46.2ab	59.5a	69.5a
Saranac-In	5.5c	7.8c	35.4a	34.7a
CV (%)§	33	36	41	35

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a column (growth stage), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Coefficient of variation (%).

Table 19. Root plus crown N yield of five alfalfa cultivars (averaged over seeding rates) at different growth stages when grown for establishment year seed production at Glenlea in southern Manitoba in 1993.

Cultivars	Growth stages†			
	LV	T%B	F%B	Seed
	----------kg N ha^{-1}----------			
Algonquin	14.6a‡	19.9a	30.3a	42.7b
Saranac	12.3ab	19.9a	29.8a	42.2b
Nitro	16.7a	20.7a	31.8a	59.0a
CUF 101	15.1a	16.6a	27.8a	49.0ab
Saranac-In	7.7b	6.2b	9.6b	14.3c
CV (%)§	34	24	29	27

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a column (growth stage), means followed by the same letter are not significantly different based on Fisher's protected LSD (P≤ 0.05).
§ Coefficient of variation (%).

Table 20. Root plus crown N yield of five alfalfa cultivars (averaged over seeding rates) at different growth stages when grown for establishment year seed production at Homewood in southern Manitoba in 1993.

Cultivars	Growth stages†			
	LV	T%B	F%B	Seed
	kg N ha^{-1}			
Algonquin	11.1a‡	13.8a	23.2ab	53.2a
Saranac	13.2a	20.4a	30.4a	48.8ab
Nitro	15.5a	13.9b	23.7ab	40.1b
CUF 101	14.7a	20.8a	30.3a	42.9ab
Saranac-In	10.6a	10.9b	14.1b	21.7c
CV (%)	30	22	41	25

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a column (growth stage), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Coefficient of variation (%).

Table 21. Percentage nitrogen derived from atmosphere (% Ndfa) of alfalfa (averaged over seeding rates and cultivars) at different growth stages (GS) when grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992 and 1993.

Year	Location	GS†	Root+crown	Herbage	Total
			----------------	% Ndfa	---------------
1992	Glenlea	LV	45	49	50
		T%B	68	63	64
		F%B	55	47	50
		Seed‡	65	64	65
	Homewood	LV	35	24	25
		T%B	35	14	20
		F%B	24	17	23
		Seed‡	22	20	20
1993	Glenlea	LV	54	58	56
		T%B	65	66	66
		F%B	66	71	70
		Seed	64	65	64
	Homewood	LV	24	18	19
		T%B	36	30	31
		F%B	43	51	49
		Seed	49	54	53

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ In 1992, at mature seed stage, there was a location effect ($P \leq 0.05$) for root plus crown, herbage and total (roots and crowns) %Ndfa.

Table 22. Symbiotic N_2 fixation by alfalfa (averaged over seeding rates and cultivars) at different growth stages when grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992 and 1993.

Year	Location	GS	Root+crown N	Herbage N	Total N
			----------------	kg N ha^{-1}	----------------
1992	Glenlea	LV	7	21	28
		T%B	29	64	93
		F%B	29	43	72
		Seed‡	47	60	107
	Homewood	LV	3	14	17
		T%B	17	20	37
		F%B	17	17	34
		Seed‡	19	21	40
1993	Glenlea	LV	9	26	35
		T%B	13	33	46
		F%B	20	63	83
		Seed	31	47	78
	Homewood	LV	4	7	11
		T%B	7	18	25
		F%B	13	37	50
		Seed	25	40	65

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ In 1992, at mature seed stage, there was an effect ($P \leq 0.05$) of location for herbage and total (herbage and roots plus crowns) symbiotic N_2 fixation.

Table 23. Total (herbage and roots plus crown) symbiotic N_2 fixation of four alfalfa cultivars (averaged across seeding rate) at 50%- to full flowering stage when grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1993.

	Cultivar			
Location	Algonquin	CUF 101	Nitro	Saranac
	$kg\ ha^{-1}$			
Glenlea	97a†	63a	81a	91a
Homewood	46a	55a	40a	59a

† Within a row, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 24. Mean squares for wheat grain, straw and nitrogen yield as influenced by previous year alfalfa cultivar (at two seeding rates) and a wheat control at Glenlea and Homewood in southern Manitoba in 1993.

Source	Mean squares†		
	Grain yield	Straw yield	N-yield
Location	20826282 ***	55242400 *	55811 **
Rate	280539 NS	47714 NS	30 NS
Cultivar	116879 NS	875271 NS	379 NS
Location*Cultivar	268412 **	478504 NS	826 *
Rate*Cultivar	74896 NS	1543745 NS	926 *
Location*rate*cultivar	20699 NS	448951 NS	98 NS
Residual error	158043 ***	830492 ***	440 NS

† The above ANOVA was conducted using a mixed statistical model. Location was treated as random factor and seeding rate and cultivar were considered fixed effects.

*, **,*** Significance at P≤ 0.05, 0.01 and 0.001 level, respectively and NS = non-significance.

Tables 25. Grain yield, straw dry matter yield and total nitrogen yield of wheat following a one year alfalfa stand managed for seed production and a wheat control at two locations in southern Manitoba in 1993.

Location	Grain yield	Straw yield	Total N-yield
	--------------kg ha^{-1}------------		---kg N ha^{-1}---
Homewood	1914a†	5908a	130a
Glenlea	907b	4252b	78b

† Within a column, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 26. Grain yield and nitrogen yield associated with previous year alfalfa cultivars managed for seed production and a wheat control at two locations in southern Manitoba in 1993.

Location	Treatment	Grain yield	N yield
		$kg\ ha^{-1}$	$kg\ N\ ha^{-1}$
Homewood	Algonquin	1920	133
	Saranac	1787	121
	CUF 101	1990	139
	Nitro	2004	132
	Saranac-In	2071	137
	Wheat	1714	121
Glenlea	Algonquin	574†	79
	Saranac	831	81
	CUF 101	781	74
	Nitro	998	92
	Saranac-In	925	63
	Wheat	1173	79

† Failure to completely control previous alfalfa crop for same cultivars resulted in excess competition with wheat that influenced grain yield.

Table 27. Nitrogen yields of wheat associated with previous year alfalfa cultivars grown at two seeding rates and two locations in southern Manitoba in 1993.

Trts†	Alfalfa cultivars and Wheat					
	Algonquin	Saranac	CUF 101	Nitro	Saranac-In	Wheat
	----------	----------	(kg N ha^{-1})	----------	----------	----------
High	113(2)‡	111(3)	95(5)	115(1)	92(6)	101(4)
Low	110(2)	94(5)	124(1)	110(2)	102(3)	99(4)

† The treatments (Trts) consisted of low (3.36 kg ha^{-1}) and high (16.8 kg ha^{-1}) seeding rate for the alfalfa cultivars from the previous year.

‡ There was no differences between cultivars, but cultivar ranking for each seeding rate is enclosed in parentheses.

4. Agronomic Practices for Alfalfa Seed Production in the establishment year

4.1. ABSTRACT

Alfalfa (*Medicago sativa* L.) seed production is an important industry in western Canada, but because most seed is produced in the years following establishment, further industry expansion is limited to alternative cultivars than can survive the winter. The development of a seed production system that enables seed production during the year of establishment would be beneficial and allow industry to expand the seed production through utilization of moderately dormant and non-dormant cultivars. The objectives of this research were to determine the effect of the seeding rate, clipping management and cultivar on alfalfa seed yield components on establishment year seed production. Field experiments were established at two seeding rates, 1.12 kg ha^{-1} and 3.36 kg ha^{-1}, with two clipping treatments (clipped and unclipped) and three cultivars (CUF 101, Cimarron VR, and Algonquin) at Glenlea and Homewood in southern Manitoba in 1992 and 1993. Flowering percentage and racemes per metre of row were highest for Cimarron VR. There was no influence of clipping treatment or seeding rate on plant height (later part in the growing season), flowering percentage, number of racemes per metre of row, number of pods per raceme and seed yield. Although clipping reduced lodging, it also delayed flowering and, therefore, it is not recommended for establishment year seed production. Dormant, moderately dormant and non-dormant cultivars had similar seed yield. The seed yield components were

important because they are predictors of potental seed yield. This was particularly of importance in both years of this study because adverse environmental conditions directly influenced pollination, seed set, seed development, seed maturation and final seed yield. The seed yield obtained was below provincial average in both years. This research will provide basic information on the agronomic requirements of an establishment-year-seed crop. However, the seed yield obtained was similar to that from established stands in Manitoba in both year, suggesting that other factors beside the production system affected the results. The main factor was the prevailing environmental conditions during both the growing season.

1. INTRODUCTION

Alfalfa (*Medicago sativa* L.) is a perennial forage legume that is grown for stored feed, pasture and seed production. In addition, it is an important component of many crop rotations, where it is known to increase soil N and organic matter (Sheaffer *et al*., 1989). In the western Canadian provinces of Manitoba, Saskatchewan and Alberta alfalfa seed production is an important enterprise (Fairey and Lefkovitch, 1992: Smith, 1992) worth 25 million dollars annually.

Alfalfa seed production in western Canada involves establishing the crop during first year and harvesting seed during the subsequent years. Therefore, seed production has been restricted almost exclusively to winterhardy, fall dormant cultivars (Fairey and Lefkovitch, 1991, 1992). Moderately dormant and non-dormant cultivars rarely survive the winter in western Canada, therefore seed production of these cultivars is not possible under current practices. Therefore, the development of a seed production system that enables seed production during the year of establishment would be beneficial.

There several other advantages from producing an alfalfa seed crop in the establishment year. Seed production in the establishment year would enable producers and companies specializing in seed multiplication, the opportunity to produce seed from most cultivars including non-dormants. In addition, it would provide a management system for introducing alfalfa as an "annual" in rotations with other cereals and oilseed crops. This could significantly increase the number of hectares planted for alfalfa seed production.

Alfalfa seed crops are normally established at lower seeding rate in comparison to hay crops in order to maximize seed yield (Rincker *et al.*, 1988). Clipping alfalfa plants early in the vegetative stage is a potential practice to reduce excessive growth which causes lodging, reduce the growth of weeds, and stage flowering.

A study was conducted during the 1992 and 1993 growing season at two sites, Homewood and Glenlea, in southern Manitoba. The research was initiated with the working hypothesis that alfalfa seed production during the establishment year is possible in western Canada. This hypothesis is based on the apparent suitability of average environmental conditions for growth of alfalfa in the primary seed producing regions including growing degree days, growing season, temperature, solar irradiance and precipitation. The specific objectives of this research were: 1) to compare seed yield of non-dormant, moderately dormant and early fall dormant alfalfa cultivars during the year of establishment and 2) to determine the effect of seeding rate and clipping management on alfalfa seed yield and seed yield components.

4.3. MATERIALS AND METHODS

Field experiments were conducted to study the effects of clipping treatment, seeding rate and cultivar on seed yield and seed yield components of alfalfa. The experiments were established in the spring of 1992 and 1993 at three locations in Manitoba: Homewood (56 km southwest of Winnipeg), Glenlea (15 km south of Winnipeg), and Arborg (150 km north of Winnipeg). The experimental plots were established on 7 May, 13 May and 22 May, 1992 at Homewood, Glenlea and Arborg, respectively, and at the same sites on 12 May, 5 May and 14 May, 1993, respectively. The soil type at Homewood was a Sperling mixed loam, at Glenlea a Red River clay (lacustrine fine clay) and at Arborg a Tano series clay (Peat meadow). The experiment at Arborg did not reach reproductive maturity during either year due to flooding in 1992 and cool temperature in 1993, therefore this paper will only present results for the Homewood and Glenlea sites.

Soil tests were conducted at each experimental site during fall 1991 and 1992 to determine the nutrient requirements of an alfalfa seed crop. Phosphorus was applied as 0-46-0 fertilizer at a rate of 20 kg ha^{-1} of P_2O_5 . In addition sulphur was also applied at soil test recommendations.

The alfalfa seed industry uses a 1-9 rating system to differentiate the fall dormancy of individual cultivars with "1" designating those cultivars that show the least growth during the fall and "9" those cultivars that show the most fall growth (Barnes *et al.*, 1991). For the purpose of this experiment cultivars with fall dormancies from 1-3 were considered dormant, 4-5 moderately dormant and 6-9 non-dormant. The cultivars, Algonquin, Cimarron VR and CUF 101 were selected to represent their respective fall dormancy classes.

These experiments were established at two seeding rates, 1.12 kg ha^{-1} and 3.36 kg ha^{-1}. The three alfalfa cultivars that were used for this experiment and their respective fall dormancy classes are as follows: 'CUF 101' (9), a non dormant cultivar of Indian and African origin (Gilchrist *et al.*, 1982), 'Algonquin' (2), a winterhardy, 16-clone synthetic developed at the Agriculture Canada Research Station, Ottawa, Ontario (Baenziger, 1975) and 'Cimarron VR' (4.5), a moderately dormant cultivar (Alfalfa Variety Review Board, 1989).

The experimental design was a randomized block design with a split-split-plot treatment arrangement and four replications. Clipping was assigned to main plots, seeding rate was assigned to the main sub-plots and cultivar to the sub-sub-plots. One half of each block was mowed (clipped) using a garden mower to act as a staging treatment for flowering and to promote tillering of individual plants, 6 weeks after planting. Each sub-plot was 1.8 m by 5 m, with a 30 cm row spacing. In 1993, a row spacing of 45 cm was used. The seeding rate of 3.36 kg ha^{-1} was included in the study to evaluate whether a higher than recommended rate might be an advantage for establishment year seed crop. The seeds were inoculated before planting with *Rhizobium meliloti* L. Dang.

In this experiment, weed control was accomplished using a combination of chemicals, cultivation and hand weeding. Specific herbicides used included: 1) pre-emergence herbicides: Edge 50 DF (Ethalfluralin) or [N-ethyl-N-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl) benzenamine] and Treflan (Trifluralin) or {2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine}; 2) post-emergence: Pursuit (Imazethapyr) or {2-[4,5-dihydro-4-methyl-4-(1-methylenthyl)-5-oxo-1H-imididazol-2-yl]-3-pyridinecarboxylic acid} and Poast (Sethoxydim) or {2-[1-(ethoxyimino)]-5-[2-(ethylthio)propyl]-3-hydroxy-2 cyclohexen-1-one} and Roundup (Glyphosate) or {isopropylamine salt of N-(phosphono-methyl) glycine}. These herbicides were used to control annual grassy and broadleaf weeds with the exception of Roundup which was spot applied in both years to control Canada thistle. Ethalfluralin and trifluralin were applied in the spring and incorporated with a cross directional cultivation one week before planting. Imazethapyr was applied on 2 June and 11 June, 1992 at Homewood and Glenlea, respectively. Poast was applied on 7 July and 9 July, 1993. The herbicides were applied at recommended rates, except in 1993, where Pursuit was accidentally applied at ten times the recommended rate.

Scouting for insects was done frequently to check for any alfalfa pests. Lygus bug, alfalfa plant bug, pea aphid, and other insect control was achieved with Cygon (Dimethoate) or [o,o-dimethyl S-(methylcarbamoylmethyl) phosphorodithioate] and Dylox (trichlorfon) or [dimethyl (2,2,2-trichloro-1-hydroxyethyl) phosphonate]. Some insecticides are harmful to alfalfa leafcutting bees, therefore, Dimethoate was sprayed one week before bee release and Dylox was applied at night when the bees were dormant in their shelters. Dimethoate was applied on 26 July, 1992 at both site and 5 July and 9 July, 1993 at Homewood and Glenlea, respectively, and Dylox was applied on 29 July, 1993. The control of these insects was effective and insect damage had no influence on seed production, as subsequent scouting showed that the insects were below the threshold level that may cause any substantial damage.

Alfalfa leafcutting bees were used for pollination in both years. Six leafcutter shelters were placed around the periphery and in the centre of the entire area which included two other experiments. Incubation trays containing recently emerged bees were placed in each shelter when the flowering averaged 25% across the experiment. Additional leafcutter bees were placed on the experiments at the 100% flowering stage to insure a bee population of 88,000 ha^{-1} and makes bees not to be limiting factor in seed set.

Morphological traits associated with alfalfa seed yields measured included: 1) seedling vigour score, 2) plant height, 2) % flowering, 4) lodging, and 5) stem counts. Stem counts were made on the basis of the number of green stems from two 1 m sections of row randomly chosen from each sub-sub-plot at the 50 % flowering stage. Seedling vigour scores were taken on 10 June, 1992 and on 10 June, 1993 at both locations. Scoring was based on a 1 to 5 range with "1" corresponding to least vegetative growth and "5" corresponding to the greatest vegetative growth.

Plant height was measured at approximately 7, 9, 11 and 14 weeks after planting beginning 28 June, 1992 and 29 June, 1993. Fifteen stems were randomly selected from each sub-sub-plot for plant height measurements in 1992 but reduced to ten stems per sub-sub-plot in 1993. Starting in mid-July of each year flowering percentage (number of stems with flowers) was recorded at weekly intervals until plants reached approximately 100% bloom. Lodging was scored in mid-September with scores ranging from 1 to 5, with: "1"= 0%-20% of stem lodged in horizontal position, "2"= 21% to 40% of stem lodged in horizontal position, "3"=41% to 60% of stem lodged in horizontal position, "4"= 61% to 80% of stem lodged in horizontal position and "5" indicating that over 80% of stems were lodged in a horizontal position. In 1993, there was very little lodging, therefore this score was not recorded.

Racemes per stem (racemes $stem^{-1}$) and racemes forming pods were measured on fifteen randomly selected stems in 1992 and ten in 1993 starting approximately at the 50 % flowering stage. In both years racemes measurements were initiated during mid-August and continued every two weeks until harvest.

Pods per raceme was measured by counting the number of pods on 30 racemes randomly selected per sub-sub-plot at harvest in 1992. This measurement was not taken in 1993 due to low pod set. Seeds per pod was measured from the same 30 randomly sampled racemes in 1992.

The desiccant Harvest [(2-amino-4-(hydroxymethylphosphinyl) butanoic acid] was sprayed at Homewood and Glenlea on 28 and 30 September, 1992, respectively. Four rows from each plot were direct harvested with a Hege-plot combine in Homewood and Glenlea on 7 October and 9 October to determine total seed yield. In 1993, desiccant was sprayed at Glenlea and Homewood on 24 September, 1993. Seed was harvested at Glenlea by hand picking all mature pods from the plants on 5 October, 1993. No seed were available for harvest at Homewood in 1993 due to the severe weather conditions which resulted in severe flooding damage.

Analysis of variance (ANOVA) was conducted by GLM procedure of the Statistical Analysis Systems procedure (SAS Institute, 1988) with all treatments considered fixed effects, except locations. Bartlett's Chi-square test (Steel and Torrie, 1960) was used to determine homogeneity of variance across years and locations. In all cases variances did not meet the criteria for homogeneity across years, and data transformation did not solve the problem, therefore data analysis was conducted within each year. Data variances were homogeneous over locations within years therefore the data was pooled over locations in each year. Analysis were conducted with block, clipping treatment, seeding rate and cultivars considered fixed effects and location considered a random effect. Treatment means were compared using Fisher's protected least significant difference procedure.

4.4. RESULTS

4.4.1. Seedling Vigour

There was no effect of location and seeding rate on seedling vigour in either year, nor were there interactions between treatments (data not shown). Cultivar ranking for seedling vigour in 1992 and 1993 placed CUF 101 highest, followed by

Cimarron VR and Algonquin, although cultivar differences were significant only in 1993 (Table 1 and 2). Seedling vigour is agronomically important because it provides a relative measure of establishment success and competitiveness with weeds.

4.4.2. Plant Height

Statistical analysis was not performed over years due to non-homogeneity of error variances, but plants of all cultivars were taller in 1992 than 1993 (Figure 1). Heights of cultivar did not differ in either year with the exception of 7 weeks after planting in 1993 (Figure 2 and 3). At this measurement date, the plant height of CUF 101 and Cimarron VR was equivalent (16 cm vs. 15 cm), but taller than Algonquin (13 cm). In both years cultivar ranking for plant height from highest to lowest followed general trend: CUF 101, Cimarron VR and Algonquin. However, at 11 weeks after planting in 1992 and at 14 weeks after planting in 1993 the ranking from highest to lowest height was: Cimarron VR, CUF 101 and Algonquin. Plant growth was rapid during the 7 to 14 week period after planting with a 3.5 fold increase in 1992 and 3.8 in 1993.

There was a location effect on plant height in 1992 at 9 weeks after planting [Homewood (47 cm) and Glenlea (37 cm)] and in 1993 at 9 [Homewood (32 cm) and Glenlea (25 cm)] and 14 weeks after planting [Homewood (67 cm) and Glenlea (48 cm)]. In both years, plant height was higher at Homewood in comparison to Glenlea (data not shown). Clipping treatment did not influence plant height in 1993, but did influence plant height at the 9 weeks after planting in 1992 [unclipped treatment (48 cm) and clipped treatment (36 cm)]. Plants were taller in the unclipped treatment versus the clipped treatment during both years (data not shown). Seeding rate only influenced plant height at 9 weeks after planting in 1993 [high seeding rate (29 cm) and low seeding rate (27 cm)].

There were very few interactions between treatments for plant height with the exception of clipping*cultivar at 7 weeks after planting in 1992 and clipping*seeding rate at 11 weeks after planting in 1992 and 1993. The clipping*cultivar interaction at 7 weeks after planting in 1992 was likely due to differences in cultivar height for the unclipped plants. Plant height ranking between the clipped (C) and unclipped (UC) treatments was as follows: CUF 101 (C-17 cm, UC-32 cm), Algonquin (C-16.5 cm, UC-27cm) and Cimarron VR (U-15 cm, UC-30 cm).

The relationship between clipping and seeding rate was most obvious at the 11 week measurement date in 1992 and 1993. In 1992, average plant height after clipping was 67 cm and 63 cm at the high and low seeding rates, respectively, where as the unclipped treatments were 71 cm and 70 cm at the above seeding rates. Clipping had a similar influence on plant height in 1993 with clipping treatments at 44 cm and 41 cm and unclipping treatments at 47 cm and 44 cm for the high and low seeding rate respectively.

4.4.3. Flowering

There was no influence of location, clipping treatment or seeding rate (data not shown) on flowering percentage in either year, with the exception of a cultivar effect on 29 July and 5

August, 1992 (Table 3). At both dates Cimarron VR had the highest flowering percentage followed by CUF 101 and Algonquin. Although there were no cultivar differences in 1993, the ranking was similar to 1992 at all scoring dates. For example, flowering percentage on 5 August, 1993 was as follows: Cimarron VR (41%), CUF 101 (35%) and Algonquin (31%).

Initial flowering occurred at approximately the third week of July in both years. Flowering percentage was closely related to date of first flower with Cimarron VR flowering earliest, followed by CUF 101 and Algonquin (data not shown), but the interval from first to last flowering date was only 2-4 days.

There was a location*clipping interaction for flowering percentage on 24 July, with 0% and 1% for clipped treatments and 10% and 35% for unclipped treatments at Glenlea and Homewood, respectively. On 29 July 1992, there was a clipping*cultivar interaction for flowering percentage. The unclipped cultivar treatments had a higher flowering percentage [Cimarron VR (51%), CUF 101 (38%) and Algonquin (30%)] in comparison to the clipped cultivar treatments [Cimarron VR (4.3%), Algonquin (3%) and CUF 101 (2.5%)].

There was a location*clipping*cultivar interaction on 24 July, 1992 with clipping substantially reducing flowering at both sites (Table 4). For the unclipped treatments at Homewood, Algonquin had the lower flowering percentage than Cimarron VR and CUF 101. When plants were unclipped, the flowering was higher for all cultivars at Homewood versus Glenlea, but cultivar ranking was constant. There was also a location*clipping*cultivar interaction for flowering percentage on 5 August, 1992 (Table 4). However, the flowering percentage for the clipped treatments was higher for all cultivars at Homewood versus Glenlea, with a different cultivar ranking (Table 4). Cultivar differences were present for flowering percentage at this date and it shows that Cimarron VR had the best flowering ability. Flowering percentage for unclipped treatments was also higher at Homewood than Glenlea for CUF 101 and Algonquin, but Cimarron VR had similar flowering percentages at both sites.

4.4.4. Lodging

Cool temperatures and adequate moisture in 1992 provided the kind of a growing conditions which resulted in excessive plant growth and subsequent lodging at both locations. Although lodging had a negative influence on seed yield in 1992, all cultivars showed a similar amount of lodging (Table 1). However, clipping reduced lodging, and lodging score on a 5-point scale were [clipped (1.2) and unclipped (2.4)]. There were no interactions for lodging between any of the experimental treatments. Also, there was little or no lodging in 1993.

4.4.5. Seed Yield And Seed Yield Components

4.4.5.1. Stems per m^{-1} of row

The number of stems m^{-1} of row was measured at full flowering in both years as a component of seed yield. The number of stem m^{-1} of row was not affected by location, clipping treatment or seeding rate (data not shown). Number of stems m^{-1} of row was analyzed over years due to heterogeneous error variances, but tended to be higher in 1993 than in 1992 (Tables 1 and 2). Cultivar differences were present in 1993 with CUF 101 producing the greatest number of stems m^{-1} of row followed by Cimarron VR and Algonquin. This same cultivar ranking was present in 1992, but the differences were not significant.

4.4.5.2. Racemes $stem^{-1}$

In both years, there was no influence of location or clipping treatment on the number of racemes $stem^{-1}$ (data not shown). Unclipped treatments tended to have higher racemes $stem^{-1}$ than clipped treatments at all sampling dates (data not shown). Seeding rate influenced the number of racemes $stem^{-1}$ on 16 September, 1992, but there was no seeding rate effect at any other sampling date in 1992 or 1993. On 16 September, 1992 the number of racemes $stem^{-1}$ was higher for low seeding rate (12 racemes $stem^{-1}$) in comparison to the high seeding rate (8 racemes $stem^{-1}$). At all other sampling dates, racemes $stem^{-1}$ tended to be higher for the low seeding rate versus the high seeding rate (data not shown).

On 31 August, 1992 the number of racemes $stem^{-1}$ was highest for Cimarron VR with Algonquin and CUF 101 producing an equivalent number of racemes $stem^{-1}$ (Table 5). On 23 September, 1993 the number of racemes $stem^{-1}$ was equivalent for Algonquin and Cimarron VR, with CUF 101 having the lower number (Table 6). The number of raceme $stem^{-1}$ declined in both years between 31 August, 1992 and 1993 and the date of final sampling.

On 16 September, 1992 there was a clipping*cultivar interaction for racemes $stem^{-1}$. When separated within each clipping treatment the cultivars showed the same ranking. The unclipped treatment had higher number of raceme stem^{-1} compared to the clipped treatment for Cimarron VR and CUF 101 (13 and 9 vs. 12 and 8, respectively), whereas Algonquin had the same number (10 racemes stem^{-1}) across both treatments.

There was a location*clipping*cultivar interaction for racemes per stem on 23 September, 1993. Cultivar ranking for racemes stem^{-1} was not consistent over locations or between clipping treatments (Table 7). At the low seeding rate Cimarron VR performed better than all other cultivars, but at the high seeding rate it had more flowering percentage than CUF 101, but equivalent to Algonquin. However, it is important to note that CUF 101 ranked lowest for this trait at all locations for both clipping treatments.

4.4.5.3. Racemes m^{-1} of row

In both years there was no influence of location, clipping or seeding rate on the number of racemes m^{-1} of row (data not shown). However, at all sampling dates during both years the number of racemes m^{-1} of row ranked higher for the high seeding rate than the low seeding rate (data not shown). Cultivar differences were observed on 31 August, 1992 and 23 September, 1993 (Table 5 and 6). On both dates, Cimarron VR produced the highest number of racemes m^{-1} of row, whereas, Algonquin and CUF 101 had a similar number of racemes m^{-1} of row. At all other dates the three cultivars had equivalent number of racemes m^{-1} of row. In both years, racemes m^{-1} of row decreased from the 31 August of each year to the last day of sampling (Table 5 and 6).

A rate*cultivar interaction for racemes m^{-1} of row occurred on 31 August, 1993. There was a higher number of racemes m^{-1} of row at the high seeding rate for all cultivars in comparison to the low seeding rate (Table 8). This difference was most pronounced for Algonquin it that it produced the highest number of racemes m^{-1} of row when grown at the high seeding rate for this date.

4.4.5.4. Percentage of racemes that formed pods

The percentage of racemes with pods was lower ($P \le 0.05$) for the unclipped treatment on 16 September and 2 October, 1992, (Table 9). At all other measurement dates, the percentage of the racemes with pods tended to be higher for the unclipped treatment than the clipped treatment (Table 10). This trait was not influenced by location or seeding rate at any date in either year (data not shown).

In 1992, there were cultivar differences for percentage of racemes with pods on 18 August (Table 5). Algonquin and Cimarron VR had an equivalent percentage of racemes with pods, with a lower percentage for CUF 101. There were also cultivar differences for percentage of racemes with pods on 31 August and 23 September, 1993 (Table 6). On both dates Algonquin had the highest percentage of racemes with pods followed by Cimarron VR and CUF 101.

A location*clipping*seeding rate interaction occurred on 18 August, 1992 and 16 September, 1992 for percentage of racemes with pods. The result from this interaction is shown in Table 9. On 18 August, 1992 the percentage of racemes with pods tended to be higher at Homewood than Glenlea for both unclipped and clipped treatments. On 16 September, 1992 the percentage of racemes with pods tended to be higher at Homewood than Glenlea for both unclipped and clipped treatments (Table 10). On both dates, the high seeding rate tended to have a higher percentage of racemes with pods than high seeding rate, but was only significant ($P \leq 0.05$) on 16 September, 1992 for the unclipped treatments at Glenlea (Table 10). The only exception was for the unclipped treatment at Glenlea on both dates, where the low seeding rate had a higher percentage of raceme with pods.

A seeding rate*cultivar interaction occurred on 31 August, 1993. The percentage of racemes with pods tended to be high at the low seeding rate for Cimarron VR and CUF 101 as compared to the high seeding rate (Table 11). However, the percentage of racemes with pods for Algonquin was the same across both seeding rates. Algonquin had a higher percentage of racemes with pods followed by Cimarron VR and CUF 101 at either seeding rates (Table 11). In 1993, the percentage of raceme with pods decreased for Cimarron VR and CUF 101 between 31 August and 23 September (Table 6), with a larger decrease for CUF 101.

4.4.5.5. Pods per raceme and seeds per pod

The number of pods per raceme and seeds per pod was only determined in 1992 and there was no influence of location, clipping treatment, seeding rate (data not shown) or cultivar (Table 1) for this trait. There were no interactions among the treatments. The extremely low number of seeds per pod resulted from poor seed development and numerous empty pods.

4.4.5.6. Seed yield

In 1992 there was no influence of location, clipping treatment or seeding rate on seed yield (data not shown). In both years there were no cultivar differences for seed yield when pooled over treatments (Tables 1 and 2), but higher seed yields were obtained in 1992 in comparison to 1993. There was a location*clipping*seeding rate interaction for seed yield (Table 12). Seed yield tended to be higher at Homewood than Glenlea for both unclipped and clipped treatments. Seed yield tended to be higher for the low seeding rate, with exception of unclipped plots at Homewood, where seed yield was the same at both seeding rates. However, at Homewood when the plants were clipped, seed yield was higher ($P \leq 0.05$) at the low seeding rate than at the high seeding rate (Table 12).

Due to flooding damage at Homewood in 1993 seed yield was harvested only at Glenlea. Clipping treatment and seeding rate did influence ($P \leq 0.05$) seed yield in 1993. The unclipped treatment had higher yield than the clipped treatment (1.54 kg ha^{-1} vs. 0.4 kg ha^{-1}), and the high seeding rate had lower seed yield than the low seeding rate (0.6 kg ha^{-1} vs. 1.34 kg ha^{-1}). The overall seed yield over all treatments was 36 kg ha^{-1} in 1992 and 1 kg ha^{-1} in 1993.

4.5. DISCUSSION

4.5.1. Environmental conditions

The 1992 and 1993 growing season were characterised by extreme environmental conditions, with 1992 being one of the coolest seasons on record and 1993 being one of the wettest (Table 7, Appendix). More precipitation than normal was recorded in both years. However, extremely high precipitation in the months of July and August in 1993 had severe implications on plant growth.

High rainfall in July and early August (Table 7, Appendix) led to flooded fields at both sites in 1993. Although the soil was heavier at Glenlea in comparison to Homewood, The plots at Glenlea had better surface drainage compared to Homewood. As a result water stayed longer on plots at Homewood than Glenlea. Flooding induced plant stress and saturated soil conditions in 1993 reduced overall plant growth and caused leaf chlorosis. Flood damaged plants continued to lose leaves after the water receeded. New leaves eventually (1-2 weeks) developed on the least damaged plants and stem elongation was re-initiated. Although lodging in 1992 led to similar leaf losses, the effect on leaf loss was less dramatic, with the exception of mortality of some of the lodged stems.

Soil flooding has been observed to stop root growth, with prolonged flooding causing the deterioration of the root system. Thompson and Fick (1981) suggested that photosynthate normally used for root growth is probably needed to sustain anaerobic respiration during flooding and plants do not always re-initiate shoot elongation during the post flooding period.

In 1992 and 1993 adverse conditions included high soil moisture, low temperatures, high precipitation and low solar irradiance and previous research has demonstrated that these conditions depress seed yield (Pederson et al. 1972). These environmental stresses reduce seed yields by affecting general plant health, reduced photosynthesis and pollinator activity.

During the months of July and August, 1992 and 1993, the average monthly temperature was lower than the normal temperatures (Table 7, Appendix). July and August are the months when alfalfa leafcutter bees are in the field. Lower temperatures and high precipitation with cloudy conditions are unfavourable for bee activity. Alfalfa leafcutting bees are known to be most effective as pollinators during clear, sunny and warm days with low rainfall and wind (Richards, 1984).

4.5.2. Seedling Vigour

The superior seedling vigour of the non dormant cultivar, CUF 101 could be an important advantage for establishment year seed production over Cimarron VR and Algonquin (Table 1 and 2). Cultivars with vigorous seedlings may have an advantage for seed production in the establishment year due to improved competitiveness with weed growth. Seedling plant growth and development are typically slower than regrowth from established plants because seedlings lack the crown, root, and nodule systems of older plants (Pearson and Hunt, 1972).

4.5.3. Plant height

Average plant heights were taller in 1992 than in 1993 (Figure 1). This probably resulted from the flooding stress that occurred in 1993. Cameroon (1973) reported that plant height was decreased when alfalfa was maintained under flooded conditions in greenhouse pots (Cameroon, 1973). Flooding induced plant stress and saturated soil conditions in 1993 reduced overall plant growth and caused leaf chlorosis. Thompson and Fick (1981) suggested that photosynthate normally used for root growth is probably needed to sustain anaerobic respiration during flooding and that plants did not always re-initiate shoot elongation during the post flooding period.

Cultivar differences for plant height were only observed at 7 weeks after planting in 1993 (Figure 2 and 3). However, CUF 101 and Cimarron VR generally displayed better growth than Algonquin in both years. Other studies have also reported that non-dormant and moderately dormant cultivars show superior plant growth over dormant cultivars (Heichel *et al.*, 1989).

4.5.4. Flowering percentage

Flowering percentage was measured to determine the relative rate of maturation between alfalfa cultivars and to assess the effect that profuseness of flowering had on seed yield potential. In this experiment, a moderately dormant cultivar (Cimarron VR) was observed to have flowered earlier than the other two cultivars. Furthermore, Cimarron VR attained a higher flowering percentage than the dormant cultivar, Algonquin, or the non-dormant cultivar, CUF 101 (Table 3). In 1992 Cimarron VR ranked lowest for seed yield. This is in contrast to research results from Kentucky and Washington, U.S.A, where earlier flowering alfalfa clones produced the highest seed yields (Dade et al., 1967). Alfalfa plants developed more flowers at Homewood than Glenlea when scored on July 24 and August 5, 1992 (Table 4). This may have resulted from the fact that the experiment at Homewood was planted a week earlier and had higher initial soil N (data not shown).

Although no comparisons were made between seedling plants from this study and the regrowth from established stands in the spring (current practices), it is commonly accepted that seedling plants will flower later in the season. This hypothesis was supported by a study conducted by Pearson and Hunt (1977). They demonstrated that seedling plants from 'Vernal' and 'Moapa' took 47 to 61 days to reach 50% bloom, whereas regrowth from mature plants from these same cultivars only required 23 to 28 days to flower respectively. Late flowering may reduce the chance of the plants to develops mature seed before the first killing frost in this region.

4.5.5. Lodging

Alfalfa plants that produced tall, dense vegetative growth as a result of cool moist conditions. This condition resulted in lodging (Table 1). Lodging stimulated new shoot regrowth by exposing the crown to light. These new shoots either flowered very late in the season or did not flower at all. Therefore, these new shoots did not contribute to seed production and they may have negatively affected seed development in existing pods by influencing nutrient partitioning within the plant. Flowers and developing pods on the lodged stems were shedded and caused a reduction in potential sites for seed development.

Additionally, lodging may have led to decreased air movement, increased humidity, decreased accessibility for pollinating bees and decreased light penetration through the canopy. These conditions have been reported to negatively influence seed yield (Pederson *et al.*, 1955, 1959; Plews, 1973). Tysdal (1946) and Taylor *et al.* (1959) suggested that excessive lodging of alfalfa plants was a cause of low seed yields through its effect on the micro-environment around individual plants. Furthermore, Fick *et al.* (1988) reported that lodging can affect photosynthesis and photosynthate partitioning through shading and new regrowth. Stand lodging was not observed in 1993, therefore it was not a contributing factor to low seed yields.

Clipping did influence ($P \leq 0.05$) lodging of plants, with very little lodging in the clipped treatments. These results are particularly important because clipping not only reduces growth of weeds, but reduced lodging could lead to increased seed yield. Obviously though, clipping delays maturity so the potential advantages from reduced lodging could be easily offset by the delay in seed maturation.

4.5.6. Seed Yield and Seed Yield Components

Measurements of seed yield components such as:stems m^{-1} row, racemes per stem, racemes m^{-1} of row, pods per raceme and seeds per pod are often used as indicators of seed yield potential. These components were particularly important indicators for seed yield potential in both years of this study since the adverse environmental conditions negatively influenced pollination, seed set, seed development, seed maturation and final seed yield. The results from these experiments indicate that even the expression of these seed yield components were limited under the conditions of this experiment. Previous studies have shown that to develop accurate seed yield predictors from seed yield components, it is essential that alfalfa plants are grown under environmental conditions that favour maximum potential seed yield (Rincker et al., 1988; Smith and Bouton, 1988).

4.5.6.1. Number of stems m^{-1} row

There was no effect of seeding rate on the number of stems m^{-1} of row in these experiments (Table 1 and 2). The initial competition for light and nutrients among the plants established at the high seeding rate may have led to some loss of plants. This might have led to the two seeding rates to produce similar number of stems per m^{-1}. In contrast, other research indicated that seeding rate influenced the number of plants per unit area or stems per unit area (Fick et al., 1988). Cultivars showed similar ranking for seedling vigour and stem m^{-1} in both years. The higher stems m^{-1} of row for the non-dormant cultivar CUF 101, suggest that it had superior tillering ability to the other two cultivars.

4.5.6.2. Racemes stem^{-1} and racemes m^{-1} of row

Obviously, racemes stem^{-1} and racemes m^{-1} of row are both important components of final seed yield, but the environmental conditions of 1992 and 1993 (Table 7, Appendix) limited the predictive ability of either trait. By combining stems m^{-1} row and racemes stem^{-1} row the seed yield component of racemes m^{-1} is determined. This component may be the best predictor of seed yield since it is a measure of racemes area^{-1}.

Although, CUF 101 had more stems m^{-1} of row, it showed the least number of racemes stem^{-1} and racemes m^{-1} of row (Table 5 and 6). The higher stems m^{-1} of row could have caused crowding and competition among the stems, thereby limiting racemes stem^{-1}. In contrast to CUF 101, Cimarron VR tended to have a higher number of racemes stem^{-1} and per racemes m^{-1} of row. The number of racemes stem^{-1} was lower in this experiment (Table 5 and 6) compared to the results of other researchers (Pedersen et al., 1959; Pedersen and Nye, 1962).

The low seeding rate tended to have higher number of racemes stem^{-1}, but lower number of racemes m^{-1} of row (data not shown). The high seeding rate tended to have higher racemes m^{-1} with Algonquin expressing the greatest differences between the two seeding rates (Table 8). At Glenlea higher number of racemes m^{-1} in the high seeding rate did not translate into higher seed yield and with the clipped treatment at Homewood the opposite was true (Table 12). Traditionally, low seeding rates produce the highest seed yields (Pedersen et al., 1959; Rincker et al., 1988; Plews, 1973).

A decline in the number of racemes stem^{-1} and number of racemes m^{-1} of row were observed in both years later in the season (Table 5 and 6). These results suggest that stripping or shedding of racemes (either with pods or flowers) must have occurred. This could have been caused by competition between the racemes for nutrients, environmental factors like precipitation and wind and or stresses due to lodging or flooding.

Flowering shedding and pod abortion is a phenomenon which has been observed in other legumes. Flowers and maturing pods in *Vicia faba* often abort because of competition for assimilate between flowers, (McEwen, 1972). Flower and pod abortion also occurs in the annual medics, where the potential size of the photosynthetic sink at each node seems to dictate flower and pod survival (Cocks, 1990).

4.5.6.3. Percentage of racemes that formed pods

The low percentage of racemes with pods for the clipped treatments (Table 9) suggested that this treatment was not desirable for seed yield in the year of establishment. The results suggested that Algonquin was a better at converting racemes into racemes with pods than the other cultivars (Table 5 and 6). This result may indicate that Algonquin is more adapted to the cool environmental conditions that prevailed during both growing seasons.

4.5.6.4. Pods raceme^{-1} and seeds pod^{-1}

Only a few racemes developed mature pods before harvest during either year. Most of the pods were immature and had underdeveloped seeds. The number of seeds pod^{-1} (Table 1) was much lower than those typically found in other study, ranging 2.1 to 6.4 (Pedersen et al., 1959; Teuber et al., 1984; Smith and Bouton, 1989; Abu-Shakra et al., 1969). The results on seeds per pod suggests that either ovules were not fertilized or seed did not develop. Competition among seeds within each pod may have reduced the total number of seeds produced in addition to the effect of adverse environment and low pollination. Competition among seeds within each pod was believed to have reduced the total number of seeds produced by medics (Cocks, 1990). The results from this research for pods raceme^{-1} (Table 1) were similar to that reported earlier (Pedersen et al., 1959; Abu-Shakra et al., 1969).

4.5.6.5. Seed yield

Clipping delayed the onset of flowering, reduced the length of the flowering period and delayed seed maturity. Clipping apparently did not have a large effect on seed yield, with the exception of the high seeding rate in 1993 (Table 12). However, the extremely low seed yield in both years may bias any interpretation made from these results. Although there is no information available for alfalfa clipped during the year of establishment, previous research involving clipping of an established stand indicates that seed yield is reduced (Rincker et al., 1988; Plews, 1973).

The seed yields from these experiments were much lower 0.8 to 40 kg ha^{-1} (Table 1 and 2) than the yields reported by Ricker (1976) at Prosser, Washington, USA, of 214 kg ha^{-1} for an establishment year stand seeded at 1.12 kg ha^{-1}. Similar research in Manitoba (Smith, 1992) also reported yields in the range of 197 kg ha^{-1} to 418 kg ha^{-1} from an establishment year stand seeded at 3.4 kg ha^{-1}. Comparisons for seed yields with other studies conducted in western Canada are difficult to make because seed is traditionally not harvested during the year of establishment (Moyer *et al*, 1991, Fairey and Lefkovitch, 1992). However, our result was similar to seed yield obtained by commercial producers in Manitoba. A survey conducted by Smith *et al*. (1993 and 1994) showed that the corresponding longterm yield from commercial field under current management in southern Manitoba was 261 kg ha^{-1}, whereas a seed yield of 46 and 35 kg ha^{-1} was obtained in 1992 and 1993, respectively. Therefore, the prevailing environmental conditions during the growing season, rather than the production system might have affected the seed yield from our experiments.

4.6. CONCLUSION

The effect of the experimental treatments (clipping, seeding rate and cultivar) on seed yield and seed yield components were not fully expressed under the environmental conditions of this experiment. There was no influence of clipping and seeding rate on plant height (later in the growing season), flowering percentage, number of racemes $stem^{-1}$, number of racemes m^{-1} of row and number of pods per raceme. Clipping reduced lodging, but did not affect seed yields. However, clipping is not recommended in an establishment year seed production system because it delays maturity by about 1 to 2 weeks. Flowering percentage and racemes per m^{-1} of row were higher for Cimarron VR than CUF 101 and Algonquin. Cool temperatures and lodging in 1992 and excessive moisture and flooding in 1993, coupled with low alfalfa leafcutting bee activity in both years, were major seed yield limiting factors. Establishment year seed production is a associated with a higher degree of risk, since the flowering date is later than for established stands resulting in a shorter period frost-free for pod set and seed development. The seed yield obtained was low in both years. This research will provide basic information on the agronomic requirements of an establishment-year-seed crop. However, the seed yield obtained was similar to that from established fields suggesting that other factors beside the production system affected the results. The main factor was the prevailing environmental conditions during both the growing season.

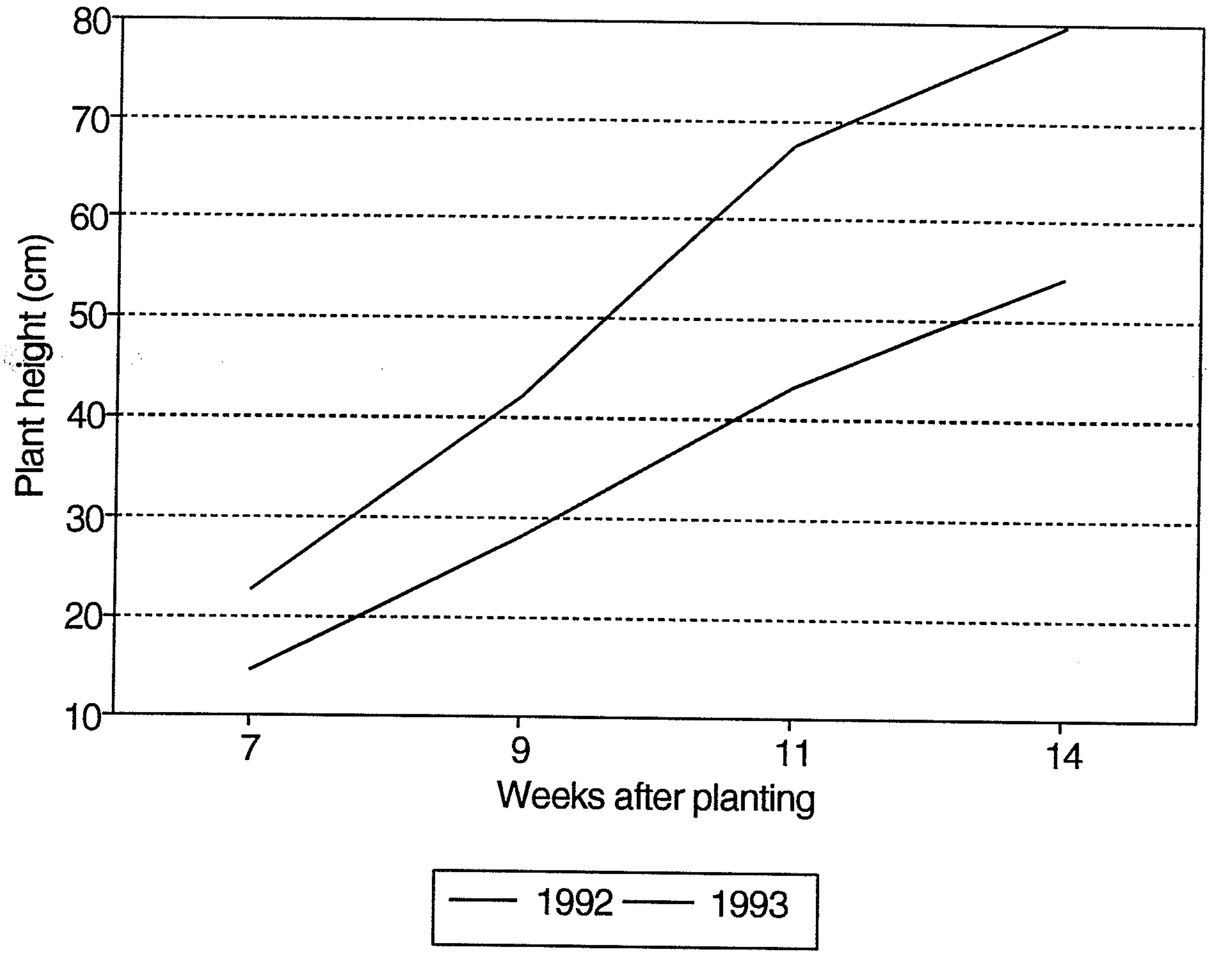

Figure 1. Plant height of alfalfa averaged over location (Homewood and Glenlea) and treatment (clipping, seeding rate and cultivar) when grown for establishment year seed production in southern Manitoba in 1992 and 1993.

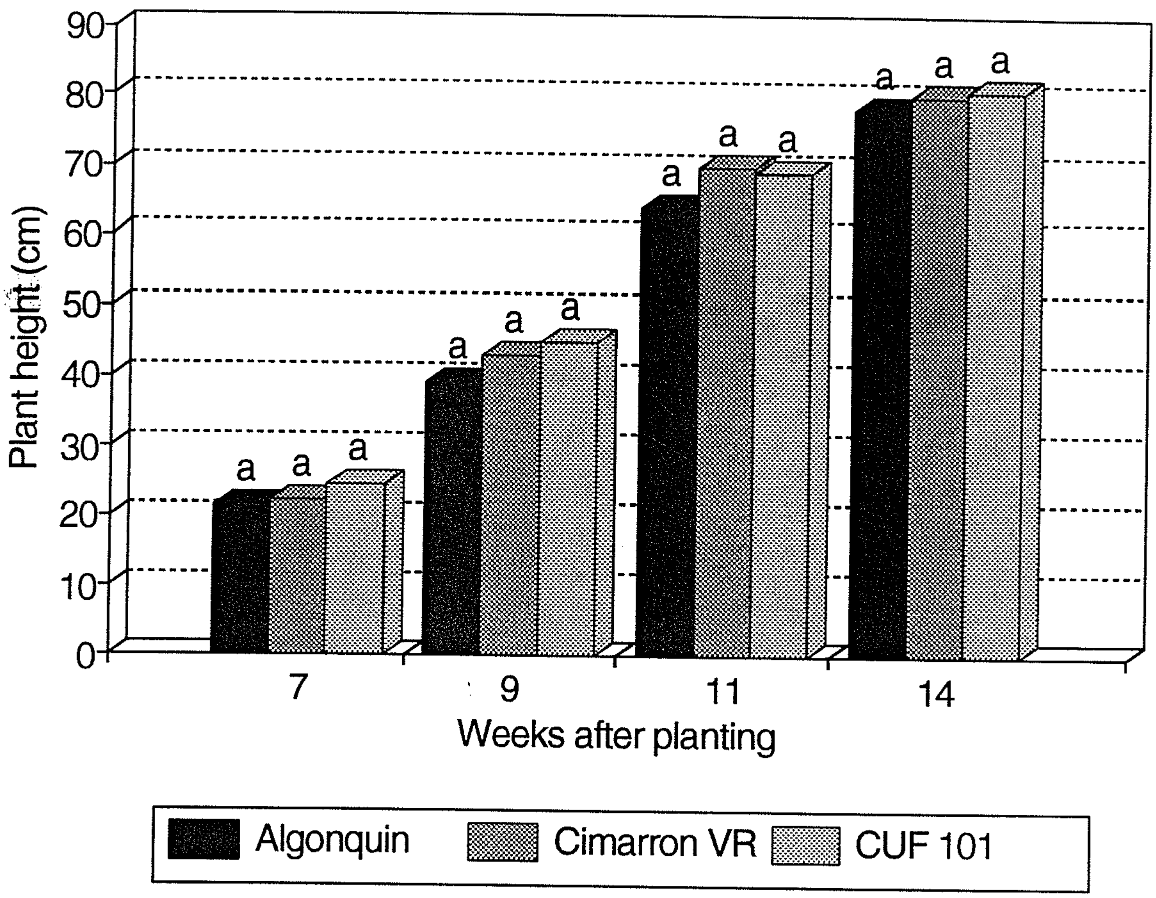

Figure 2. Plant height of three alfalfa cultivars averaged over locations (Homewood and Glenlea) and treatments (clipping and seeding rate) when grown for establishment year seed production in southern Manitoba in 1992. Within series (weeks after planting), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

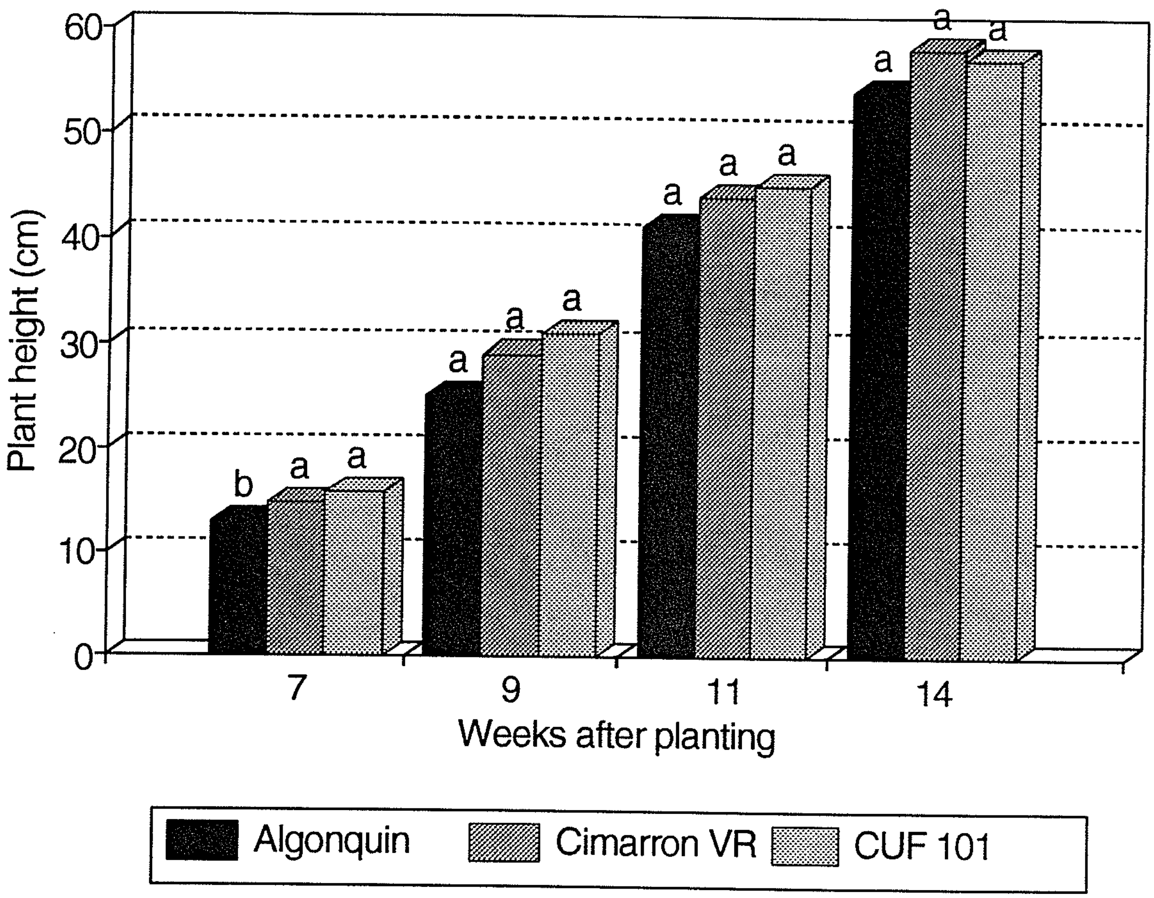

Figure 3. Plant height of three alfalfa cultivars averaged over locations (Homewood and Glenlea) and treatments (clipping and seeding rate) when grown for establishment year seed production in southern Manitoba in 1993. Within series (weeks after planting), means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 1. Seed yield and seed yield components and agronomic traits of three alfalfa cultivars (CV) grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992.

CV†	Agronomic traits					
	Seed Yield	Pods raceme^{-1}	Seeds pod^{-1}‡	Lodging score§	Seedling vigour¶	stems m^{-1} of row
	-kg/ha--	---no.	---------no.--	----score 1-5	----	-- no.--
ALG	40a#	8a	0.2a	1.8a	2.7a	44a
CVR	30a	8a	0.2a	1.6a	3.4a	49a
CUF	39a	7a	0.2a	1.9a	4.3a	54a

† Cultivar (CV) were: Algonquin (ALG), Cimarron VR (CVR), and CUF 101 (CUF).
‡ The extremely low number of seeds per pod abnormal and due to poor pollination and seed development.
§ Score: 1= all stems vertical to 5= all stems on the ground.
¶ Score: 1= low vigorous plants to 5= very vigorous plants.
# Within traits, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 2. Seed yield and agronomic traits of three alfalfa cultivars (CV) grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1993.

Cultivar	Agronomic traits		
	Seed yield†	Seedling vigour	stem m^{-1}
	---kg ha^{-1} ---	----- Score‡ ---	---- no.----
Algonquin	1.0a§	3.0c	55c
Cimarron VR	1.0a	3.7b	66b
CUF 101	0.8a	4.6a	74a

† Seed yield was obtained from the Glenlea site only.
‡ Seedling vigour score: 1= low vigorous plants to 5= very vigorous plants.
§ Within traits, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 3. Flowering percentage (%) for three alfalfa cultivars grown for establishment year seed production at Homewood and Glenlea in southern Manitoba in 1992.

Cultivar	Sampling dates		
	24 July	28 July	5 August
	% †		
Algonquin	8a‡	16c	27c
Cimarron VR	14a	28a	44a
CUF 101	12a	20b	36b

† Flowering % was determined as a visual estimation of the fraction of alfalfa stems with at least one open flower, within a sub-sub-plot.

‡ Within dates, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 4. Flowering percentage score (%) for three alfalfa cultivars with and without clipping treatment on two dates at Homewood and Glenlea in southern Manitoba in 1992.

Date	Location	Treatment	Cultivar		
			Algonquin	Cimarron VR	CUF 101
			%		
24/7	Glenlea	Unclipped	6a	13a	10a
		Clipped	0a	0a	0a
	Homewood	Unclipped	24b	43a	38a
		Clipped	1a	1a	0a
5/8	Glenlea	Unclipped	34b	64a	42b
		Clipped	7b	13a	16a
	Homewood	Unclipped	45b	64a	58a
		Clipped	21b	33a	28a

‡ Within dates and clipping treatments, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 5. The number of racemes per stem, number of racemes per metre of row and percentage of racemes with pods for three alfalfa cultivars grown for establishment year seed production at Homewood and Glenlea in southern Manitoba in 1992.

Cultivar	Sampling dates: 18 August	31 August	16 September	2 October
	racemes $stem^{-1}$ ‡			
Algonquin	6a‡	12b	10a	7a
Cimarron VR	8a	15a	13a	8a
CUF 101	5a	10b	8a	5a
	racemes per metre of row §			
Algonquin	259a	553b	458a	331a
Cimarron VR	313a	659a	533a	357a
CUF 101	275a	543b	411a	276a
	percentage of racemes with pod			
Algonquin	34a	54a	78a	98a
Cimarron VR	33a	52a	70a	96a
CUF 101	31b	47a	61a	98a

† Racemes $stem^{-1}$ were determined by averaging the total number of racemes counted from 15 randomly selected stems per plot.
‡ Within dates, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Racemes per metre of row was determined by the number of racemes m^{-1} by number of stems m^{-1} of row.

Table 6. The number of racemes per stem, number of racemes per metre of row and percentage of racemes with pods for three alfalfa cultivars grown for establishment year seed production at Homewood and Glenlea in southern Manitoba in 1993.

Cultivar	Sampling date: 18 August	31 August	23 September
	racemes $stem^{-1}$ †		
Algonquin	3a‡	6a	5a
Cimarron VR	5a	7a	5a
CUF 101	3a	4a	3b
	racemes per metre of row §		
Algonquin	183a	337a	271b
Cimarron VR	337a	446a	347a
CUF 101	219a	269a	242b
	percentage of racemes with pod		
Algonquin	27a	48a	66a
Cimarron VR	22a	36b	34b
CUF 101	14a	17b	13c

† Racemes $stem^{-1}$ were determined by averaging the total number of racemes counted from 15 randomly selected stems per plot.
‡ Within dates, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Racemes per metre of row was a product of racemes m^{-1} multiplied by the number of stems m^{-1} of row.

Table 7. The number of racemes per stem for three alfalfa cultivars with and without a clipping treatment on 23 September, 1993 at Homewood and Glenlea in southern Manitoba in 1993.

Location	Treatment	Cultivar		
		Algonquin	Cimarron VR	CUF 101
		------------- racemes $stem^{-1}$ ----------		
Glenlea	Unclipped	6.0a†	5.0a	3.0b
	Clipped	3.8b	5.2a	3.0b
Homewood	Unclipped	4.0b	6.0a	3.0b
	Clipped	4.0a	4.0a	3.0a

† Within location and treatment, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 8. The number of racemes m^{-1} of row at two seeding rates of alfalfa grown for seed production in the establishment year on 31 August, 1993 at Homewood and Glenlea in southern Manitoba.

Seeding Rate	Cultivar		
	Algonquin	Cimarron VR	CUF 101
	------------- racemes m_{-1} of row ----------		
Low (1.12 kg ha^{-1})	230b†	437a	260b
High (3.36 kg ha^{-1})	427a	501a	279b

† Within seeding rate, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 9. The percentage of racemes with pods for different dates and clipping treatments of alfalfa grown for seed production in the year of establishment at Homewood and Glenlea in southern Manitoba.

Dates	Clipping treatments	
	Unclipped	Clipped
	%	
18 August 1992	35a†	30a
31 August 1992	54a	48a
16 September 1992	76a	64b
2 October 1992	98a	96b
18 August 1993	24a	19a
31 August 1993	39a	28a
23 September 1993	45a	29a

† Within dates, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 10. The percentage of racemes with pods per stem for different dates, clipping treatments and seeding rates of alfalfa grown for seed production in the year of establishment at Homewood and Glenlea in southern Manitoba.

Date	Location	Treatment	Seeding rates	
			1.12 kg ha^{-1}	3.36 kg ha^{-1}
			%	%
18/8/92	Glenlea	Unclipped	34a†	30a
		Clipped	24a	34a
	Homewood	Unclipped	36a	42a
		Clipped	29a	34a
16/9/92	Glenlea	Unclipped	75a	67b
		Clipped	55a	63a
	Homewood	Unclipped	76a	83a
		Clipped	67a	70a

† Within dates, location, and treatment, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 11. The percentage of racemes with pods per stem for seeding rate and cultivar of alfalfa grown for seed production in the establishment year on 31 August, 1993 at Homewood and Glenlea in southern Manitoba.

Seeding Rate	Cultivar		
	Algonquin	Cimarron VR	CUF 101
	----------	%	----------
Low (1.12 kg ha^{-1})	66a†	35b	19c
High (3.36 kg ha^{-1})	66a	32b	8c

† Within seeding rate, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 12. Seed yield for clipping treatment and seeding rate of alfalfa grown for establishment year seed production at Homewood and Glenlea in southern Manitoba in 1992.

Location	Treatments	Seeding rates 1.12 kg ha^{-1}	3.36 kg ha^{-1}
		----------------kg ha^{-1}	-------------
Glenlea	Unclipped	18a†	15a
	Clipped	14a	11a
Homewood	Unclipped	64a	64a
	Clipped	65a	35b

† Within location and treatment, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

5. GENERAL SUMMARY AND CONCLUSIONS

The working hypothesis of this study was that alfalfa seed production in the establishment year is possible in western Canada and that substantial quantities of N_2 are fixed during the reproductive phase. The specific objectives of this research were as follows: 1) to compare seed yield and dry matter productions of non-dormant, moderately dormant and early fall dormant cultivars during the establishment year, 2) to determine the effect of seeding rate and clipping management on alfalfa seed yield and seed yield components during the establishment year, 3) to determine how cultivar, plant density and stage of plant development affect N_2 fixation in a seedling year stand of alfalfa.

Although seeding rate did not influence flowering percentage, lodging, and seedling vigour the higher seeding rate was detrimental to seed yield and in addition resulted in shorter plants. The non-dormant cultivars (CUF 101 and Nitro) ranked highest for seedling vigour and lodging and were followed by Algonquin, Saranac, and Saranac-In. Lodging apparently contributed to decreased seed yields in 1992, as indicated by cultivar ranking for seed yield with Algonquin and Saranac yielding higher than Nitro, CUF 101 and Saranac-In.

Seeding rate only influenced dry matter, N yield, and symbiotic N_2-fixed at a few sampling dates. However, dry matter, N yield and symbiotic N_2-fixed tended to be higher for the high seeding rate than the low seeding rate at all growth stages. There were no consistent cultivar differences for measured traits over the growing season. Surprisingly, the non-dormant cultivars had no higher fall dry matter yield than other cultivars in stands managed for seed production during establishment year.

In 1992, the total (herbage and roots plus crowns) %Ndfa was 37%, 42%, 37%, 43% for late vegetative, 10% to 20% bloom, 50% to full bloom and mature seed stage, respectively. Whereas, in 1993, the total %Ndfa was 38%, 49%, 60%, 59% for late vegetative, 10% to 20% bloom, 50% to full bloom and mature seed stage, respectively. In 1992, averaged over treatments the corresponding total symbiotic N_2-fixed was 23 kg N ha^{-1}, 64 kg N ha^{-1}, 54 kg N ha^{-1}, and 74 kg N ha^{-1} for late vegetative, 10% to 20% bloom, 50% to full bloom and mature seed stage, respectively. Whereas, in 1993, the total symbiotic N_2 fixed was 23 kg N ha^{-1}, 35 kg N ha^{-1}, 67 kg N ha^{-1}, and 70 kg N ha^{-1} for late vegetative, 10% to 20% bloom, 50% to full bloom and mature seed stage respectively.

Lodging, flooding stress and new shoot regrowth from the crown affected seed yield, dry matter yield, N yield, and symbiotic N_2-fixation in these experiments. The root plus crown dry matter yield and N yield are components of an alfalfa seed stand available for fall incorporation. Therefore, this research indicated that 1,674 to 2,320 kg ha^{-1} dry matter and 41 to 59.6 kg ha^{-1} of N (of which 28 to 33 kg ha^{-1} was from symbiotically fixed N_2) was available for fall incorporation and production of subsequent crops.

Generally, there is yield and nitrogen response from crop production when the preceding crop was alfalfa in comparison to a non-leguminous crop. However, these research results did not show differences in wheat straw dry matter yield, N yield, and grain yield when wheat was grown on plots following alfalfa grown for seed production.

This research will be the first published information on N_2-fixation in alfalfa during seed production. During 1992 and 1993, alfalfa seed yields were very low in our research plots and in commercial seed fields using conventional management. Therefore, extrapolation of these results to a "normal" year may be difficult, but this research provides important basic information on N_2-fixation during seed development in alfalfa. This research will also be helpful in determining the N contribution of an alfalfa seed crop for rotations and in determining the influence of stand density and cultivar on N_2-fixation.

Measurements of seed yield components were used as an indicator of seed yield potential. This was particularly important in both years of this study since the environmental conditions directly influenced seed set, seed development and maturation and final seed yield. The morphological traits evaluated were chosen by their potential relationship to seed yield. The results of these experiments are in agreement with previous studies that to develop accurate seed yield predictors, it is essential that alfalfa plants are grown under environmental conditions that favour maximum potential seed yield (Rincker et al., 1988; Smith and Bouton, 1988) and these conditions were not obtained in Southern Manitoba in 1992 or 1993.

There was no influence of clipping and seeding rate on plant height (later in the growing season), flowering percentage, number of racemes stem^{-1}, number of racemes m^{-1} of row and number of pods per raceme. Clipping reduced lodging, delayed maturity by about 1 to 2 weeks, but did not affect the seed yields. Flowering percentage and racemes per m^{-1} of row were higher for Cimarron VR than CUF 101 and Algonquin. Cool temperatures and lodging in 1992 and excessive moisture and flooding in 1993, coupled with low alfalfa leafcutting bee activity in both years were major seed yield limiting factors. Establishment-year seed production is associated with a higher degree of risk, since the flowering date is later than for established stands resulting in a shorter frost free period for pod set and seed development. Cool temperature, lodging and subsequent regrowth in 1992 and excessive moisture and flooding in 1993 coupled with low alfalfa leafcutting bee activity in both years were major seed yield limiting factors.

In conclusion, the seed yield obtained from these experiments in 1992 and 1993 was disappointing. This research will provide basic information on the agronomic requirements of an establishment-year-seed crop. However, the seed yield obtained was similar to that from established stands in Manitoba, suggesting that other factors beside the production system affected the results. The main factor was the prevailing environmental conditions during both the growing season.

6. REFERENCES

Abu-Shakra, S., M. Aktar and D.W. Bray. 1969. Influence of irrigation and plant density on alfalfa seed production. Agron. J. 61:569-571.

Arakeri, H.R. and A.R. Schimid. 1949. Cold resistance of various legumes and grasses in early stages of growth. Agron. J. 41:182-185.

Ahring, R.M., J.O. Moffet and R.D. Morrison. 1984. Date of pod-set and Chalcid Fly infestation in alfalfa in alfalfa seed crops in the Southern Great Plains. Agron. J. 76:137-140.

Baenziger, H. 1975. Algonquin alfalfa. Can. J. Plant Sci. 55:1093-1094.

Baldock, J.O., R.L. Higgs, W.H. Paulsen, J.A. Jackobs and W.D. Schrader. 1981. Legume and mineral N effects on crop yields in several crop sequences in the upper Mississippi valley. Agron. J. 73:885-890.

Barber, S.A. 1972. Relation of weather to the influence hay crops on the subsequent corn yields on a Chalmers silt loam. Agron. J. 64:8-10.

Barnes, D.K., G.H. Heichel, C.P. Vance and W.R. Ellis. 1984. A multiple-trait breeding program for improving the symbiosis for nitrogen fixation between Medicago sativa L. and Rhizobium meliloti. Plant and Soil. 82:303-314.

Barnes, D.K., G.H. Heichel, C.P. Vance and R.N. Peaden. 1990. Registration of 'ineffective Agate' and 'ineffective Saranac' non-nitrogen-fixing alfalfa germplasms. Crop. Sci. 30:752-753.

Barnes, D. K, D.M. Smith, L.R. Teuber and M.A. Peterson. 1991. Fall dormancy. In Standard tests. Published by North America Alfalfa Improvement Conference. USDA-ARS, Beltsville, Maryland, USA.

Barnes, D.K., C.C. Vance, G.H. Heichel, D.M. Smith and R.N. Peaden. 1988. Registration of 'Nitro' alfalfa. Crop Sci. 28:718

Bass, L.N., C.R. Gunn, O.B. Hesterman and E.E. Ross. 1988. Seed physiology, seedling performance and seed sprouting. pp. 961-983 in A.A. Hanson *et al.*, eds. Alfalfa and alfalfa improvement. Agronomy no. 29. AM. Soc. Agron., Madison, WI.

Beacon, S.E. 1991. Forage Crops in the Aspen Parkland of Western Canada. Agric. Canada. Publication. 1871/E.

Belzie, L. 1984. Influence des cultivars, des dates et des doses de semis sur le rendement et la qualite de la luzerne semee en fin d'ete. Can. J. Plant Sci. 64: 667-675.

Belzie, L. and R. Rioux. 1984. Influence des cultivars, des dates et des doses de semis sur le rendement et la qualite de la luzerne l'annee du semis. Can. J. Plant Sci. 64: 309-317.

Beveridge, J.L. and C.P. Wilsie. 1959. Influence of depth of planting, seed size, and variety on emergence and seeding vigour in alfalfa. Agron. J. 51;731-734.

Bolton, J.L. 1956. Alfalfa seed production in the Prairie Provinces. Publication 984. Canada Department of Agriculture, Ottawa, ON.

Bolton, E.F., V.A. Dirks and J.W. Aylesworth. 1976. Some effects of alfalfa, fertilizer, and lime on corn yields in rotations on clay soil during a range of seasonal moisture conditions. Can. J. Soil Sci. 56:21-25.

Bolton, J.L., B.P. Goplen and H. Baenziger. 1972. World distribution and historical developments. Seed production practices. *In* C.H. Hanson (ed) Alfalfa science and technology. Agronomy 15:1-34.

Bowren, K.E., D.A. Cooke and R.K. Downey. 1969. Yields of dry matter and nitrogen from tops and roots of sweet clover, alfalfa, and red clover at five stages of growth. Can. J. Plant Sci. 49:61-68.

Bruulsema, T.W. and B.R. Christie. 1987. Nitrogen contribution to succeeding corn from alfalfa and red clover. Agron. J. 77:96-100.

Cameroon, D.G. 1973. Lucerne in wet soils-the effect of stage of regrowth, cultivar, air temperature, and root temperature. Aust. J. Agric. Res. 24:851-861.

Campbell, W.A., R.P. Zenter, H.H. Jansen and K.E. Bowren. 1990. Crop rotation studies on the Canadian Prairies. pp., 110-112.

Carter, P.R. and C.C. Sheaffer. 1983. Alfalfa response to soil water deficits. III. Nodulation and N_2 fixation. Crop Sci. 23:985-990.

Cocks, P.S. 1990. Dynamics of flower and pod production in annual medics (*Medicago spp.*) in spaced plants. Aust. J. Agric. Res. 41: 911-921.

Cooper, C.S., R.L. Ditterline and L.E. Wety. 1979. Seed size and seeding rates effects upon stand density. Agron. J. 71:83-85

Cowett, E.R. and M.A. Sprague. 1962. Factors affecting tillering in alfalfa. Agron. J. 54:294-297.

Cowett, E.R. and M.A. Sprague. 1963. Effect of stand density and light intensity on the microenvironment and stem production of alfalfa. Agron. J. 55:432-434.

Cralle, H.T. and G.H. Heichel. 1986. Photosynthate and dry matter distribution in effectively and ineffectively nodulated alfalfa. Crop Sci. 26:117-121.

Cralle, H.T., G.H. Heichel and D.K. Barnes. 1986. Photosynthate partitioning in plants of alfalfa population selected for high and low nodule mass. Crop Sci. 27:96-100.

Curran, B.S., K.D. Kephardt and E.K. Twidwell. 1993. Oat companion crop management in alfalfa establishment. Agron. J. 85:998-1003.

Dade, E., N.L. Taylor and C.S. Garrison. 1967. Differential seed production of alfalfa clones at two diverse locations. Crop Sci. 7:663-664.

Engelke, M.C. and J.B. Moutray. 1980. Forage seed production in the south?. Proceeding of the 37th Southern Pasture and Forage Crop Improvement Conference, Nashville, Tennessee. pp. 88-91.

Fairey, D.T. and L.P. Lefkovitch. 1991. Hard seed content of alfalfa grown in Canada. Can. J. Plant Sci. 71:437-444.

Fairey, D.T. and L.P. Lefkovitch. 1992. Can alfalfa seed be produced more efficiently?. Proceedings of 11th Annual Canadian Alfalfa and Forage Seed Conferences, Winnipeg, Manitoba. pp. 3-8.

Farnham, D.E. and J.R. George. 1993. Dinitrogen fixation and nitrogen transfer among red clover cultivars. Can. J. Plant Sci. 73:1047-1054.

Fick, G.W., D.A. Holt and D.G. Lugg. 1988. Environmental Physiology and Crop Growth. In A.A. Hanson, D.K. Branes, and R.R. Hill, Jr. (eds.) Alfalfa and Alfalfa Improvement. Agron. Monogr. No. 29. Am. Soc. Agron., Madison, Wisc. pp. 163-194.

Fox, R.H. and W.P. Piekielek. 1988. Fertilizer N equivalence of alfalfa, birdsfoot trefoil, and red clover for succeeding corn crops. J. Prod. Agric. 1:313-317.

Fribourg, H.A and I.J. Johnson. 1955. Dry matter and nitrogen yields of legume and roots in the fall of the seeding year. Agron. J. 47:73-77.

Genest, J. and H. Steppler. 1973. Effects of companion crops and their management on the undersown forage seedling environment. Can. J. Plant Sci. 53:285-290.

Gibson, A.H. 1977. The influence of the environment and management practices on the legume-rhizobium symbiosis. pp. 395-450. *In* R.W.F. Hardy and A.H. Gibson (ed) A Treatise on nitrogen fixation. John Wiley and Sons, New York.

Gilcrest, D.G., L.R. Teuber, A.N. Martensen and W.A. Cowling. 1982. Progress in selecting for resistance to Stemphylium botryosom (Cool-temperature biotype) in alfalfa. Crop Sci. 22:1155-1159.

Gist, G.R. and G.O. Mott. 1956. Some effects of light, temperature, and soil moisture on the growth of alfalfa, red clover and birdsfoot trefoil seedlings. Agron. J. 48:33-36.

Goplen, B.P., H. Baenziger, L.D. Bailey, A.T.H. Gross, M.R. Hanna, R.Michaud, K.W.Richards and J.Waddington. 1982. Growing and managing alfalfa in Canada. Agric. Canada. Publication 1705/E.

Groya, F.L. and C.C. Sheaffer. 1985. Nitrogen from forage legumes: harvest and tillage effects. Agron. J. 77:105-109.

Ham, G.E., I.E. Liener, S.D. Evans, R.D. Frazier and W.W. Nelson. 1975. Yield and composition of soybean seed as affected by N and S fertilization. Agron. J. 67:293-297.

Hanson, L.H. and C.R. Krueger. 1973. Effects of establishment method, variety and seeding rate on the production and quality of alfalfa under dryland and irrigation. Agron. J. 65:755-759.

Hardarson, G., G.H. Heichel, D.K. Branes and V.P. Vance. 1982. Rhizobial strain preference of alfalfa populations selected for characteristics associated with N_2 fixation. Crop Sci. 22:55-58.

Harris, G.H. and O.B. Hesterman. 1990. Quantifying the nitrogen contribution from alfalfa to soil and two succeeding crops using nitrogen-15. Agron. J. 82:129-134.

Heichel, G.H. 1978. Stabilizing Agriculture Energy Needs: Role of Forages, Rotations and Nitrogen fixation. J. of Soil Water Conservation. 33:279-282.

Heichel, G.H., D.K. Barnes and C.P. Vance 1981. Nitrogen fixation of alfalfa in the seeding year. Crop Sci. 21:330-335.

Heichel, G.H. and D.K. Barnes. 1984. Opportunities for meeting crop N needs from symbiotic N- fixation., In Organic Farming: Current Technologies and its role in a Sustainable Agriculture. Publication of AM. Soc. Agron., Madison, WI.

Heichel, G.H., D.K. Barnes, C.P. Vance and K.I. Henjum. 1984a. Nitrogen fixation, and N and dry matter partitioning during a 4-year alfalfa stand. Crop Sci. 24:811-815.

Heichel, G.H., G. Hardarson, D.K. Barnes and C.P. Vance. 1984b. Dinitrogen fixation, herbage yield, and Rhizobial preference of selected alfalfa clones. Crop Sci. 24:1093-1097

Heichel, G.H. and C.P. Vance. 1979. Nitrate-N and rhizobium strain roles in alfalfa seedlings nodulation and growth. Crop Sci. 19:512-518.

Heichel, G.H., C.P. Vance, D.K. Barnes and K.I. Henjum. 1985. Dinitrogen fixation, and N and dry matter distribution during a 4-year stands of birdsfoot trefoil and red clover. Crop Sci. 25:101-105.

Heichel, G.H., D.K. Barnes, C.P. Vance and C.C. Sheaffer. 1989. Dinitrogen fixation technologies for alfalfa improvement. J. Prod. Agric. 2:24-32.

Henson, R.A. and G.H. Heichel. 1984a. Partitioning of symbiotically fixed nitrogen in soybean and alfalfa. Crop Sci. 24:986-990.

Henson, R.A. and G.H. Heichel. 1984b. Dinitrogen fixation of soybean and alfalfa: Comparison of the isotope dilution and difference methods. Field Crops Research 9:333-346.

Hesterman, O.B., M.P. Russelle, C.C Sheaffer and G.H. Heichel. 1987. Nitrogen utilization from fertilizer and legume residues in legume-corn rotations. Agron. J. 79:726-731.

Hesterman, O.B., C.C. Sheaffer, D.K. Barnes, W.E. Leuchen and J.H. Ford. 1986b. Alfalfa dry matter and N production, and fertilizer N response in legume-corn rotations. Agron. J. 78:19-23.

Hesterman, O.B., C.C. Sheaffer and E.I. Fuller. 1986a. Economic comparison of crop rotations including alfalfa, soybean and corn. Agron. J. 78:24-28.

Hesterman O.O.B., L.R. Teuber and A.L. Livingston. 1981. Effect of environment and genotype on alfalfa sprout production. Crop Sci. 21:720-726.

Hoffman, D. and B. Melton. 1981. Variation among alfalfa cultivars for indices of nitrogen fixation. Crop Sci. 21:8-10.

Huebner, G. 1992. Forage Seed Production Manual.Manitoba Forage Seed Association, Manitoba, Canada. pp.1-62.

Kelner, D. 1994. Short term alfalfa stands in cropping systems: Benefits related to nitrogen. MSc. Thesis, University of Manitoba.

Kroonje, W. and W.R. Kehr. 1956. Legume top and root yields in the year of seeding and subsequent barley yield. Agron. J. 48:127-131.

LaRue, T.A. and T.G.Patterson. 1981. How much nitrogen do legumes fix? Adv. Agron. 34:15-38.

Liang, G.H.L. and W.A. Riededl. 1964. Agronomic traits influencing forage and seed yield in alfalfa. Crop Sci. 4:394-396.

McEwen, J. 1972. Effects of defoliating different zones of the plants in field beans (*Vicia faba*). J. Agric. Sci. 78: 487-490.

Moyer, J.R., K.W. Richards and G.B. Schaalje. 1991. Effect of plant density and herbicide application on alfalfa seed and weed. Can. J. Plant Sci. 71:481-489.

Muller, C.S. 1992. Recent developments in alfalfa seed production in California. Proceeding of 11th Annual Canadian Alfalfa and Forage Seed Conferences, Winnipeg, Manitoba. pp. 23-27.

Olson, K.D., N.E. Matin, D.R. Hicks and M.A. Schmitt. 1991. Economic analysis of including an annual forage in a corn-soybean farming system. J. Prod. Agric. 4:599-606.

Palmer, J.T. and I.W Foster. 1965. Observation on the pollination of lucerne. New Zealand J. of Agric. Res. 8:340-349.

Pankiw, P. 1975. Effects of isolation distance and border removal on contamination in red clover seed production. Can. J. Plant Sci. 55:391-395.

Pearson, C.J. and L.A Hunt. 1972. Effects of temperature on primary growth and regrowth of alfalfa. Can. J. Plant Sci. 52:1017-1027.

Pedersen, M.W., 1967. Cross-pollination studies involving three purple-flowered alfalfas, one white-flowered line, and two pollinator species. Crop Sci. 7:59-62.

Pedersen, M.W., G.E. Bohart, M.D. Levin, W.P. Nye, S.A. Taylor and J. L. Haddock. 1959. Cultural practices for alfalfa seed production. Utah Agric. Exp. Station Bulletin No. 408.

Pedersen, M.W., G.E. Bohart, V.L. Marble and E.C. Klostermeyer. 1972. Seed production practices. *In* C.H. Hanson (ed.) Alfalfa science and technology. Agronomy 15:689-720.

Pederson, M.W. and D.R. McAllister. 1955. Section 1. Agronomic Practices, in Growing Alfalfa for Seed. Agricultural Experiment station, Utah State Agric. College in cooperation with the USDA. Circular 135. pg. 7-19.

Pederson, M.W. and W.P. Nye. 1962. Alfalfa seed production: Part 11. Additional factors associated with seed yields. Utah Agric. Exp. Station Bulletin No. 436.

Peterson, M.A. and D.K. Barnes. 1981. Inheritance of ineffective nodulation and non-nodulating traits in alfalfa. Crop Sci. 21:611-616.

Peterson, A.T. and M.P.Russelle. 1991. Alfalfa and Nitrogen cycle in the Corn Belt. J. of Soil Water Conservation. 46:229-235.

Philips, D. A. and James P. Bennet. 1978. Measuring symbiotic nitrogen fixation in rangelands plots of Trifolium. Agron. J. 70:671-674.

Plews, K.W. 1973. A study of the influence of management practices in alfalfa seed production in Manitoba, MSc Thesis, University of Manitoba.

Poehlman, J.T. 1959. Breeding field crops. Henry Holt and Company, Inc. New York. pg. 360.

Porter, T.K. and J.H. Reynolds. 1975. Relationship of alfalfa cultivar yields to specific leaf weight, plant density, and chemical composition. Agro. J. 67:625-629.

Power, J.F. and J.A. Zachariasen. 1993. Relative nitrogen utilization by legume cover crop species at three soil temperatures. Agron. J. 85:134-140.

Rennie, R.J. 1984. Comparison of N balances and ^{15}N isotope dilution to quantify N_2 fixation in field grown legumes. Agron. J. 76:785-790.

Rice, W.A., P.E. Olsen, L.D. Bailey, V.O. Biederbeck and A.E. Slinkard. 1993. The use of annual legume green-manure crops as a substitute for summerfallow in the Peace River region. Can. J. Soil Sci. 73:243-252.

Richards, K.W. 1984. Alfalfa Leafcutter Bee Management in Western Canada. Publication 1495E. Research Branch, Agic. Canada, Ottawa, Ontario.

Rincker, C.M. 1976. Alfalfa seed yields from seeded rows vs. spaced transplants. Crop Sci. 16:268-270.

Rincker, C.M., V.L. Marble, D.E. Brown and C.A. Johansen. 1988. Seed production practices: pp. 985-1022 in A.A. Hanson, D.K. Barnes, and R. R. Hill (eds). Alfalfa and Alfalfa Improvement. Agronomy No. 29. Am. Soc. Agron., Inc. Madison, WI.

Rumbaugh, M.D. 1963. Effects of population density on some components of yield of alfalfa. Crop Sci. 5:423-424.

Ruschel, A.P., P.B. Vose, R.L. Victoria and E. Salatai. 1979. Comparison of isotope techniques and non-nodulating isolines to study the effect of ammonium fertilization on dinitrogen fixation in soybean, *Glycine max*. Plant Soil 53:513-525.

SAS Institute, Inc. 1988. SAS/STAT user's guide: Release 6.03 edition. SAS Inst., Inc. Cary, NC., U.S.A.

Sanderson, M.A. and R.M. Jones. 1993. Stand dynamics and yield components of alfalfa as affected by phosphorus fertility. Agron. J. 85:241-246.

Seatin, M.W. and D.K. Barnes. 1977. Variation among alfalfa genotypes for rate of acetylene reduction. Crop Sci. 17:783-787.

Schmid, A.R. and R. Behrens. 1972. Herbicides vs. oat companion crops for alfalfa establishment. Agron. J. 64:157-159.

Sheaffer, C.C., D.K. Barnes and G.H. Heichel. 1989. 'Annual' alfalfa in crop rotations. Minnessota Agric. Exp. Stat. University of Minnesota. Station Bulletin. 588.

Sheafer, C.C., D.K. Barnes, G.H. Heichel, G.C. Marten and W.E. Lueschen. 1988a. Seeding year nitrogen and dry matter yields of nondormant and moderately dormant alfalfa. J. Prod. Agic. 1:261-265.

Sheaffer, C.C., D.K. Barnes and G.C. Marten. 1988. Companion crop vs. solo seeding: Effect on alfalfa seeding year forage and N yields. J. Prod. Agric. 1:270-274.

Sheaffer, C.C., G.D. Lacefield and V.L. Marble. 1988b. Cutting Schedules and stands. In A.A. Hanson, D.K. Branes, and R.R. Hill, Jr. (eds.) Alfalfa and Alfalfa Improvement. Agron. Monogr. No. 29. Am. Soc. Agron., Madison, Wisc. pp. 411-437.

Sheaffer, C.C., M.P. Russelle, G.H. Heichel, M.H. Hall and F.E. Thicke. 1991. Nonharvested forage legumes: Nitrogen and dry matter yields and effects on a subsequent corn crop. J. Prod. Agric. 4:520-525.

Smith, D. 1956. Influences of fall cutting in the seeding year on the dry matter and nitrogen yields of legumes. Agron. J. 48:236-239.

Smith, S.R. Jr. 1992. Non-dormant alfalfa cultivar research project. Proceedings of the 11th Annual Canadian Alfalfa and Forage Seed Conference, Winnipeg, Manitoba. pp. 32-34.

Smith, S.R., Jr. and J.H. Bouton. 1989. Seed yield of grazing-tolerant alfalfa germplasms. Crop Sci. 29:1195-1199.

Smith, S.R. Jr., F. Katepa-Mupondwa and G. Heubner. 1993. Manitoba forage seed production in 1992: problems and opportunities. Presented at the Jan 7-8, 1993, Manitoba forage seed Assocaition Annual Meeting. Winnipeg, Manitoba.

Smith, S.R. Jr., F. Katepa-Mupondwa and G. Heubner. 1994. Manitoba forage seed production in 1992 and 1993. Presented at the Jan 17-18, 1994, Manitoba forage seed Assocaition Annual Meeting. Winnipeg, Manitoba.

Sparrow, S.D., V.L. Cochran and E.B. Sparrow. 1993. Herbage yield and nitrogen accumulation by seven legume crops on acid and neutral soils in a subarctic environment. Can. J. Plant Sci. 73:1037-1045.

Steel, R.G.D and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd ed. McGraw-Hill, New York, NY.

Stewart, B.A., Jr., F.G.Viets and G.L. Hutchinson. 1968. Agriculture's effect on nitrate pollution of groundwater. J. Soil and Water Cons. 23:13-15.

Stickler, F.C. and I.J. Johnson. 1959a. Dry matter and nitrogen production of legumes and legume association in the fall of the seeding year. Agron. J. 51:135-137.

Stickler, F.C. and I.J. Johnson. 1959b. The influence of clipping on dry matter and nitrogen production of legume green manures. Agron. J. 51:137-138.

Suzuki, M. 1991. Effects of stand age on agronomic, morphological, and chemical, characteristics of alfalfa. Can. J. Plant Sci. 71;445-452.

Talbott, H.J., W.J. Kenworthy and J.O. Legg. 1982. Field comparison of the Nitrogen-15 and difference methods of measuring nitrogen fixation. Agron. J. 74:799-804.

Taylor, S.A., J.L. Haddock and M.W. Pederson. 1959. Alfalfa irrigation for maximum seed production. Agron. J. 51:357-360.

Tesar, M.B. and V.L Marble. 1988. Alfalfa establishment. pp. 303-332 in A.A. Hanson et al (ed.) Alfalfa and alfalfa improvement. Agron. Madison. Monogr. 29. ASA, CSSA, and SSSA, Madison, WI.

Trimble, M.W, D.K. Barnes, G.H. Heichel and C.C. Sheaffer. 1987. Forage yield and nitrogen partitioning responses of alfalfa to two cutting regimes and three soil nitrogen regimes. Crop Sci. 27:909-914.

Tysdal, H.M. 1946. Influence of tripping, soil moisture, plant spacing, and lodging on alfalfa seed production. J. Amer. Soc. Agron. 38:515-535.

Vance, C.P., G.H. Heichel, D.K. Barnes, J.W. Bryan and L.E. Johnson. 1979. Nitrogen fixation, nodule development, and vegetative regrowth of alfalfa (Medicago sativa L.) following harvest. Plant Physiol. 64:1-8.

Vance, C.P., G.H. Heichel and D.A. Philips. 1988. Nodulation and symbiotic dinitrogen fixation. pp. 229-257, In A.A. Hanson et al., (eds.) Alfalfa and alfalfa improvement. Agronomy no. 29. Amer. Soc. Agron., Madison, WI.

Viands, D.R., D.K. Barnes and G.H. Heichel. 1981. Responses to bidirectional selection for characteristics associated with Nitrogen fixation in alfalfa. USDA Tech. Bulletin. 1645.

Viands, D.R., C.P. Vance, G.H. Heichel and D.K. Barnes. 1979. An ineffective nitrogen fixation trait in alfalfa. Crop Sci. 19;905-908.

Wagner, G.H. and F. Zapata. 1982. Field evaluation of reference crops in the study of nitrogen fixation by legumes using isotope techniques. Agron. J. 74:607-612.

Walter, L.E. and E.H. Jensen. 1970. Effect of environment during seed production on seedling vigour of two alfalfa varieties. Crop Sci. 10:635-638.

Weber, C.R. 1966. Nodulating and nondulating soybean isolines: Response to applied nitrogen and modified soil conditions. Agron. 58:46-49.

Williams, W.A., M.B. Jones and C.C. Delwiche. 1977. Clover N fixation measurement by Total N-Difference and ^{15}N A-values in lysimeters. Agron. J. 69:1023-1024.

7. Appendix

Nitrogen Fixation and Dry Matter Production During Seed Production in the Establishment Year

Table 1. Dry matter production by alfalfa (averaged over seeding rates and cultivars) at different growth stages (GS) when grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992 and 1993.

Year	Location	GS†	Root+crown DM	Herbage DM	Total DM
			kg ha^{-1}		
1992	Glenlea	LV	478	1186	1664
		T%B	1444	3600	3918
		F%B	1668	3166	4834
		Seed	2240	3180	5420
	Homewood	LV	357	1359	1716
		T%B	1203	2716	5044
		F%B	2050	3730	5780
		Seed	2399	3354	5720
1993	Glenlea	LV	587	880	1467
		T%B	755	1281	2036
		F%B	1348	2454	3802
		Seed	1701	2235	3936
	Homewood	LV	572	838	1410
		T%B	911	1732	2643
		F%B	1315	2278	3594
		Seed	1745	2475	4219

† Growth stages are as follows: LV-late vegetative, T%B-10 to 20 % bloom, F%B-50% to full bloom and Seed-mature seed stage.

Table 2. Total N yield by alfalfa (averaged over seeding rates and cultivars) at different growth stages when grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992 and 1993.

Year	Location	GS†	Root+crown N	Herbage N	Total N
			kg N ha^{-1}		
1992	Glenlea	LV	11	32	42
		T%B	39	107	145
		F%B	40	72	113
		Seed‡	59	75	134
	Homewood	LV	8	55	62
		T%B	32	83	115
		F%B	60	103	163
		Seed‡	60	83	143
1993	Glenlea	LV	13	36	49
		T%B	16	41	57
		F%B	26	74	99
		Seed	43	60	100
	Homewood	LV	13	31	44
		T%B	17	47	62
		F%B	24	56	80
		Seed	42	60	102

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.

Table 3. Total (herbage and root plus crown) percentage nitrogen derived from atmosphere (%Ndfa) of four alfalfa cultivars (averaged over location and seeding rates) at different growth stages when grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992 and 1993.

		Growth stages†			
Year	Cultivars	LV	T%B	F%B	Seed
		$kg\ ha^{-1}$			
1992	Algonquin	30a‡	41a	37a	38a
	Saranac	47a	39a	41a	40a
	Nitro	37a	46a	34a	49a
	CUF 101	35a	43a	35a	45a
	CV (%)§	42	44	38	42
1993	Algonquin	35a‡	48a	60a	62a
	Saranac	36a	58a	64a	56a
	Nitro	43a	39a	56a	60a
	CUF 101	38a	49a	59a	62a
	CV (%)	36	28	27	23

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a column (growth stage) in a year, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Coefficient of variation (%).

Table 4. Total (herbage and root plus crown) and root plus crown N_2-fixed (kg N ha^{-1}) of alfalfa for different growth stages when grown at two seeding rates (SR) during establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992 and 1993.

Year	SR‡	Growth stages†			
		LV	T%B	F%B	Seed
		Total (herbage and root plus crown) N_2-fixed			
		---kg N ha^{-1}---			
1992	High	27.6a§	60.5a	59.7a	67.2a
	Low	16.9b	66.3a	47.9a	78.9a
1993	High	31.2a	37.8a	65.9a	78.5a
	Low	14.1a	32.3a	66.3a	62.4a
		Root plus crown N_2-fixed			
		---kg N ha^{-1}---			
1992	High	6.8a	22.9a	28.6a	35.1a
	Low	3.2a	22.4a	17.2a	31.3a
1993	High	8.0a	10.9a	15.8a	28.9a
	Low	4.3a	8.9a	17.1a	27.4a

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Seeding rates (SR) are: High (16.8 kg ha^{-1}) and Low (3.36 kg ha^{-1}).
§ Within a column (growth stage) in a year, and for each trait measured, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).

Table 5. Total (herbage and root plus crown) N_2-fixed (kg N ha^{-1}) of four alfalfa cultivars (averaged over location and seeding rates) at different growth stages when grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992 and 1993.

Year	Cultivars	Growth stages†			
		LV	T%B	F%B	Seed
		kg ha^{-1}			
1992	Algonquin	15a‡	65a	55a	53a
	Saranac	22a	57a	63a	73a
	Nitro	31a	70a	48a	88a
	CUF 101	22a	62a	50a	79a
	CV (%)§	67	68	66	61
1993	Algonquin	22a‡	37a	71a	76a
	Saranac	21a	45a	75a	71a
	Nitro	29a	28a	61a	67a
	CUF 101	19a	30a	59a	66a
	CV (%)	47	35	46	25

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a column (growth stage) ina year, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Coefficient of variation (%).

Table 6. Root plus crown) N_2-fixed (kg N ha^{-1}) of four alfalfa cultivars (averaged over location and seeding rates) at different growth stages when grown for establishment year seed production at Glenlea and Homewood in southern Manitoba in 1992 and 1993.

Year	Cultivars	Growth stages†			
		LV	T%B	F%B	Seed
		--------------------kg ha^{-1}			------------------
1992	Algonquin	3a‡	14a	20a	26a
	Saranac	5a	17a	22a	35a
	Nitro	7a	31a	23a	36a
	CUF 101	5a	28a	26a	36a
	CV (%)§	62	60	86	62
1993	Algonquin	5a‡	8a	15a	30a
	Saranac	5a	12a	18a	27a
	Nitro	8a	9a	17a	31a
	CUF 101	6a	11a	16a	24a
	CV (%)	51	35	59	42

† Growth stages are as follows: LV=late vegetative, T%B=10 to 20 % bloom, F%B=50% to full bloom and Seed=mature seed stage.
‡ Within a column (growth stage) in a year, means followed by the same letter are not significantly different based on Fisher's protected LSD ($P \leq 0.05$).
§ Coefficient of variation (%).

Table 7. Monthly precipitation and mean temperature (long term averages [LTA (1967 to 1991), 1992, and 1993] for the growing season at Glenlea, Manitoba†.

Month	LTA (1967 to 1991)	Year‡ 1992	1993
	Average monthly temperature (°C)		
May	12.0	13.2	11.3
June	16.7	15.1	15.1
July	19.4	15.2	17.5
August	17.7	16.3	17.6
September	12.7	11.4	10.4
October	4.8	4.6	2.9
	Total monthly precipitation (mm)		
May	57.8	26.4	41.0
June	95.9	98.4	72.8
July	72.2	95.8	246.0
August	59.7	68.0	160.0
September	54.5	70.4	31.8
October	39.3	3.8	39.8

† Complete data was not available for Homewood, Manitoba (the other site for the experiment), however precipitation data was obtained for months of July (228 mm), August (70 mm), and September (4 mm) from a data logger placed on the experimental plots.
‡ Data obtained from Environmental Canada