PASTURE RENOVATION:

INTRODUCTION OF LEGUMES IN A GRASS DOMINATED PASTURE WITH PHYSICAL SUPPRESSION OF THE RESIDENT VEGETATION

By

Philippe Seguin

Department of Plant Science
McGill University, Macdonald Campus
Ste-Anne-de-Bellevue, Qc., Canada

May 1997

A thesis submitted to the Faculty of Graduate Studies
and Research in partial fulfilment of the
requirements for the degree of
Master of Science

0-612-37165-4

Suggested short title:

PHYSICAL SOD SUPPRESSION DURING PASTURE RENOVATION WITH CLOVER

P. Seguin

ABSTRACT

Herbicide sod suppression during pasture renovation by legume sod-seeding often results in the loss of potentially usable forage, weed encroachment, and inadequate grass-legume ratios. A study was conducted to investigate the viability of sod suppression by sheep grazing or mowing, as alternatives to herbicide, during pasture renovation with no-till seeding of red clover (*Trifolium pratense* L.) or white clover (*Trifolium repens* L.). Sod suppression methods evaluated were: strategically timed mowing or sheep grazing to 5 or 10 cm at seeding and during legume establishment, or similarly managed mowing or sheep grazing with an additional defoliation to 5 cm the previous fall. Additional treatments included suppression by herbicide and, unsuppressed and unseeded controls. Treatments were evaluated by determining clover plant population, botanical composition, forage yield and quality. Physical (mowing or grazing) and herbicide sod suppression resulted in similar clover plant populations; clover yields tended to be higher with herbicide suppression. However, increasing the intensity of physical suppression increased clover yields. Forage quality was increased only with sod suppression by grazing or herbicide when compared with the unimproved control. Although, for grazing this was attributed to a more frequent defoliation regime and not to the renovation itself. Unlike suppression with herbicide, physical suppression did not decrease total seasonal forage yields in the renovation year when compared with controls.

RÉSUMÉ

La rénovation de pâturages via l'introduction de légumineuses par semis direct avec la suppression par herbicide de la végétation résidente, résulte souvent en: la perte de fourrage potentiellement utilisable, l'invasion du pâturage par des mauvaises herbes, et des ratios graminées-légumineuses inapropriés. Une étude fut conduite afin de déterminer la viabilité de la suppression de la végétation résidente par tonte mécanique ou paissance (moutons), comme alternatives à l'utilisation d'herbicide au cours de la rénovation de pâturages par le semis direct de trèfle rouge (*Trifolium pratense* L.) ou blanc (*Trifolium repens* L.). Les méthodes de suppression de la végétation résidente furent: la tonte mécanique ou la paissance à intervalles stratégique, à une hauteur résiduelle de 5 ou 10 cm au cours du semis et durant l'établissement des légumineuses, ou une tonte mécanique ou animale de façon similaire mais avec une défoliation additionnelle au cours de l'automne précédant. Les traitements additionnels inclurent la suppression par herbicide ainsi que des contrôles semés sans suppression de la végétation ou bien non-semés. Les traitements furent évalués grâce à la détermination de la population de trèfle, la composition botanique, ainsi que les rendements et la qualité du fourrage. La suppression physique (tonte mécanique ou paissance) et par herbicide résultèrent en des population de trèfle similaires. Le rendement en trèfle fut supérieur avec l'utilisation d'herbicide. Cependant, une augmentation de la sévérité des méthodes de suppression physique résulta en des rendements de trèfle supérieurs. La qualité du fourrage fut accrue uniquement lorsque la végétation résidante fut supprimée par paissance ou par herbicide, si comparé à un contrôle non rénové. Par contre pour la suppression par paissance ceci fut attribué à des défoliations plus fréquentes, et non au processus de rénovation. Contrairement à la suppression par herbicide, la suppression physique ne résulta pas en une réduction des rendements fourrager au cours de l'année de rénovation.

ACKNOWLEDGMENTS

I would like to thank my supervisor and thesis director, Dr. P.R. Peterson for many helpful discussions, and his guidance during the course of this study; as well as for his availability, help, and encouragement. Also, I would like to thank him for giving me the chance to undertake this project. I would like also to thank Dr. D.L. Smith, who took over my supervision at the end of this study, especially for his rapidity in giving me back reviewed material, despite a very busy schedule.

I would like also to thank the members of my committee: Drs. Toni DiTommaso and Katrine Stewart, for their support and interest during the course of this work. I wish to thank Dr. Pierre Dutilleul for his encouragement, great statistical knowledge and for giving me the opportunity to be a teaching assistant for his statistics course in 1996-1997.

I also thank the technicians of the "Emile A. Lods Agronomy Research Centre" of McGill University: Wendy Asbil, Scott Couture, Jim Straughton, and Stuart Willox; as well as all the summer students and colleagues who helped me in the field: Farial Karimian, Wen Li, Mario Lira jr., and Tiger. A special thanks to Stephen R. Kramer and Bob Allhouse of the "William H. Miner Agricultural Research Institute" for their help and the training required for the quality analysis of my samples, as well as for the use of their laboratory facilities and equipment. Also, I would like to thank everybody in the Plant Science Department, as well as Patrice, Pierre, Nicolas and Karim for their friendship during all those years.

I am grateful to the Fonds pour la Formation de Chercheurs et l'Aide à la Recherche (FCAR) for financial support.

I would like to acknowledge my family, to which I dedicate this thesis, Dr. Hermas Seguin, Mrs. Annick Seguin and Mr. Charles Seguin, for the education they gave me, as well as their constant support and love. Finally, I would like to thank Farial for her love and support during the course of this work, as well as her patience during my numerous absences.

CONTRIBUTIONS OF CO-AUTHORS TO MANUSCRIPTS FOR PUBLICATION

This thesis is submitted in the form of original papers suitable for journal publications. The first section is a general introduction followed by a literature review placing the research in its context and presenting the theory and previous knowledge on this topic. The next two sections represent the body of the thesis (each being a complete manuscript). The last section is a general discussion and a synthesis of the major conclusions. This format has been approved by the faculty of Graduate Studies and Research, McGill University, and follows the conditions outlined in the Guidelines Concerning Thesis Preparation, section B.2 "Manuscript and Authorship" which state as follows:

"The candidate has the option, **subject to the approval of their Department**, of including as part of their thesis, copies of the text of a paper(s) submitted for publication, or the clearly duplicated text of a published paper(s), provided that these copies are bound as an integral part of the thesis.

If this option is chosen, **connecting texts, providing logical bridges between the different papers, are mandatory**.

The thesis must still conform to all other requirements of the "Guidelines Concerning Thesis Preparation" and should be in a literary format. It should be more than a mere collection of manuscripts published or to be published. The thesis must include, as separate chapters or sections: (1) a Table of Contents, (2) a general abstract in English and French, (3) an introduction which clearly states the rationale and objectives of the thesis, (4) a comprehensive review of the background literature to the subject of the thesis, when this review is appropriate, and (5) a final overall conclusion and/or summary.

Additional material (procedural and design data as well as descriptions of equipment) must be provided where appropriate and sufficient detail (e.g. in appendices) to allow a clear and precise judgment to be made of the importance and originality of the research reported in the thesis.

In the case of manuscripts co-authored by the candidate and others, **the candidate is required to make explicit statement in the thesis of who contributed to such work and to what extent**; supervisors must attest to the accuracy of such claims at the Ph.D. Oral Defense. Since the task of the Examiners is made more difficult in these cases, it is in the candidate's interest to make perfectly clear the responsibilities of the different authors of co-authored papers."

Although all the work presented herein is the responsibility of the candidate, the project was supervised by Dr. P.R. Peterson, Department of Crop and Soil Environment Sciences, Virginia Polytechnic Institute and State University; and Dr. D.L. Smith, Department of Plant Science, Macdonald Campus of McGill University. Both manuscripts are co-authored by myself, Dr. P.R. Peterson and Dr. D.L. Smith. Dr. P.R. Peterson provided funds and assistance for this research, including supervisory guidance and the reviewing of manuscripts; Dr. D.L. Smith reviewed manuscripts.

For consistency and convenience all manuscripts follow the same format. The copies that will be sent to the respective journals, however will follow the requirements of each journal. The first manuscript "Physical sod suppression effects on productivity and composition following pasture renovation with clover" will be sent to the Journal of Agronomy and Crop Science, the second "Research note: Forage quality following pasture renovation by legume sod-seeding with herbicide or physical sod suppression" to Grass and Forage Science.

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1.0 GENERAL INTRODUCTION

In the last decade, there have been a number of political and economic changes that are affecting Quebec agriculture. International agreements such as GATT and NAFTA, numerous cuts in subsidies from both federal and provincial governments, and new environmental policies, will force Quebec livestock and dairy producers to find alternatives to current production practices. It is now crucial for the Quebec agricultural sector to adapt to these changes, by finding viable methods to produce at a lower cost with minimal governmental participation and minimal effects on the environment.

One area where there is considerable possibility for improvement is animal nutrition. Most Quebec dairy producers rely heavily on concentrates and conserved forages, both of which are costly, and minimize the use of pasture. One reason for this is that pastures are typically poorly managed and thus have low availabilities of quality forage. Most pastures are characterized by low producing grass and weed species that tend to be of low quality. Whereas leguminous species offer a greater nutritional quality, they are less persistent than grass species (Kunelius et al., 1982). Pasture nutritional quality and production can be improved by renovating old grass-dominated pastures.

Renovation entails the introduction of desirable forage species, usually legumes such as red clover (*Trifolium pratense* L.), white clover (*Trifolium repens* L.) or birdsfoot trefoil (*Lotus corniculatus* L.); or legume-based mixtures into a grass-dominated pasture (Sprague, 1960; Robinson and Winch, 1985). The introduction of the legumes can be done by: direct seeding which involves plowing (Decker and Taylor, 1985; Robinson and Winch, 1985), oversowing (broadcasting seeds onto the sod) (Cullen, 1970; Asbil and Coulman, 1992) or sod-seeding (drilling seeds) (Kunelius et al., 1982; Kunelius and Campbell, 1984). The introduced legumes benefit the pasture in three ways:

i) they eliminate the need for application of costly N fertilizers, due to N_2 fixation by the legumes and transfer of this fixed N to spatially associated grasses (Haynes, 1980; Decker and Taylor, 1985; Frame and Newbould, 1986);

ii) they permit the stabilization of forage dry matter (DM) production throughout the year, due to differences in seasonal yield distribution among grass and legume species (Haynes, 1980; Robinson and Winch, 1985), and;

iii) they increase the quality of forage available to grazing animals (Frame and Newbould; 1986).

For renovation to be successful, the resident vegetation must be adequately suppressed or controlled. Methods of sod suppression have included full cultivation, reduced tillage, herbicides, grazing, or some combination of these (Robinson and Cross, 1960; Wilkinson and Gross, 1964; Taylor et al., 1969; Groya and Scheaffer, 1981; Vogel et al., 1983; Robinson and Winch, 1985; Evers, 1988). Sod suppression ensures adequate establishment of the introduced forage species by reducing the competition between the newly seeded forage species and the resident vegetation.

These establishment and vegetation suppression methods vary in environmental impact, associated cost, and efficiency. Indeed, renovation with conventional tillage (direct seeding) is associated with high costs, a loss of production in the seeding year, and high erosion potential. Renovation by oversowing has several disadvantages. It is thought to put additional stress on the seedling in the establishment phase, when compared with other establishment methods. Also the seeding rates required to obtain adequate stands are double those used with conventional tillage, and seeding must be done in early spring, a time when field access is often limited (Mueller and Chamblee, 1984). This method may be best suited for localized renovation, not for renovation of an entire pasture.

Renovation by sod-seeding may minimize adverse environmental effects and reduce costs. Results obtained with sod-seeding are, however, extremely variable, and no conclusive data exist to demonstrate the viability of this method in Quebec and Eastern Canada (Rioux, 1979; Kunelius and Campbell, 1986; Rioux, 1994). A disadvantage of renovation by sod-seeding is that herbicides are often used to control the resident vegetation. The use of herbicides represents both economic (Jubinville et al., 1988) and environmental costs. In addition, suppression by herbicides often results in a loss of potentially usable forage in the seeding year, due to excessive sod suppression, as well as weed encroachment and inappropriate grass-legume ratios.

Few studies have focused on the viability of legume sod-seeding with physical suppression of the resident vegetation, which could alleviate some of the problems associated with herbicide suppression. Although it has proven to be successful in several studies, none have looked at the particular sod management that would give maximal chances of successful legume establishment in eastern Canada. Kunelius et al. (1982) underlined the need for research on improved grass sod management techniques.

The current research will investigate alternative strategies for pasture renovation by legume sod-seeding. Red and white clover will be used. The choice of white clover is justified by its importance in Quebec pastures and that of red clover by the excellent results reported when established by sod-seeding. Also, it has been reported to be the most reliable species in eastern Canada (Kunelius and Campbell, 1984).

Research goals:

1) determine the effects of sod suppression methods on pasture botanical composition,

2) determine the effects of sod suppression methods on forage yields,

3) determine the effects of sod suppression methods on forage quality,

4) find alternatives to herbicides as the method of resident vegetation control, both grazing and mowing will be investigated.

Research hypothesis: Legume sod-seeding with physical suppression of the grass sod, can allow favourable legume establishment, while increasing forage quality and preserving yields in the renovation year.

This research will help Quebec livestock producers, by providing them information on the viability of modified sod-seeding technologies for renovating pasture, that could be easily integrated into rotational grazing systems. These technologies would be consistent with the new standards for production techniques, ones associated with lower costs and minimal effects on the environment.

2.0 LITERATURE REVIEW

2.1 PASTURE DYNAMICS AND GRASS-LEGUME INTERFERENCE.

The success of legume sod-seeding in a grass dominated sod depends on the outcome of interference amongst legumes, grasses, weeds and herbivores. It is thus essential to identify the various types, sources and usual outcome of interference among these three pasture components. The pasture ecosystem must be fully understood in order to elaborate reliable and viable sod-seeding techniques.

2.1.1 Types and Sources of Interference.

The various sources or factors of competition will be presented separately; however, it is important to remember that the competition for each of these will vary depending on the availability of the others.

2.1.1.1 Competitive Interactions

2.1.1.1.1 LIGHT: Competition for light has been reported to be one of the most important sources of competition during legume establishment in a grass sod (Wilkinson and Gross, 1964; Groya and Scheaffer, 1981). Most legumes have greater light requirements and lower tolerances to shading than grasses (Haynes, 1980; Frame and Newbould, 1986; Michaud, 1989).

The reason for the poor light competitive ability of legumes is essentially morphological. Legumes tend to have horizontally oriented leaves, which allows them to intercept light from only a few layers of leaves. This makes them more susceptible to shading than grasses which, apart from being generally taller, have a more even light absorption distribution (Haynes, 1980). Shading often leads to a reduction of both root and nodule mass, which jeopardizes subsequent legume growth (Frame and Newbould, 1986). However, leguminous species vary in their susceptibility to shading (Gist and Mott, 1957). For example, when shaded, white clover has the ability to extend its petioles and thus place leaves in areas with higher light intensity (Frame and Newbould, 1986). Butler (1959) reported that among the most commonly used leguminous species, white clover and birdsfoot trefoil were the most susceptible to shading, and alfalfa (*Medicago sativa* L.) and red clover the least.

With legume sod-seeding, grass competition for light is critical in the period following germination. Once legumes have emerged and used the starch reserves stored in the seed, they are dependent on light for the production of carbohydrates (Robinson and Cross, 1960). Thus, sufficient control of the grass vegetation must be provided to ensure proper legume establishment and growth.

2.1.1.1.2 NUTRIENTS: Competition for nutrients has been reported to be of greater importance than competition for light in some studies (Haynes, 1980). Indeed, competition for nutrients greatly affects the rate of growth which in turn influences competition for light.

With grass-legume mixtures, plant nitrogen (N) is derived from both mineral forms and N_2 fixation. Usually, high soil mineral N levels are detrimental to legumes. High mineral N levels reduce nodulation and thus N_2 fixation, favour vigorous grass growth, and thus generally lead to a decrease in legume populations (Ledgard and Steele, 1992). Interestingly, N_2 fixation by a legume ultimately acts against itself in a grass-legume association. Indeed, N_2 fixation contributes in increasing the N level of the soil, thus benefitting grass growth and competitiveness (Ledgard and Steele, 1992). But N_2 fixation confers a competitive advantage over grasses when soil N levels are low.

Grasses are generally more competitive for immobile elements, such as P, K, and S, due to differences in root morphology (Haynes, 1980). Indeed, legumes tend to have less ramified root systems than grasses (Metcalfe and Nelson, 1985). However, infection of legume roots by vesicular-arbuscular mycorrhizal fungi (VAM) allows legumes to exploit a larger soil volume (Haynes, 1980). P is critical during legume establishment and often banded P will result in improved stands (Decker and Taylor, 1983).

Legumes are poor competitors for K^+ and other cations with a single positive charge compared with grasses because they have a higher cation exchange capacity (CEC) (Asher and Ozanne, 1961). When grown together in solution, legumes become deficient in K

(Mengel and Kirkby, 1980). As a result of their high root negative charge (due to a high CEC), legumes are more prone to absorb divalent cations and thus fewer monovalent cations such as K^- (Haynes, 1980).

2.1.1.1.3 MOISTURE: The importance of competition for moisture in a grass-legume mixture varies by region and season. Grasses are generally more competitive than legumes for water for two reasons. First, the more ramified root system of grasses allows them to exploit a greater volume of soil for water uptake (Haynes, 1980). The exception to this is alfalfa which has a root system that can penetrate deeper in soil than any other pasture species. Peterson (1972) reported that under some conditions alfalfa roots can penetrate soil as deep as 10 m. Second, grasses tend to have greater water use efficiency (WUE) than legumes due, in part, to a greater ability to control stomatal opening (Haynes, 1980).

Competition for these three resources (light, nutrients and moisture) places legume seedlings at a competitive disadvantage against vigorous, well-established grasses.

2.1.1.2 Allelochemical Interactions

Allelopathy can be defined as a direct or indirect adverse effect on growth exerted by one plant on its neighbouring plants via the production of chemical substances (Rice, 1979; Fuerst and Putnam, 1983). It is especially of concern in pasture and no-till situations because it occurs more often where plant residues are left on the soil surface (Haynes, 1980). However, as Fuerst and Putnam (1983) underlined, it is difficult to assess or determine the importance of allelopathy in those systems. Despite this fact, Smith and Martin (1994) showed that aqueous extracts of tall fescue (*Festuca arundinacea* Schreb.), Italian ryegrass (*Lolium multiflorum* Lam.) and little barley (*Critesion pusillum* Nutt.) were able to reduce alfalfa seed germination and seedling growth in bioassays. There have also been reports of autoallelopathy, for example, alfalfa produces allelochemicals that reduce germination and rate of seedling growth of its own species (Guenzi et al., 1964). Autoallelopathy might be a way to limit potential competition between plants of a same species.

2.1.1.3 Herbivorous Interferences

The impact of grazing animals on the pasture ecosystem is an extremely broad topic of study. This review will focus only on points of relevance to the present study.

Most of the effects of herbivores on pasture plant populations can be attributed to defoliation (Curll and Wilkins, 1982b). The impact of grazing on a grass-legume mixture depends on the type of animal present (Briseno de la Hoz and Wilman, 1981; Yarrow and Penning, 1994). This arises essentially from differences in selectivity due to differences in mouth anatomy (Matches, 1992). Indeed, sheep are much more selective than cattle. Sheep tend to graze on legumes more than grasses at both low (Frame and Newbould, 1986) and high stocking rates (Laidlaw, 1983), because of a higher palatability of legumes compared to grasses. This often leads to excessive legume defoliation . For white clover, this results in a more prostate growth form (Frame and Newbould, 1986), a decrease in stolon production (Curll and Wilkins, 1982b), and a reduction in photosynthetic potential (Parsons et al., 1991). Thus under sheep grazing, the proportion of legumes will often decrease immediately followed by the establishment of a lower equilibrium which will be maintained over the long term (Yarrow and Penning, 1994). In contrast, cattle grazing does not affect grass-legume proportions, due mainly to less selective grazing (Yarrow and Penning, 1994). Cattle grazing has a similar effect to that of cutting (Briseno de la Hoz and Wilman, 1981). Grazing frequency and severity also affect pasture plant populations. This aspect will be discussed in more details in the following section.

Treading can generate substantial damage to pasture plants, especially legumes (Matches, 1992). Edmond (1964) showed that there is a great difference among species in susceptibility to treading. Indeed Kentucky bluegrass (*Poa pratensis* L.) yield was reduced by 30% due to treading by 79 sheep ha^{-1}. In the same experiment, treading reduced white clover and red clover yields by 60% and 87%, respectively. These yield reductions were attributed to damage to growing points, leaves, roots and stems (Matches, 1992). Thus, treading can be expected to cause shifts in botanical composition.

Finally, grazing animals affect the pasture plant population via the return of excreta.

Generally, excreta benefit grasses more than legumes, due to a stimulation of their growth and competitiveness by excreted N (Ledgard et al. 1996). In addition, legumes are more prone to urine burn than grasses (Frame and Newbould, 1986). However, P and K in urine and feces can benefit legumes.

In summary, the pasture ecosystem is a complex one where several types of interferences can result in a low proportion of legumes compared with grasses.

2.1.2 Management Effects on the Pasture Population

The effect of pasture management on grass-legume dynamics has been extensively studied. Perron and Germain (1988) reviewed pasture management for Quebec. The severity (ie: height) and frequency (ie: timing) of defoliation are the two main pasture management variables (Frame and Newbould, 1986).

It is well documented that frequency of defoliation greatly influences pasture production and grass:legume ratio. In general, increasing the interval between cuts or grazing periods increases total forage production. However, there is a point at which increasing this interval may actually reduces forage production (Frame and Newbould, 1986); because some species can benefit from more frequent defoliations via, for example, an increase in tiller production, or a modification of plant morphology or physiological characteristics. After a certain regrowth period, average regrowth rate reach a ceiling value. Defoliation should occur before this value is reached (Robson et al., 1989). Frequency of defoliation can be managed in two ways in a pasture. First, under continuous grazing, frequency can be reduced by decreasing stocking rates (Curll and Wilkins, 1982a). Second, management intensive grazing (MIG) or rotational grazing facilitates precise management of defoliation frequency (Gerrish et al., 1994; Peterson, 1995). The optimal grazing frequency recommended in Quebec is 4 times per grazing season (Perron and Germain, 1988). This allows a regrowth period of approximately 30 days between each of the 4 grazing events. This favours legume persistence and a good grass:legume ratio. Whereas with 2 grazing cycles per season, which provides maximum yields, legumes fail to persist (Perron and Germain, 1988).

Optimal severity of defoliation varies with species; and few definitive recommendations actually exist (Drapeau, 1983). A residual height of 5 cm would appear to be suitable for most of the common grass-legume associations (Drapeau, 1983; Perron and Germain, 1988). However, more severe defoliation could be beneficial to legumes. As reported by Perron and Germain (1988), white clover produced greater yields with a 3.75 cm than a 7 cm cutting height. For grasses, responses were reported to be similar. Frame and Newbould (1986) attributed an increase in the number of nodules and growing points in white clover to increased light availability. These morphological changes resulted in increased legume content in the sward. Early research by Robinson and Sprague (1947) showed that white clover percentage in a sward increased from 36% when the sward was cut to 5 cm, when it had reached 11.5 cm, to 57% when cut to 1.25 cm. As for the impact of defoliation height on grass yield and persistence, it varies with species (Jones, 1983). In a three year study, low cutting height (5 cm) resulted in lower yield and persistence of ryegrass (*Lolium perenne* L.) and Italian ryegrass compared with cutting at 8 cm. Yields of orchardgrass (*Dactylis glomerata* L.), meadow fescue (*Festuca pretensis* Huds.) and tall fescue increased in the second harvest year but decreased in subsequent years, with a low cutting height compared with a higher cutting height.

2.2 LEGUME SOD-SEEDING

2.2.1 Potential Benefits

Sod-seeding has resulted in successful legume establishment in a wide range of climatic and edaphic conditions, in regions as diverse as: eastern Canada (Kunelius et al., 1982 and 1987), south eastern U.S.A. (Decker et al., 1969), central Canada (Schellenberg et al., 1994), central U.S.A. (Olsen et al., 1981; Sheaffer and Swanson, 1982), Japan (Nada and Takahashi, 1988), New Zealand (Campbell, 1985) and Europe (Davies and Davies, 1981). For example, 60 days after seeding birdsfoot trefoil, Olsen et al. (1981) obtained densities of 152 plants m^{-2}, and legume yields of 7.3 tons ha^{-1} the year following seeding, this representing more than 50% of the total forage production for the year (13.4 tons ha^{-1}).

Legume sod-seeding in grass dominated sods is beneficial in several ways. First, sod-seeded legumes increase total forage production. Kunelius and Campbell (1984) reported total season yield increases of 46, 34, and 12% for sod-seeded red clover, white clover, and alfalfa, respectively when compared with the unimproved control the year after seeding. In another study, swards with sod-seeded white and red clover had greater total forage DM yields (8.2 and 8.0 tons ha^{-1}, respectively) than a N fertilized control (6.7 tons ha^{-1}) in the year after seeding (Kunelius, 1982). Similar results have been obtained in other studies (Taylor and Allinson, 1983; Koch et al., 1987).

Second, introduction of legumes increases pasture forage quality. Taylor and Allinson (1983) reported that red clover sod-seeding resulted in greater crude protein yields (CP) (0.45 ton ha^{-1}) when compared with a grass control (0.38 ton ha^{-1}). In some cases, legume sod-seeding even resulted in CP yields similar to those obtained with N fertilized controls (276 vs. 266 kg ha^{-1}) (Kunelius and Campbell, 1984). An increase in digestible dry matter yield (DDM) in the seeding year and the two following years was also reported when compared with an unimproved grass control (Taylor and Allinson, 1983). Increased forage quality provided by legume sod-seeding results in increased animal performance, by increasing DM intake, N intake and body tissue retention of N by dairy animals, when compared with a N fertilized control (Koch et al., 1987).

Although pasture renovation by legume sod-seeding has many potential benefits, results reported to date are highly variable. As reported earlier, low legume persistence (Kunelius et al., 1982), inconsistent results (Rioux, 1994), and excessive grass suppression resulting in: undesirable grass:legume ratio (Muller-Warrant and Koch, 1983), weed encroachment (Rioux, 1994), and loss of potentially usable forage in the seeding year (Bryan, 1985); are often associated with legume sod-seeding. Management factors involved in the sod-seeding process warrant further discussion and investigation.

2.2.2 Suitability of Various Legumes to Sod-Seeding

2.2.2.1 Legume Species

Leguminous species vary in suitability for sod-seeding. As underlined by Robinson and Cross (1960), the success of legume sod-seeding in a grass sod, depends, in part, on the inherent ability of the legume species to compete with grass. Tolerance to shading and lack of moisture are of greatest importance.

The most encouraging results to date has been obtained with red clover (Belzile, 1988). However, white clover, birdsfoot trefoil, and alfalfa have also been successfully established using this method (Olsen et al., 1981; Kunelius and Campbell, 1984). Crownvetch (*Cornilla varia* L.) generally fails to establish with sod-seeding (Olsen et al., 1981; Taylor and Allinson, 1983); however, Decker et al. (1969) reported successful crownvetch sod-seeding.

2.2.2.2 Cultivar Effects

Cultivars within a species vary in suitability for sod-seeding. For example 'Anik' alfalfa had variable establishment and poor persistence whereas 'Anchor' alfalfa had good establishment and persistence 3 years after seeding (Kunelius and Campbell 1984). Red clover swards sod-seeded with 'Lakeland' produced 4,296 kg ha^{-1} of forage DM in the seeding year whereas swards sod-seeded with 'Altaswede' produced only 2,913 kg ha^{-1}. Interestingly, in the second and third years, results were reversed with a significantly higher forage DM production with 'Altaswede'. Schellenberg et al. (1994) reported differences among alfalfa cultivars for suitability to sod-seeding. In some years, 'Rangelander' produced higher seedling counts than 'SCMf3713'. Selection of cultivars for sod-seeding should be based upon resistance to shading and drought and ability to persist (Robinson and Cross, 1960).

2.2.3 Factors Determining the Outcome of Legume Sod-Seeding During Seeding Operations

2.2.3.1 Seeding Date

Sod-seeding can be performed in spring or fall. Adequate moisture is essential (Taylor et al., 1969; Muller-Warrant and Koch, 1980). In Quebec, higher soil moisture levels occur in the spring; however, grass competitiveness is greatest at this time. In summer and fall, grass growth and competitiveness are lower. However, soil moisture is also generally low.

To take advantage of the better soil moisture status associated with a spring seeding, it is critical to adequately control grass competition.

Martin et al. (1983) observed that spring sod-seeding (late April, early May and late May), resulted in greater alfalfa DM yields in both the seeding and post-seeding years than early June seeding. This is in accordance with Kunelius and Campbell (1983) who documented late April to late May as being most suitable for sod-seeding of both red clover and alfalfa in eastern Canada. Later seeding dates (late June and July) result in lower plant counts, total forage DM yields, legume DM yields and CP yields in the seeding year. The best spring seeding date was dependent upon the level of grass suppression and the herbicide used (ie: late April with Dalapon and late May with glyphosate applied in spring). When spraying occurred at seeding, Dalapon effectively controlled grass at all spring seeding dates, whereas glyphosate was effective only in early and late May. Mueller-Warrant and Koch (1983) also observed a difference in optimal spring seeding date depending on the herbicide used. In addition, they showed that when glyphosate (2.1 kg ha^{-1}) was applied in mid-October to control grass, an early May seeding date result in greater alfalfa DM yields in the seeding year (1,100 kg ha^{-1}) and post-seeding year (3,700 kg ha^{-1}) compared with mid-May seeding (800 and 3,200 kg ha^{-1}, respectively).

Rioux (1979) identified the first week of August as the best sod-seeding date for red clover in late summer-early fall. Later dates do not allow sufficient grass suppression and red clover development; thus winter survival is poor. With fall seeding, efficiency of herbicide grass suppression is independent of the seeding date, unlike spring seeding. This is probably due to differences in the level of grass competitiveness. In fall, the most important factor appears to be the number of growing degree days left after legume seeding (Rioux, 1979).

In summary, the optimal legume sod-seeding date varies with season, herbicide used, and, in some cases, season when the herbicide is applied.

2.2.3.2 Plant Population Considerations

Legumes should represent less than 50% of the total pasture yield to reduce bloat potential. Depending on the species, this corresponds to a coverage of 10 to 30% of the pasture surface area by legumes (Sheehy, 1989). It has been suggested that legume establishment and persistence should be monitored by using legume population number as a key parameter (Clements, 1989). Favourable legume persistence can be defined as a legume population that is stable and achieves the various expectations of the ecosystem (Sheath, 1989). However, it is difficult to determine a population number that would achieve this objective because of factors such as legume plasticity. In addition, it is often difficult to accurately determine the density of some clonal legumes (eg: white clover) (Forde et al., 1989). Ideal white clover establishment (50% of yield and 30% of ground cover) has been reported to be achieved with 150 plants m^{-2}, 3 months after seeding (Frame and Newbould, 1986). This value appears somewhat inflated when compared to results obtained in other studies. For example, Kunelius and Campbell (1984) seeded 'California ladino' white clover at a rate of 5 kg ha^{-1} and obtained 27% of a total DM yield of 7,018 kg ha^{-1} with 9.4 plants m^{-2} in the post seeding year. This was reported to result in successful establishment and adequate persistence. Thus, evaluation of objectives and assessment of legume establishment should be based on legume yields desired, rather than plant counts.

2.2.3.3 Seeding Rate

There are no specific seeding rate recommendations for legume sod-seeding in Quebec. Elsewhere various seeding rates have produced highly variable results.

Sheaffer and Swanson (1982) showed that optimum seeding rates depend upon the level of competition by the grass sward, legume species, and location. With a low level of competition, increasing the seeding rate of both red clover and alfalfa from 4.4 to 17.6 kg ha^{-1} did not affect legume yields in the seeding year. However, with high grass competition, increasing the seeding rate to 17.6 kg ha^{-1} significantly increased legume DM yields of red clover at the first harvest and alfalfa at second harvest as well as for the yearly total. This effect was not observed in the post-seeding year. It should be noted that in this study, red clover represented 81 to 94% of total DM yield and alfalfa 78 to 82%, which is substantially above the desired 50%. Sund et al. (1966) suggested that with precise seeding, seeding rates could be decreased when compared with conventional seeding rates (red clover 7 to 3.3 kg ha^{-1} and alfalfa 12 to 4.4 kg ha^{-1}). Seeding rate data are lacking for other key pasture species.

In summary, seeding rates similar or even below those recommended for conventional seeding should be adequate for legume sod-seeding. Recommended seeding rates for legumes in Quebec are: alfalfa (9 kg ha^{-1}), birdsfoot trefoil (7 kg ha^{-1}), red clover (5-7 kg ha^{-1}) and white clover (1-2 kg ha^{-1}) (Belzile et al., 1989).

2.2.3.4 Seeding Depth

Seeding depth is an important factor for legume sod-seeding (Barnhart and Wedin, 1981) because of the small size, and thus very limited food reserves, of the legume seeds (Frame and Newbould, 1986).

Campbell (1985) evaluated the influence of seeding depth on the emergence of sod-seeded red clover both in fall and spring. In both fall and spring, a seeding depth of 13 mm was optimal, resulting in emergence of 90-95% of the seeds. With a depth of 0 mm, many seedlings failed to penetrate the soil surface, especially in the fall. Seeding depths of 26 and 39 mm, resulted in germination rates of 79 and 62%, respectively. Taylor et al. (1969) confirmed that placing seed under the soil surface (12 mm for alfalfa and 6 mm for red clover) provide better establishment when compared with seed placed on the soil surface. However, with the current no-till seeders, it is often difficult to ensure a constant and even seeding depth (Campbell, 1985).

2.2.3.5 Seeder Type

The type of seeder used for legume sod-seeding will often have a great impact on the success of legume establishment. A successful no-till drill will provide good soil opening despite the presence of residues on the surface, good seed calibration, good seed-soil contact and good soil compaction above the seed (Allen, 1979). Waddington (1992) categorized drills in three groups based on the opener type: disk-type furrow opener, hoe type opener and powered-disk furrow opener. Any of these drill types can provide adequate legume emergence and establishment. However, results obtained with individual drills can vary. A John Deere Power-till resulted in 186 seedlings m^{-2} of alsike clover (*Trifolium hybridum* L.)

compared with 33 for a Melroe 701 no-till drill (Welty et al., 1981).

2.2.3.6 Resident Vegetation

2.2.3.6.1 GRASS SPECIES: It is essential to examine the effect of various grass species on the establishment and production of sod-seeded legumes. This will permit the identification of desirable grass-legume associations for sod-seeding. Considerable research has been conducted on grass-legume associations. The choice of a particular mixture depends on intended forage use, field edaphic characteristics, and on field life expectancy (Coulman, 1988). For Quebec pastures, both birdsfoot trefoil and white clover are recommended in association with smooth bromegrass and timothy. Birdsfoot trefoil/reedcanary grass (*Phalaris arundinacea* L.) and white clover/orchardgrass associations are also recommended (Belzile et al., 1989). However the situation might be different when legumes are introduced by sod-seeding in an already established grass sward.

The influence of grass species on the outcome of legume sod-seeding is greatest when the grass is suppressed rather than killed because of grass competitiveness. However, grass species can affect legume establishment even when herbicides are used to kill the grass. Kunelius et al. (1982) reported that with both physical (mowing) and herbicide suppression of the resident vegetation, alfalfa and birdsfoot trefoil failed to establish in a Kentucky bluegrass/quackgrass (*Elytrigia repens* L.) dominated sward; however, establishment was successful in a timothy (*Phleum pratense* L.)/quackgrass sward. In most cases, establishment of various legumes within a range of grass species has been successful when herbicides are used: alfalfa and red clover in tall fescue (Olsen et al., 1981), white clover in tall fescue (Rogers et al., 1983), birdsfoot trefoil and crownvetch in Kentucky bluegrass (Decker et al., 1969), alfalfa in orchardgrass (Byers and Templeton, 1988), and red clover and alfalfa in smooth bromegrass (*Bromus inermis* Leyss.) (Sheaffer and Swanson, 1982).

However, Eltun et al. (1985) showed that both seedling emergence and development are affected by the dominant grass species present in a sod suppressed by herbicide. In some years, seedling emergence can be reduced depending on the grass species present. But reduction of legume seedling growth will invariably be greater in timothy than in orchardgrass or Kentucky bluegrass. Groya and Sheaffer (1981), had lower alfalfa plant counts with smooth bromegrass than with Kentucky bluegrass. Eltun et al. (1985) suggested that this variability might originate from the release of allelochemicals by the grasses. Bioassay studies have confirmed the role of allelochemicals in legume sod-seeding (Eltun et al., 1985; Smith and Martin, 1994). However, Smith and Martin (1994) observed that aqueous extracts of leaves and stems of three cool-season grass species (little barley, tall fescue and Italian ryegrass), only affected alfalfa when the extract was taken during the mature stage of grass development. Alfalfa germination was reduced by half at tissue concentrations varying between 2.8 and 6.7 g dry wt L^{-1}, and growth at concentrations varying between 2.5 and 5.1 g dry wt L^{-1}. Generally, allelochemicals have a greater effect on seedling growth than on germination (Eltun et al., 1985; Smith and Martin, 1994).

With physical grass suppression, total forage and legume yields are affected by the grass species present at seeding because of both allelochemical and competitive interactions originating from the grass species (Taylor and Allinson, 1983). For example, birdsfoot trefoil yields were lower in smooth orchardgrass and tall fescue than in either smooth bromegrass or timothy. These workers concluded that for alfalfa and birdsfoot trefoil establishment, orchardgrass was the most competitive grass, while timothy and smooth bromegrass were the least competitive. The results also showed that in the seeding year, alfalfa is less suited than birdsfoot trefoil for association with smooth bromegrass and timothy, and that these two grass species are better suited than orchardgrass or tall fescue to be in an association with birdsfoot trefoil. In post-seeding years, tall fescue sod provided better legume survival by reducing winter heaving. Three years after seeding, differences amongst the various grass-legume mixtures were non-significant. Similar results were obtained by Eltun et al. (1985) with herbicide suppression of the grass sod. In their study, alfalfa yields in the seeding year were lower when associated with orchardgrass (780 kg ha^{-1}) and timothy (830 kg ha^{-1}) as compared with Kentucky bluegrass (1,120 kg ha^{-1}). In contrast, Vogel et al. (1983) observed no differences in legume yields (1,200 kg ha^{-1}) in alfalfa sod-seeded in smooth bromegrass, meadow bromegrass (*Bromus biebersteinii* Roem and Schult.), intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.), tall wheatgrass (*Agropyron elongatum* (Host)

Beauv.) or orchardgrass.

In summary, favourable associations for legume sod-seeding could be birdsfoot trefoil/smooth bromegrass, alfalfa/timothy or, alfalfa/Kentucky bluegrass (Taylor and Allinson, 1983; Eltun et al., 1985). Over the long term, associations of these legumes with tall fescue might be preferable (Taylor and Allinson, 1983). There is a lack of information on grass-clover associations; but we can conclude that the grass species present can be expected to influence the choice of the legume to be sod-seeded. However, careful suppression and management of the grass sod together with good seeding conditions should minimize the importance of grass species on legume establishment, especially with herbicide grass suppression.

2.2.3.6.2 GRASS HEIGHT: Grass height at the time of seeding and during legume establishment (with physical suppression of the grass sod), affects the success of legume introduction by sod-seeding.

Mowing or grazing the grass vegetation prior to seeding, is recommended to improve conditions for the drill seeder, reduce legume shading and improve herbicide action (Sprague, 1960; Rioux, 1979; Welty et al., 1981; Byers and Templeton, 1988). However, Welty et al. (1983) showed that although cutting grass down to 8 cm prior to spraying increased legume stand establishment by 89%, legume yields were reduced by 21%. This was attributed to inadequate translocation of the herbicide in the grasses. The importance of this effect should be reduced for contact herbicides such as paraquat.

There is no mention in literature of studies examining ideal grass height at seeding. Mowing/grazing heights reported for legume sod-seeding studies have been highly variable: 2-3 cm (Taylor and Allinson, 1983), 5 cm (Taylor et al., 1969; Mueller and Chamblee, 1984), and 10 cm (Eltun et al., 1985).

2.2.4 Herbicide Related Factors Determining Legume Sod-Seeding Outcome

2.2.4.1 Adequate Herbicide

As stated by Sprague (1960), a good herbicide for pasture renovation via legume sod-seeding would be: broad spectrum, fast and non-persistent. It should suppress resident vegetation long enough to allow good legume establishment (Olsen et al., 1981), yet be temporary enough to allow favourable forage production during the renovation year and to limit the legume proportion to 50% of the forage production.

Many of the studies which have addressed sod-seeding of legumes have indicated that glyphosate is the best herbicide to suppress resident vegetation (Martin et al., 1983; Muller-Warrant and Koch, 1983; Vogel et al., 1983; Leroux and Harvey, 1985) at application rates between 0.6 and 1.7 kg ha^{-1} (Martin et al., 1983; Muller-Warrant and Koch, 1983). Glyphosate has been successful because it kills the grass sod. As much as 90% of the resident grass population can be killed at rates of 1.68 kg ha^{-1} (Rioux, 1979). The sod-seeded legume greatly benefits from this severe grass suppression, and as a result will be the greatest forage yield constituent. A rate of 1.7 kg ha^{-1} of glyphosate, in Minnesota, resulted in red clover yields as high as 7.59 tons ha^{-1} which represented 94% of the total seeding year forage production (Sheaffer and Swanson, 1982). These results are supported by those of Vogel et al. (1983) and Koch et al. (1987), where glyphosate application resulted in forage comprised of 95% to 100% sod-seeded alfalfa. However, this severe grass suppression promotes weed infestations (Rioux, 1979; Davies and Davies, 1981; Rioux, 1994); and often substantially reduces forage yield in the seeding year (Muller and Chamblee, 1984; Bryan, 1985).

Other herbicides such as paraquat have also been investigated for grass suppression with sod-seeded legumes. However, grass suppression provided by these herbicides is lower than with glyphosate (Martin et al., 1983). Unlike glyphosate, paraquat will not kill grass but rather temporarily suppress it (Koch et al., 1987). This results in lower sod-seeded legume yields and establishment when compared with glyphosate (Martin et al., 1983; Muller-Warrant and Koch, 1983). Koch et al. (1987) reported seeding year forage yields comprised of 80% sod-seeded alfalfa when glyphosate was used, and only 40% when paraquat was used. Mueller-Warrant and Koch (1983), in New-Hampshire, noted a decrease in alfalfa seedling density with paraquat (115 plants m^{-2}), when compared with glyphosate (178 plants m^{-2}). Also, sod-seeded legume yield with paraquat was less (100 kg ha^{-1}) than with glyphosate (800 kg ha^{-1}). Some studies, however, reported better grass suppression, legume establishment and yield in the seeding year with paraquat than with glyphosate. Indeed, in Illinois, paraquat applied at 0.3 kg ha^{-1} produced a sod-seeded red clover yield of 9.3 tons ha^{-1}; compared with 8.0 tons ha^{-1} with 1.8 kg ha^{-1} of glyphosate (Olsen et al., 1981). According to Waddington (1992), some of this variation might be due to geographic differences. Indeed, the author underlined that in eastern Canada paraquat allowed successful legume sod-seeding, while in western Canada only glyphosate did so. This might be attributable to the lower soil moisture found in Western Canada. By killing grass vegetation, glyphosate eliminates competition for water thus allowing better legume establishment. Also, herbicide efficiency greatly depends on the grass developmental stage at which it is applied. For example, glyphosate should be applied past the 3 leaf stage (Martin et al., 1983). Some of the conflicting results may be due to herbicide application at an improper growth stage.

Thus, glyphosate is an effective herbicide for legume sod-seeding if the goal is to obtain stands with a high percentage of legumes, for example in hayfields, but it is undesirable for pastures. According to results presented herein, it appears that for legume sod-seeding in pastures, paraquat would be a better choice. This is supported by Koch et al. (1987) who reported that unlike glyphosate, paraquat allowed an increase in forage quality without decreasing the DM production, when compared with an unseeded control. Also it gave a grass:legume yield ratio of 50:50 which is optimal. Martin et al. (1983) determined that paraquat applied at a rate of 0.8 kg ha^{-1} is adequate for pasture renovation in May; this rate resulted in legume yields representing 21 to 50% of total forage production.

2.2.4.2 Herbicide Toxicity on Legume and Grass Seeds

Herbicide efficiency might be related to some degree to its toxicity to grass and legume seeds and seedlings. Salazar and Appleby (1982) showed that glyphosate applied at a rate as low as 1 kg ha^{-1} reduced alfalfa and red clover germination and dry weight when the seeds were placed on the soil surface. However, paraquat at rates of 1.0 and 3.0 kg ha^{-1} did not affect either of these factors. These results are in accordance with observations of Appleby and Brenchley (1968) who reported no effect of paraquat application at 1.12 kg ha^{-1} on germination and dry weight of alfalfa and red clover, either placed on the soil surface or at a depth of 0.6 cm.

Segura et al. (1978) showed that red clover seeds covered by 5 mm of soil had reduced germination with glyphosate application on the soil surface at rates of 2, 3 and 4 kg ha^{-1} when compared with germination without herbicide application. Moreover, shoot dry weight 38 days after seeding, was reduced with a glyphosate application of 4 kg ha^{-1}. Since recommended glyphosate application rates in legume sod-seeding are 0.6 to 1.7 kg ha^{-1}, glyphosate toxicity to the legume would not likely be a concern. These results are supported in greenhouse experiments by Moshier and Penner (1978) who showed that alfalfa seed covered by 0.3 cm of soil was not affected by soil application of glyphosate at rates as high as 17.9 kg ha^{-1}. However, in simulated sod-seeding of alfalfa, glyphosate application at a rate of 2.2 kg ha^{-1} to 9.0 kg ha^{-1} to a Kentucky bluegrass sod resulted in lower alfalfa establishment compared with an untreated control. Differences between results obtained from soil and grass sod application of herbicides were attributed to longer herbicide inactivation when grass was present. Allelopathy may have also been involved.

The effect of herbicides on grass seeds is important in that reductions in germination or growth could suppress potential competition from these for a longer period within the seeding year. Salazar and Appleby (1982) showed that Kentucky bluegrass, perennial ryegrass, bentgrass (*Agrostis tenuis* Sibth.), tall fescue, red fescue (*Festuca rubra* L.) and orchardgrass had reduced germination and dry foliage mass with soil application of paraquat (1.0 kg ha^{-1}). However, the effect of glyphosate was less severe since only perennial ryegrass, tall fescue and red fescue had reduced germination, though all species had reduced mass. Klingman and Murray (1976) obtained similar results with paraquat applied at a rate of 2.2 kg ha^{-1} with Kentucky bluegrass, red fescue and tall fescue. In this study, however, glyphosate applied directly to the soil or on turf clippings did not affect grass germination.

2.2.4.3 Spraying/Seeding Interval:

Both allelochemical and herbicide toxicity to legume seedlings and seeds might be avoided by increasing the interval between spraying and seeding. This would allow leaching or inactivation of allelochemicals, total grass desiccation and thus complete suppression of competition, and herbicide inactivation.

Davies and Davies (1981) showed that there is a significant increase in red clover establishment when the interval between spraying glyphosate at 1.44 kg ha^{-1} and seeding is increased from 7 to 21 days. This was attributed, in part, to the 14 days required for glyphosate to completely desiccate grass. Thus during this period, competition will persist These results were supported by Eltun et al. (1985) who observed an increase in alfalfa seedling number, growth and yields, with increased spraying-seeding interval. Seedling number averaged over two years and four grass sods increased from 460 m^{-2} with a 1-day interval between spraying and seeding to 610 m^{-2} with a 28-day interval. For the first harvest in the seeding year, alfalfa yields increased from 960 kg ha^{-1} with a 1-day interval to 1,460 kg ha^{-1} with a 28-day interval.

Muller-Warrant and Koch (1983) sprayed the grass sod in the fall prior to spring legume sod-seeding. Fall herbicide application provided better grass suppression than spring application. However, it conferred no advantages to sod-seeded alfalfa as plant counts and yields did not differ between spring and fall application. The significant difference was the broadleaf weed content. With glyphosate sprayed in fall or spring at a rate of 1.1 kg ha^{-1}, the weed content of first harvest was 33% and 9%, respectively. Also, delayed spring seeding resulted in more broadleaf weeds. The author attributed this to better germination conditions provided by greater grass suppression associated with fall herbicide application.

In summary, both sod-seeded legume establishment and production can benefit from an interval between spraying and seeding. Welty et al. (1981) recommended that this interval be between 14 to 28 days.

2.2.4.4 Herbicide Disposition:

Broadcast herbicide application with sod-seeding often results in reduced forage yields in the seeding year and in an inappropriate grass:legume ratio for pastures. Herbicide banding rather than broadcasting could alleviate these problems (Bryan, 1985).

Rioux (1994) investigated differences in forage production and sod-seeded alfalfa production between herbicide broadcasting and banding. Banding the herbicide resulted in significantly greater total forage production in the seeding year compared with broadcasting (3.80 vs. 1.35 tons ha^{-1}). In addition, herbicide banding resulted in lower proportions of broadleaf weeds, alfalfa, as well as lower CP and IVDDM in one year out of two.

Byers and Templeton (1988), reported lower total forage production (1,256 vs. 1,470 kg ha^{-1}), sod-seeded alfalfa yields (144 vs. 373 kg ha^{-1}), DDM (810 vs. 975 kg ha^{-1}), CP (155 vs. 218 kg ha^{-1}) and similar weed yields (24 vs. 34 kg ha^{-1}) with herbicide banding compared with broadcasting. The percentage of alfalfa in the total forage production was only 11%. Thus, benefits of banding herbicides may be limited. Taylor et al. (1969) reported no effect of herbicide band width on alfalfa establishment (germination and seedling growth).

2.2.5 An Alternative to Herbicide: Physical Sod Suppression.

2.2.5.1 Physical Vs. Herbicide Sod Suppression:

From the present literature review, it is evident that although sod-seeding with herbicide sod suppression is often successful, several disadvantages are still present. These include variability in success, difficulty in achieving a desirable grass:legume ratio, weed encroachment, high costs, and excessive grass suppression. As Bryan (1985) pointed out, herbicides can work against one of the primary goals of pasture renovation, that of increasing forage productivity; because of excessive grass suppression in the seeding year. Legume sod-seeding with physical suppression of the resident vegetation (eg: mowing or grazing), may be a potential alternative, as grass forage could be used rather than being killed, or excessively suppressed.

The establishment of legumes by sod-seeding with physical grass suppression has been shown to be successful in several studies (Olsen et al., 1981; Kunelius et al. 1982; Taylor and

Allinson, 1983). Taylor and Allinson (1983) showed that red clover sod-seeding with physical grass sod suppression increased total DM yields, DDM yields and CP yields compared with an unseeded control. Mowing the sward every 2 or 4 weeks for 8 weeks, did not differ in effectiveness.

Herbicide and physical methods of grass suppression may result in similar sod-seeded legume establishment. Rioux (1994) reported similar forage CP and IVDDM yields with legume sod-seeding following herbicide and physical grass suppression. Olsen et al. (1981) showed that legume plant counts and height were not different between grass suppression with or without herbicides. However, legume yields were significantly lower without herbicides.

Kunelius et al. (1982) demonstrated that intensive management of the resident vegetation during establishment of sod-seeded legumes can be more beneficial compared with methods relying on herbicides. In the seeding year, mowing the vegetation down to 4 cm when it reached 12 cm, gave higher total forage yields (1,703 kg ha^{-1}) than either paraquat (1,563 kg ha^{-1}) or glyphosate (1,515 kg ha^{-1}) used at rate of 1.1 kg ha^{-1}. Also, in the post-seeding year, grass suppression by mowing resulted in lower broadleaf weed yield (467 kg ha^{-1}) than grass suppression by paraquat (806 kg ha^{-1}). However, plant number in the seeding year and sod-seeded legume yields in post seeding years, were lower with mowing, than for herbicide treated plot. Rioux (1994) also reported higher total forage production when alfalfa was sod-seeded without herbicides (5.49 tons ha^{-1}) than with banded herbicides (2.27 tons ha^{-1}).

Results of physical grass suppression have not all been favourable. Byers and Templeton (1988) showed that grass suppression via mowing down to 7 cm at weekly intervals until legumes reached clipping height resulted in lower grass yields in the seeding year than with band or broadcast applications of glyphosate at 1.7 kg ha^{-1} (778 kg ha^{-1} and 1,088 kg ha^{-1}, respectively). In some cases, forage CP content was also greater with herbicide suppression (187 kg ha^{-1}) than with physical suppression (125 kg ha^{-1}). Moreover, there were no differences in weed content or alfalfa yields.

Several studies on no-till legume establishment suggest that one advantage of herbicide use is its ability to stabilize legume yields over the longer term (Sprague, 1960; Olsen, 1981). With physical suppression of the grass sod, the benefits of legume sod-seeding are often significant only over the short term (Kunelius et al., 1982; Kunelius and Campbell, 1984). The development of better pasture grazing management techniques such as rotational grazing or management intensive grazing, as well as the identification of legume cultivars suited to sod-seeding could alleviate this problem. Also, the variability of legume establishment in the seeding year could be reduced by the elaboration of effective and reliable intensive grass suppression methods.

2.2.5.2 Physiological Basis for the Elaboration of Effective Physical Grass Suppression Methods:

The relationship between carbohydrate reserves, frequency and severity of defoliation, and grass growth rate has been known for many years (May, 1960). After a defoliation event, carbohydrate reserves are reduced until sufficient photosynthetic tissues have been regenerated to restore them (Davies, 1965; Davies, 1988; Hume, 1991). This is due to the mobilization of carbohydrate reserves for incorporation into newly formed tissues and to meet basal requirements (Davidson and Milthorpe, 1966). Photosynthates from newly formed tissues, then replenish carbohydrate reserves, also known as total non-structural carbohydrate (TNC) reserves.

The reduction of both TNC reserves and photosynthetic area following defoliation reduces grass regrowth rate (Davies, 1965; Davidson and Milthorpe, 1966; Ryle and Powell, 1975), as well as root weight (May, 1960) and nutrient uptake (Oswalt et al., 1959; Davidson and Milthorpe, 1966). Frequent and close defoliation reduces TNC reserves. Hume (1991) reported that defoliation at 1, 2 or 4 week intervals significantly reduced water soluble carbohydrate (WSC) concentration, which is part of the TNC reserves, for at least 4 weeks; but only weekly defoliation reduced WSC reserves over the long term. Effects of defoliation height on grass regrowth were minimal. According to Davies (1988) variation in the height of defoliation affects grass regrowth only if all leaf blades are removed. In this situation, photosynthetic potential is dependant on the leaf sheath and stem, which have relatively low photosynthetic potentials (Ryle and Powell, 1975; Davies, 1988). Thus, regardless of defoliation frequency, cutting down to 1.3 cm resulted in lower carbohydrate reserves than cutting down to 7.6 cm (Davies, 1988). Lowest TNC levels occur in grasses at approximately the beginning of stem elongation (Paulsen and Smith, 1968). Thus, defoliation at this stage should reduce carbohydrate reserves and subsequent grass regrowth the most. Indeed, Alberda (1966) reported that if cutting occurs when carbohydrate reserves are low, plant weight will not increase for up to 7 days. In addition, White (1973) and Davies (1988) reported that when carbohydrate reserves fall below 6% of plant total dry matter, some tillers die.

Defoliation, and in particular defoliation height (Davies, 1988) also affects grass morphology and shading potential. Lower cutting height results in more tillers and greater leaf percentage. Thus, severe defoliation produces a dense grass canopy with a high light interception potential. However, Lawrence and Ashford (1969) observed lower basal ground cover by grasses with a defoliation height of 3.8 cm compared with 7.6 or 15.6 cm. Grass response to defoliation variables (ie: height and frequency) will also vary with species (May, 1960).

Based on these physiological concepts, designing a physical grass suppression method that momentarily minimizes the photosynthetic potential of the grass by reducing its regrowth potential over the short term, should be feasible. This would reduce the grass sod growth rate, competitive ability, and shading on developing legume seedlings without jeopardizing post-seeding year production. Proper sod-seeded legume establishment should also be ensured.

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3.0 PHYSICAL SOD SUPPRESSION EFFECTS ON PRODUCTIVITY AND COMPOSITION FOLLOWING PASTURE RENOVATION WITH CLOVER

P. Seguin, P.R. Peterson, and D.L. Smith[1]

3.1 ABSTRACT

Using herbicides for sod suppression during pasture renovation by legume sod-seeding often results in the loss of potentially usable forage, weed encroachment, and inadequate grass-legume ratios. Physical sod suppression methods could alleviate some of the problems associated with suppression via herbicide. A study was conducted on two sites near Montreal, Quebec, Canada, to investigate, as an alternative to herbicide, the viability of sod suppression by sheep grazing or mowing, during pasture renovation with no-till seeding of red clover (*Trifolium pratense* L.) or white clover (*T. repens* L.). A total of nine treatments were compared. These included six physical suppression methods: mowing (M) or sheep grazing (G), to 5 (M5, G5) or 10 cm (M10, G10), at seeding and when the grass sward reached 25 to 35 cm during the first two months of clover establishment, or similarly managed mowing or sheep grazing to 5 cm with an additional defoliation the previous fall (M5+F, G5+F). Additional treatments included suppression by herbicide (glyphosate at 2.6 kg a.i. ha^{-1} + 0.5% Frigate Vol./Vol.) and two controls: sod-seeding with no sod suppression or no seeding. Treatments were evaluated by determining clover plant population, botanical composition and forage yield. More intensive physical sod suppression resulted in higher clover populations, similar to those achieved via herbicide suppression. Differences between red clover and white clover populations were not significant. Botanical composition and total forage yields varied with sites. At one site, red clover out-yielded white clover; at the other site the two yields

[1] P.Seguin and D.L. Smith, Dep. of Plant Sci., Macdonald Campus, McGill University, 21,111 Lakeshore Rd., Ste. Anne-de-Bellevue, Qc. H9X 3V9, Canada; and P.R. Peterson, Dep. of Crop and Soil Env. Sci., Virginia Polytechnic Institute and State University, 424 Smyth Hall, Blacksburg, VA 24061-0403.

were similar. Clover yields tended to be higher with herbicide. However, increasing the intensity of physical suppression increased clover yields. Weed yields were greater with herbicide than with any other treatment. Unlike suppression with herbicide, physical suppression did not decrease total seasonal forage yields in the renovation year when compared with controls. Timely mowing or grazing as methods for suppression of grass sod during renovation with legumes appear to have potential.

3.2 INTRODUCTION

Although the importance and profitability of pastures for ruminant animal production have been generally recognized, many livestock producers neglect their use, and thus rely heavily on conserved forages and concentrates (Hoveland, 1992). This often arises from pastures' low productivity, low quality, and poor seasonal yield distribution; conditions usually due to the predominance of poor producing grass and weed species, associated with a lack of management attention of the pasture.

Pasture productivity and nutritional quality can be improved by pasture renovation (Kunelius and Campbell, 1984), resulting in improved animal performance (Koch et al., 1987). Introducing legumes into an existing grass dominated pasture is a method of pasture renovation commonly done by drilling seeds into the grass sod (sod-seeding). For legume establishment to be successful, it is critical that the resident vegetation be suppressed (Taylor et al., 1969; Groya and Sheaffer, 1981; Olsen et al., 1981; Evers, 1995b).

In most cases, herbicide application is used as the suppression method. However, suppression by herbicides can result in a loss of potentially usable forage in the seeding year due to excessive sod suppression as well as weed encroachment and inappropriate grass-legume ratios. Total seeding year forage yields of pastures renovated with red clover (*Trifolium pratense* L.) or birdsfoot trefoil (*Lotus corniculatus* L.) were 30% less than that of an unseeded control; this was attributed to excessive sod suppression by herbicide (Bryan, 1985). Forage yield reductions as high as 60% have been reported in the seeding year (Kunelius and Campbell, 1986). Rioux (1994) reported substantial dandelion (*Taraxacum officinale* Weber) infestation of a smooth bromegrass (*Bromus inermis* Leyss.) sward renovated with alfalfa (*Medicago sativa* L.); as much as 45% of the second of two harvests in the renovation year was dandelion. Red clover has been reported to constitute from 74 to 99% of the total yield in the renovation year when sod-seeded into smooth bromegrass (Sheaffer and Swanson, 1982). Such values are excessive for a pasture; grazing livestock on swards with such a composition could result in bloat. Generally, 30 to 50% of the forage yield should come from legumes for the pasture composition to be considered desirable (Wolfe, 1973; Rhodes et al., 1994). Thus, the use of herbicide as a sod suppression method can result in undesirable and possibly dangerous swards. In addition, the use of herbicides represents both an economic and an environmental cost.

The use of physical sod suppression methods before seeding and during legume establishment in renovated pastures, could alleviate some of the problems associated with suppression via herbicides. Physical methods consist of suppressing the resident vegetation by mowing or grazing. Legume sod-seeding in conjunction with physical sod suppression has been successful in several renovation studies (Olsen et al. 1981; Kunelius et al., 1982; Taylor and Allinson, 1983; Bowes and Zentner, 1992). Similar establishment results with sod-seeded legumes may be achievable with different grass suppression methods. Olsen et al. (1981) reported legume plant counts and heights in the renovation year that were similar for sod suppression with or without herbicides. Seeding year yields of pasture sod-seeded with alfalfa or birdsfoot trefoil with physical sod suppression consisting of mowing every 2 or 4 weeks for 8 weeks were as much as 125% greater than that of an unseeded control (Taylor and Allinson, 1983).

Physical sod suppression methods have not always been successful. Kunelius et al. (1982) observed a 300% yield reduction during the renovation year when sod was suppressed by mowing down to 4 cm when plants reached 12 cm as compared with an unseeded control, although yields obtained with physical suppression were greater than those for herbicide suppression. In addition, excessive legume percentages have been reported in the renovation year (Mueller and Chamblee, 1984).

Previous studies have suggested that physical sod suppression during pasture renovation with legumes is a possible alternative to suppression by herbicide. However, results obtained to date have been highly variable. This arises from the lack of information regarding physical suppression methods and their effects on forage yield and composition. As a result, no specific recommendations exist for physical sod suppression methods during pasture renovation with legumes. Thus, the objectives of this study were to: (i) compare sod-seeded legume establishment following physical sod suppression methods versus herbicide suppression, (ii) compare forage yields of renovation systems involving physical sod suppression, herbicide suppression, or no improvement, and (iii) compare the effects of the levels and methods of physical sod suppression on legume establishment and forage yield.

3.3 MATERIALS AND METHODS

3.3.1 Site Description

The study was conducted for two consecutives years on two different sites of the Macdonald Campus Farm of McGill University (45° 25'45" N lat., 73° 56'00" W long.), Ste-Anne-de-Bellevue, Quebec, Canada. Experiments were conducted in 1995, on a mixed smooth bromegrass, reed canarygrass (*Phalaris arundinacea* L.) dominated pasture (site A), and in 1996 on a smooth bromegrass dominated pasture (site B). When the experiment was initiated, legumes were totally absent at both sites. The soil of site A was a mixture of Chicot fine sandy loam and Macdonald clay loam. At site B, the soil was a mixture of Soulanges silt loam and an undifferentiated alluvium. The slope in both fields was less than 1%. Both of these fields were previously used as hayfield.

In 1996, precipitation and temperature were similar to the 30-year average during the growing season (May to October). Mean total precipitation for this period was 496 mm and the mean monthly temperature was 15.7°C. In 1995, values deviated from the 30-year average. Total precipitation was 738 mm and the mean monthly temperature was 16.5°C. Most of this rainfall fell later in the growing season.

3.3.2 Plot Management

For both sites, the experiment was organized in a split-plot design with four blocks, with sod-seeded clover species as main plots and sod suppression methods as subplots. Each subplot was 9 m by 9 m. Sod-seeded clover species were 'AC Charlie' red clover and 'Shasta' white clover. In 1995, at site A, sod suppression methods consisted of herbicide application (glyphosate at 2.6 kg a.i. ha^{-1} plus 0.5% Frigate Vol./Vol.) two weeks prior to seeding, or one of four physical suppression methods (mowing (M) or sheep grazing (G), to 5 (M5, G5) or 10 cm (M10, G10), at seeding and when the grass sward reached 25 to 35 cm during the first two months of legume establishment). Two controls were also included: sod-seeding with no sod suppression and no seeding. At site B, two additional physical suppression methods were included: mowing or sheep grazing, to 5 cm as above but, in both cases, with an additional defoliation in the preceding fall (M5+F, G5+F), from October 11 to 20, 1995 for the grazed subplots, and on October 11, 1995 for the mowed subplots. Grazed treatments were stocked with 5 to 7 dry ewes to graze forage to desired heights within two days one replication at a time. Mowing was conducted with a rotary mower, and after each defoliation event, forage material was removed. At site B herbicide application occurred at the three leaf stage of the grass resident vegetation; at site A application was past that stage.

Site A was seeded on June 1, 1995 and site B on May 17 and May 21, 1996 for blocks 1 and 2, and blocks 3 and 4, respectively. Seeding in both years was done with a Great Plains no-till seeder at a depth of 5 mm. Seeding rates were 7 and 2 kg ha^{-1} for red clover and white clover, respectively. Seeds were inoculated with the appropriate *Rhizobium* species. For the physical sod suppression subplots, three defoliations were performed: the first at seeding and the later two during legume establishment. At site A, the first suppression was imposed from May 23 to 31, the second from June 12 to 20, and the third from July 3 to 8, 1995. At site B, the first suppression took place between May 10 to 15 in blocks 1 and 2, and May 16 to 20 in blocks 3 and 4, the second from June 1 to 14 and the third from July 3 to 22, 1996. Defoliation of the mowed subplots occurred near the middle of these intervals, as weather allowed. All other subplots were defoliated only once during legume establishment. At site A, subplots with herbicide suppression, sod-seeding without sod suppression, or no seeding were defoliated on July 6, 1995. At site B, defoliation was carried out on June 27 for the sod-seeded without sod suppression and unseeded subplots, and on July 30, 1996, for the herbicide suppression subplots.

Following the legume establishment phase, at both sites, forage of all treatments was harvested once: on August 8, 1995 and September 4, 1996, for sites A and B, respectively. For site A, in the post-seeding year, forage was harvested on June 14 and August 29, 1996

3.3.3 Measurements

For the physical suppression events at site B, harvestable yield was estimated as the difference between pre- and post-defoliation forage mass as determined by hand sampling to ground level. Four samples from a 0.25 m^2 rectangular quadrat were taken in each plot, following a stratified random sampling procedure (Gomez and Gomez, 1984 p. 540-541). The samples were bulked and weighed; then a 500 g fresh subsample was taken and dried at 70°C for 24 h, and the dry matter yield was determined in kg ha^{-1}. Mass of vegetation present at seeding and at the end of the season, were determined following the same procedure. Mass of vegetation at the end of the season was determined on October 1, 1995 and on October 2, 1996, for sites A and B, respectively. Yield for all other harvesting events was obtained with a flail harvester. In each plot, two 0.6 by 3.5 m strips were harvested and bulked; then as described above, a 500 g fresh subsample was taken, dried, and weighed to determine dry matter yield.

Botanical analyses were carried out in four 0.25 m^2 rectangular quadrats in each plot based on stratified random sampling. A 150 g subsample was collected from each plot and component species including clover, short grass (Kentucky bluegrass (*Poa pratensis* L.)), tall grass (mostly smooth bromegrass and reed canarygrass), weeds and other legumes were separated by hand. The components were ovendried at 70 C for 24 h and weighed. The botanical composition as percentage (data not presented) and mass of each component were subsequently determined. These samples were taken at the last harvest of the seeding and post-seeding years, and at the end of the season when mass of vegetation present was determined. Visual estimates were also used to assess the botanical composition at these same dates, as well as in May of the seeding year and at the first harvest of the post-seeding year.

Plant counts were made in five 0.25 m^2 rectangular quadrats in each plot at the last harvest in the seeding and post-seeding years and at the end of the season: September 9, 1995 for site A and October 7, 1996 for site B. In addition, at site B, a plant count was conducted on June 29, 1996. Sward height was determined at ten random locations in each subplot at seeding and before and after each defoliation by the various physical sod suppression methods.

3.3.4 Statistical Analysis

Data were analysed using the GLM procedure of the SAS Institute, Inc (SAS, 1988). Analysis of variance was used to detect mainplot by subplot interactions, and mainplot and subplot effects. When a mainplot by subplot interaction was significant, data were analysed as two randomized complete block designs, one for each clover species. When the F-tests were significant at $p \leq 0.05$, means were separated using Duncan's multiple range test. Single degree of freedom contrasts were also used to carry out preplanned comparisons of specific subplot combinations. Because these were of a priori interest, they were made regardless of significance of effects in analysis of variance (Steel and Torrie, 1980, p. 172-174). Before performing the analysis of variance, every data set was tested for normality and homoscedasticity. Data sets showing excessive deviation from normality or heteroscedasticity were subjected to transformation (Log $(x+1)$ or $(x+0.5)^{0.5}$). Data presented in text and tables are detransformed. Thus, some results may appear inconsistent, such as the sum of each of the individual constituents at one harvest being unequal to the total yield reported for that harvest; or in the percentages reported.

3.4 RESULTS AND DISCUSSION

3.4.1 Assessment of Differences in Treatment Nature

Some measurements were taken to characterize differences in the physical condition of the sward produced by each of the suppression methods. First, residual heights of the swards after defoliations by the physical suppression methods were recorded (data not presented). At both sites, swards were defoliated to target heights of 5 or 10 cm for the first two defoliation events. This was not the case for the third defoliation event however, as our goal was to defoliate above the sod-seeded clover; in both years at the time of the third defoliation event, clover seedlings were taller than the planned residual heights. At both sites, physical suppression methods involving defoliations to 5 cm and the herbicide suppression method both resulted in a shorter sward at seeding, as compared with swards physically defoliated to 10 cm which in turn were shorter than the controls. The mass of vegetation at seeding was similar, with less vegetation mass for the more intensive suppression methods.

Herbicide suppression resulted in a seeding date mass similar to the less intensive physical suppression methods at site A, and to controls at site B. These results document the varied sward conditions at seeding resulting from the sod suppression methods.

3.4.2 Sod-Seeded Clover Plant Counts

Averaged for all treatments, red and white clover population were similar in the renovation year at both sites (Table 3.1 and 3.2). As indicated by the contrasts, suppression of the resident vegetation contributed to higher clover populations at both sites, compared with sod-seeding without suppression of the sod. Sod suppression is considered to be a key factor in successful sod-seeded legume establishment (Taylor et al., 1969; Groya and Sheaffer, 1981; Olsen et al., 1981; Evers, 1995b). In addition, the higher the level of suppression, the greater were the clover populations. For example, increases in the intensity of physical suppression from G10 to G5+F resulted in population increases as high as 360%. At site A, all physical suppression methods, except for G10, resulted in clover populations similar to that produced by herbicide suppression (Table 3.1). At site B, only physical sod suppression consisting of defoliation to 5 cm in the fall preceding renovation as well as during clover establishment resulted in clover populations similar to herbicide suppression (Table 3.2). However, the other physical suppression methods resulted in populations greater than the controls.

For M5+F and G5+F, fall defoliation to 5 cm prior to spring defoliation and seeding seemed to confer an advantage over defoliation only in spring of seeding year (M5 and G5). Our results demonstrated that this was not due to differences in defoliation height among these treatments. This advantage might be due to reduced total non-structural carbohydrate (TNC) and/or N reserves (Volenec et al., 1996), and thus reduced competitiveness of the fall-defoliated sod during clover establishment. Mowing resulted in a greater clover population than grazing at site A. This was probably due to the fact that mowing tended to provide a more even defoliation, and thus probably resulted in a more even suppression of the grass competition than grazing. At both sites, the suppression method by clover species interaction was significant only at the last harvest. Analysis by clover species (data not shown), revealed that this was due to the greater sensitivity of white clover to the level of physical sod suppression. This difference in magnitude of clover response to level of sod suppression was probably due to the lower shading tolerance of white clover (Evers, 1995a).

In the post-seeding year, there were no differences among seeded treatments (Table 3.1). Clover populations were very low for both clover species, but were higher for red clover than white clover (average of 8 and 1.8 plants m^{-2}, respectively). These low clover populations were due to severe winter damage. However, while clover population is an indication of plant establishment; determination of botanical composition is essential to evaluate if observed populations meet the various expectations of the ecosystem.

3.4.3 Botanical Composition

Averaged for all treatments, sod-seeded clover yields at last harvest and mass at the end of season (October) were similar for red and white clover at site A (Table 3.3). However, at site B, yield and mass were greater for red than for white clover (Table 3.4), similar to results reported by Kunelius et al. (1984). Yield and mass of short grasses, tall grasses, weeds and legumes were not influenced by the sod-seeded species, except short grass yield at the last harvest of site A.

Effects of the sod suppression methods on botanical composition varied with site. At site A (Table 3.3), clover yields at the last harvest in the renovation year were very low, and only a small component of the total yield. Herbicide suppression and physical suppression consisting in defoliation to 5 cm (G5 and M5) resulted in the most clover: 26 to 62 kg ha^{-1} representing only 2.2 to 3.0% of the last harvest yield. The high plant counts reported for that date did not result in a significant yield contribution because clover plants were immature at that harvest due to late seeding in 1995 (June 1). At the end of season, clover mass was similar for the herbicide and all physical suppression methods, except for G10, and ranged from 148 to 467 kg ha^{-1} (7.2 to 18.0% of the total forage mass present at the end of season). Short grass yield and mass were significantly lower with herbicide suppression than the other treatments. Also, yield of other legumes were greater with herbicide suppression. As indicated by contrast analysis, the yield and mass of weeds was greater with herbicide suppression than physical suppression methods. Weeds in the herbicide suppression treatment represented 10.5 and 16.2% of the last harvest and end of season mass, respectively. Main weed species present were dandelion and Canada thistle (*Cirsium arvense* L.). Broadleaf weed encroachment is a problem that has been reported in other studies on pasture renovation with herbicide sod suppression (Kunelius et al., 1982; Rioux, 1994). As hypothesized, this was not the case with most of the physical suppression methods.

At site B, due to an earlier seeding date, clover yields at the last harvest were higher than those reported earlier at site A (Table 3.4). Indeed, herbicide suppression resulted in 239 kg ha^{-1} of clover, representing 44.8% of the total yield. Clover yields for G5+F, M5+F and M5 were similar to those observed with herbicide suppression, ranging from 62 to 83 kg ha^{-1} However, clover percentages of total yield provided by these physical suppression methods were lower than for herbicide suppression, ranging from 9 to 12%. Clover yields with the other suppression methods were negligible. At the end of season, clover mass was highest with herbicide suppression. Indeed, clover mass in the herbicide treatment was 1191 kg ha^{-1}, representing 46.5 % of the total mass. Among the other suppression methods, only the physical suppression methods consisting in defoliation to 5 cm (G5+F, G5, M5+F and M5) resulted in both clover mass (70 to 167 kg ha^{-1}) and percentage (3.1 to 7.7%) above those observed for controls. Short grass mass (26 kg ha^{-1}) and percentage (1.1%) at the end of season was lower for the herbicide treatment than for any other treatment. High clover yield and mass were associated with low short grass yield and mass at both sites. The short grass was mostly Kentucky bluegrass which forms a denser sod than the other grasses present in the study. Kunelius et al. (1982) attributed poor alfalfa and birdsfoot trefoil establishment in a Kentucky bluegrass dominated pasture to the density of the sod. Last harvest yield and end of season mass of tall grasses were lower with herbicide than any other treatment. Other legume yield and mass, and weed mass were higher with herbicide suppression than for all other treatments. However, other legumes and weeds never represented more than 10% of the total forage yield or mass. Main weed species present were dandelion and milkweed (*Asclepias syriaca* L.)

In the post renovation year, at site A, both clover species failed to make a significant contribution to yield, because of the afore mentioned winter damage which killed most of the clover plants (data not shown).

3.4.4 Total Yields

Forage yields at all dates were not affected by clover species nor was there a clover species by suppression method interaction. At site A, herbicide resulted in higher yields at the last harvest (2573 kg ha^{-1}) than all other treatments except M10 (Table 3.5). The high total yields and the relatively low clover yield of the herbicide treatment can be attributed to a somewhat ineffective herbicide treatment, probably due to application at an inappropriate grass developmental stage (ie: past the three leaf stage) (Martin et al., 1983). In the post-seeding year, total yield averaged 6790 kg ha^{-1} and was not affected by suppression method the previous year.

At site B, both last harvest and total yields were lower with herbicide suppression than for any other treatment (Table 3.6). During the establishment phase (May-July), herbicide suppression, G5+F and G10 were the lowest yielding. Total season yield for the herbicide treatment was 52 and 46% less than M5 and unseeded treatments, respectively. All physical sod suppression treatments, except G5+F and M10, resulted in total yields similar to those of the unseeded treatment. Reduction of renovation year yields with herbicide sod suppression have been reported in a number of studies on pasture renovation (Kunelius et al. 1982; Bryan, 1985; Kunelius and Campbell, 1986). Here we were able to show that physical sod suppression methods can reduce the competition provided by the resident vegetation without reducing yields in the renovation year. There was no difference among the total yields produced by the various physical suppression methods. However, forage yields during the clover establishment phase were greater with mowing than grazing; the reverse was observed at the last harvest.

It is important to note the difference in establishment phase yields among treatments defoliated to 5 cm at site B. The treatments involving an additional defoliation in the fall preceding renovation (G5+F and M5+F), had yields lower than the other 5 cm treatments (G5 and M5). This was reflected in the total renovation year yields but not at the last harvest. As mentioned earlier, this might be due to reduction in some reserves associated with sod regrowth (TNC or N reserves). This reduction seems to affect the sod productivity only during the clover establishment.

3.5 SUMMARY AND CONCLUSIONS

Physical sod suppression during no-till pasture renovation with legumes resulted in plant population levels similar to sod suppression by herbicide, but in some cases, at the end of season, clover mass was lower. The contribution of clover to yield also tended to be lower with physical suppression methods. However, in contrast to sod suppression by herbicide, physical suppression methods did not result in reduction of the total forage yields in the renovation year. Also, physical suppression methods did not result in weed encroachment. The proposed sod suppression methods during pasture renovation with clover resulted in a modification of the sward rather than a replacement. The use of intensive physical suppression methods appears to have potential and could easily be integrated into rotational grazing systems, although the resulting clover contents are still insufficient, and thus cannot be considered as an alternative to herbicide suppression at this point. Also more information is needed for post-seeding years. More research is required on the grass-legume interactions during the establishment phase, especially on the effects of physical sod suppression on the competitive ability of the sod, in order to be able to stabilize and sustain the clover content. The ideal sod suppression method will suppress grass sod intensively during legume establishment, momentarily minimizing the photosynthetic potential of the sod, while maintaining a sufficient grass cover to minimize weed encroachment; and this without jeopardizing renovation year yield. Also, there is a need to characterize the forage quality of no-till pasture renovation with legumes using physical sod suppression methods.

3.6 ACKNOWLEDGMENTS

The senior author was supported by the Fonds pour la Formation de Chercheurs et l'Aide a la Recherche du Quebec. The authors acknowledge the technical assistance of W. Asbil, S. Couture, M. Lira jr., F. Karimian., J. Straughton and S. Willox.

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3.8 TABLES

Table 3.1 Sod-seeded clover populations in renovation and post renovation years (site A).

	Clover Population		
	Renovation year		Post renovation year
Treatment	5 Aug. 1995	9 Sep. 1995	23 Aug. 1996
Suppression method (S)†		Plants m^{-2}	
Mow to 5 cm	50.8 a‡	40.3 a	4.2 a
Mow to 10 cm	21.4 b	19.1 ab	3.7 a
Graze to 5 cm	39.1 ab	22.2 a	3.7 a
Graze to 10 cm	8.5 c	9.1 bc	3.1 a
Herbicide	29.5 ab	23.4 a	5.4 a
No suppression	4.9 c	8.2 c	3.9 a
Unseeded	0 d	0 d	0.2 b
Contrasts			
Suppression Vs. No suppression	***	***	NS
Physical suppression Vs. Herbicide	NS	NS	NS
Mow Vs. Graze	*	**	NS
Clover species (C)			
Red clover	21.9 a	17.4 a	8.0 a
White clover	6.9 a	7.3 a	1.8 b
S x C interaction	**	NS	***

NS,*,**,*** Not significant or, significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

† For mow and graze, the grass sward was defoliated to 5 or 10 cm residual height at seeding and during the first two months of legume establishment, when the sward reached 25 to 35 cm.

‡ Within columns, means followed by the same letter are not significantly different at the 5% level.

Table 3.2 Sod-seeded clover populations in renovation year (site B).

Treatment	Clover Population		
	30 June 1996	27 August 1996	7 October 1996
Suppression method (S)†		Plants m^{-2}	
Mow to 5 cm + fall	66.3 a‡	55.3 a	48.7 a
Mow to 5 cm	25.6 c	24.9 b	14.3 b
Mow to 10 cm	17.2 c	14.9 b	13.3 b
Graze to 5 cm + fall	57.0 ab	49.4 a	36.1 a
Graze to 5 cm	31.8 abc	22.9 b	14.5 b
Graze to 10 cm	29.0 bc	13.5 b	11.0 b
Herbicide	68.5 a	44.7 a	65.2 a
No suppression	1.1 d	2.6 c	0.5 c
Unseeded	0.1 d	0.1 d	0.0 c
Contrasts			
Suppression Vs. No suppression	***	***	***
Physical suppression Vs. Herbicide	**	*	***
Mow Vs. Graze	NS	NS	NS
Clover species (C)			
Red clover	19.8 a	20.9 a	16.0 a
White clover	16.1 a	10.8 a	8.2 a
S x C interaction	NS	*	NS

NS,*,**,*** Not significant or, significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

† For mow and graze, the grass sward was defoliated to 5 or 10 cm residual height at seeding and during the first two months of legume establishment, when the sward reached 25 to 35 cm; +-fall, included an additional defoliation to 5 cm during the fall prior to renovation.

‡ Within columns, means followed by the same letter are not significantly different at the 5% level.

Table 3.3 Botanical composition of renovated sods at the last harvest and end of the season of the renovation year (site A).

Treatment	Last harvest (8 August, 1995)					End of the season (1 October, 1995)				
	Clover	Short grasses	Tall grasses	Weeds	Other legume	Clover	Short grasses	Tall grasses	Weeds	Other legume
	kg ha^{-1}†									
Suppression method (S)‡										
Mow to 5 cm	27 ab§	211 a	1219 a	18 a	354 b	467 a	641 a	1611 a	35 c	263 a
Mow to 10 cm	8 bc	251 a	1552 a	59 a	261 b	148 a	767 a	1868 a	212 ab	231 a
Graze to 5 cm	26 ab	144 a	1469 a	57 a	150 b	283 a	674 a	1582 a	38 c	126 a
Graze to 10 cm	5 c	222 a	1311 a	57 a	165 b	33 b	692 a	1981 a	24 c	247 a
Herbicide	62 a	11 b	1253 a	194 a	769 a	398 a	67 b	1321 a	354 a	413 a
No suppression	2 cd	238 a	1286 a	19 a	338 b	31 b	794 a	1741 a	63 bc	250 a
Unseeded	0 d	230 a	1516 a	42 a	150 b	0 c	818 a	1726 a	78 abc	376 a
Contrasts										
Suppression Vs. No suppression	**	NS	NS	NS	NS	**	NS	NS	NS	NS
Physical Vs. Herbicide	**	***	NS	**	***	NS	***	*	**	*
Mow Vs. Graze	NS	NS	NS	NS	*	NS	NS	NS	NS	NS

Table 3.3 (Continued). Botanical composition of renovated sods at the last harvest and end of the season of the renovation year (site A).

Treatment	Last harvest (8 August, 1995)					End of the season (1 October, 1995)				
	Clover	Short grasses	Tall grasses	Weeds	Other legume	Clover	Short grasses	Tall grasses	Weeds	Other legume
	kg ha^{-1}†									
Clover species (C)										
Red clover	14 a	135 b	1457 a	70 a	291 a	118 a	636 a	1600 a	81 a	282 a
White clover	6 a	209 a	1288 a	32 a	282 a	41 a	636 a	1780 a	68 a	263 a
S x C interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS,*,**,*** Not significant or, significant at the 0.05, 0.01 and 0.001 probability levels, respectively.
† The sum of all components at a given date may not be equal to the total yield reported for that date, because of data transformation during statistical analysis.
‡ For mow and graze, the grass sward was defoliated to 5 or 10 cm residual height at seeding and during the first two months of legume establishment, when the sward reached 25 to 35 cm.
§ Within columns, means followed by the same letter are not significantly different at the 5% level.

Table 3.4 Botanical composition of renovated sods at the last harvest and end of the season of the renovation year (site B).

Treatment	Last harvest (27 August, 1996) Clover	Short grasses	Tall grasses	Weeds	Other legume	End of the season (October 7, 1996) Clover	Short grasses	Tall grasses	Weeds	Other legume
					kg ha^{-1}†					
Suppression method (S)‡										
Mow to 5 cm + fall	81 a§	121 a	948 c	9 a	2 b	167 b	402 ab	1241 cd	26 b	8 b
Mow to 5 cm	62 a	98 a	993 c	11 a	3 ab	100 bc	375 ab	1504 bc	20 b	12 b
Mow to 10 cm	13 b	102 a	962 c	6 a	1 b	39 c	406 ab	1561 abc	27 b	9 b
Graze to 5 cm + fall	83 a	84 a	1050 c	8 a	1 b	167 b	666 a	1263 cd	15 bc	5 b
Graze to 5 cm	10 bc	66 a	1513 b	13 a	1 b	70 bc	358 ab	1697 abc	6 bcd	6 b
Graze to 10 cm	9 bc	134 a	1660 ab	7 a	1 b	35 c	652 a	1415 bcd	10 bcd	2 b
Herbicide	239 a	8 a	250 d	18 a	6 a	1191 a	26 c	949 d	141 a	69 a
No suppression	2 cd	32 a	1956 ab	8 a	1 b	0 d	125 bc	2119 a	2 d	2 b
Unseeded	0 d	109 a	2029 a	1 a	1 b	0 d	296 ab	1948 ab	3 cd	4 b
Contrasts										
Suppression Vs. No suppression	***	NS	***	NS	NS	***	*	***	***	*
Physical Vs. Herbicide	***	**	***	NS	***	***	***	**	***	***
Mow Vs. Graze	NS	NS	***	NS	NS	NS	NS	NS	*	NS

Table 3.4 (Continued). Botanical composition of renovated sods at the last harvest and the end of season of the renovation year (site B)

Treatment	Last harvest (27 August, 1996)					End of the season (October 7, 1996)				
	Clover	Short grasses	Tall grasses	Weeds	Other legume	Clover	Short grasses	Tall grasses	Weeds	Other legume
	kg ha^{-1}†									
Clover species (C)										
Red clover	36 a	60 a	1131 a	7 a	8 a	147 a	348 a	1499 a	11 a	7 a
White clover	10 b	95 a	1393 a	8 a	17 a	71 b	311 a	1506 a	17 a	8 a
S x C interaction	NS	NS	NS	NS	NS	NS	NS	NS	*	NS

NS,*,**,*** Not significant or, significant at the 0.05, 0.01 and 0.001 probability levels, respectively.
† The sum of all components at a given date may not be equal to the total yield reported at that date, because of data transformation during statistical analysis.
‡ For mow and graze, the grass sward was defoliated to 5 or 10 cm residual height at seeding and during the first two months of legume establishment, when the sward reached 25 to 35 cm; + fall, included an additional defoliation to 5 cm during the fall prior to renovation.
§ Within columns, means followed by the same letter are not significantly different at the 5% level.

Table 3.5 Forage yields in renovation (1995) and post-renovation (1996) years (site A).

Treatment	Last harvest (8 Aug. 1995)	Total yield (1996)
	Dry Matter, kg ha^{-1}	
Suppression method (S)†		
Mow to 5 cm	1941 c‡	6710 a
Mow to 10 cm	2290 ab	6816 a
Graze to 5 cm	2009 bc	7059 a
Graze to 10 cm	1921 c	6477 a
Herbicide	2573 a	6882 a
No suppression	1954 c	6735 a
Unseeded	2052 bc	6915 a
Contrast		
Suppression Vs. No suppression	NS	NS
Physical suppression Vs. Herbicide	***	NS
Mow Vs. Graze	NS	NS
Clover species (C)		
Red clover	2193 a	6832 a
White clover	2018 a	6748 a
S x C interaction	NS	NS

NS,*** Not significant or, significant at the 0.001 probability level.
† For mow and graze, the grass sward was defoliated to a 5 or 10 cm residual height at seeding and during the first two months of legume establishment, when the sward reached 25 to 35 cm.
‡ Within columns, means followed by the same letter are not significantly different at the 5% level.

Table 3.6 Forage yields in renovation year (site B).

Treatment	Establishment phase (May-Jul. 1996)	Last harvest (4 Sep. 1996)	Total yield (1996)
	Dry Matter, kg ha^{-1}		
Suppression method (S)†			
Mow to 5 cm + fall	3625 bc‡	1398 bc	5023 cd
Mow to 5 cm	5464 a	1422 bc	6886 a
Mow to 10 cm	3632 bc	1195 c	4827 d
Graze to 5 cm + fall	3009 cd	1429 bc	4438 d
Graze to 5 cm	4254 b	1807 ab	6061 abc
Graze to 10 cm	3380 bcd	2037 a	5418 bcd
Herbicide	2614 d	648 d	3262 e
No suppression	4230 b	2113 a	6343 ab
Unseeded	3801 bc	2256 a	6057 abc
Contrast			
Suppression Vs. No suppression	NS	***	**
Physical suppression Vs. Herbicide	***	***	***
Mow Vs. Graze	**	***	NS
Clover species (C)			
Red clover	4015 a	1451 a	5466 a
White clover	3543 a	1728 a	5271 a
S x C interaction	NS	NS	NS

NS,**,*** Not significant or, significant at the 0.01 and 0.001 probability levels, respectively.
† For mow and graze, the grass sward was defoliated to a 5 or 10 cm residual height at seeding and during the first two months of legume establishment, when the sward reached 25 to 35 cm; + fall, included an additional defoliation to 5 cm during the fall prior to renovation.
‡ Within columns, means followed by the same letter are not significantly different at the 5% level.

3.9 CONNECTING TEXT

In the previous study, the potential of physical sod suppression methods during pasture renovation by legume sod-seeding have been demonstrated. Physical sod suppression methods resulted in adequate legume establishment, without reducing forage yields in the renovation year. Forage quality improvement being one of the main objective of pasture renovation, there was then the need for determination of the effects of physical sod suppression methods on forage quality. A study was conducted to evaluate quality of forage harvested in the renovation year at site A of the previous experiment. Treatments and experimental design used in this second experiment were the same as for the previous one.

4.0 RESEARCH NOTE:
FORAGE QUALITY FOLLOWING PASTURE RENOVATION BY LEGUME SOD-SEEDING WITH HERBICIDE OR PHYSICAL SOD SUPPRESSION

P. Seguin, P.R. Peterson, and D.L. Smith[2]

4.1 ABSTRACT

During pasture renovation by legume sod-seeding herbicide or physical sod suppression can result in successful legume establishment. However, the comparative effects of suppression methods on forage quality are not available. The objective of this study was to investigate the effects of sod suppression method on percentage neutral detergent fiber (NDF), acid detergent fiber (ADF), in vitro true digestibility (IVTD), and relative feeding value (RFV) of seeding year forage. Sod suppression methods evaluated were: strategically timed mowing or sheep grazing to 5 or 10 cm at seeding and during legume establishment, and herbicide (glyphosate at 2.6 kg a.i. ha^{-1} + 0.5% Frigate Vol./Vol.). Unsuppressed and unseeded controls were also included. When red or white clover were sod-seeded, sod suppression by grazing or herbicide resulted in increased forage quality when compared with controls. For grazing treatments, this was thought to be caused to some extent by a more frequent defoliation regime and not to the renovation itself.

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[2] P. Seguin and D.L. Smith, Dep. of Plant Sci., Macdonald Campus, McGill University, 21,111 Lakeshore Rd., Ste-Anne-de-Bellevue, Qc. H9X 3V9, Canada; and P.R. Peterson, Dep. of Crop and Soil Env. Sci., Virginia Polytechnic Institute & State University., 424 Smyth Hall, Blacksburg, VA 24061-0403.

4.2 INTRODUCTION

The primary advantages of renovating grass dominated pasture by introducing legumes are increased forage productivity and quality, and better distribution of forage production throughout the year. A method of pasture renovation that is increasing in popularity is sod-seeding, where seeds are drilled into the grass sod (Thompson, 1995).

Pasture renovation by no-till seeding of legumes has resulted in adequate legume populations to contribute significantly to forage yields in a number of studies (Olsen et al., 1981; Kunelius et al., 1982; Sheaffer and Swanson, 1982; Taylor and Allinson, 1983). Successful legume establishment seems to depend on adequate suppression of the resident vegetation (Groya and Sheaffer, 1981). Herbicide sod suppression has been widely recognized as an effective suppression method, and thus is currently the method most commonly used. However, suppression by herbicides can result in a loss of potentially usable forage, due to excessive sod suppression, as well as weed encroachment and inappropriate grass-legume ratios (Sheaffer and Swanson, 1982; Kunelius and Campbell, 1986; Rioux, 1994). Physical sod suppression methods such as timely mowing or grazing could alleviate some of these problems (Seguin and Peterson, 1997). Physical sod suppression methods have resulted in similar legume establishment to that achieved with herbicide (Kunelius et al., 1982; Seguin and Peterson, 1997).

One of the main goals of pasture renovation is to increase forage quality. Legume sod-seeding with herbicide sod suppression has increased both forage crude protein (CP) yield and in vitro dry matter digestibility (IVDDM) in the post-renovation year compared with an unrenovated sod (Rioux, 1994). Koch et al. (1987) reported similar results with increased CP yields in the renovation year as well. Physical suppression methods have been reported to increase CP and digestible dry matter (DDM) yields in both renovation and post-renovation years (Taylor and Allinson, 1983). Byers and Templeton (1988) reported that sod suppression by broadcast herbicide resulted in significantly higher CP and DDM yields than suppression by banded herbicide or mowing.

Although successful legume establishment (ie: plant population and yields) of renovated pasture has been documented using herbicide sod suppression, and to some extend with physical suppression, reports on the comparative impact of these methods on forage quality are limited. Whereas some studies have demonstrated increased forage quality of pasture renovated by legume sod-seeding, none have made comparisons among the sod suppression methods currently available, including physical methods and unrenovated controls. Thus, the objective of this study was to compare the effects of various sod suppression methods on forage quality of renovated pasture.

4.3 MATERIAL AND METHODS

4.3.1 Site Description

The study was conducted at the Macdonald Campus Farm of McGill University (45° 25'45" N lat., 73° 56'00" W long.), Ste-Anne-de-Bellevue, Quebec, Canada. The experiment was conducted in 1995 on a smooth bromegrass (*Bromus inermis* Leyss.), reed canarygrass (*Phalaris arundinacea* L.) dominated pasture. When the experiment was initiated, legumes were totally absent. The soil was a mixture of Chicot fine sandy loam and Macdonald clay loam. The slope was less then 1%. The field was previously used as a hayfield.

During the experiment, precipitation and temperature deviated from the 30 year average during the growing season (May to October). The average total precipitation for this period is 496 mm and the mean monthly temperature is 15.7°C. Total precipitation was 738 mm and the mean monthly temperature 16.5°C. Most of this rainfall fell late in the growing season.

4.3.2 Plot Management

The experiment was organized in a split-plot design with four blocks, with sod-seeded clover species as main plots and sod suppression methods as subplots. Each subplot was 9 m by 9 m. Sod-seeded clover species were 'AC Charlie' red clover and 'Shasta' white clover. Sod suppression methods consisted of herbicide application (glyphosate at 2.6 kg a.i. ha^{-1} plus 0.5% Frigate Vol./Vol.) two weeks prior to seeding, or one of four physical suppression methods: mowing or sheep grazing, to 5 or 10 cm, at seeding and when the grass sward reached 25 to 35 cm during the first two months of legume establishment. Two controls were also included: sod-seeding with no sod suppression and no seeding. Grazed treatments were stocked with 5 to 7 dry ewes to graze forage to desired heights within two days. Mowing was accomplished with a rotary mower and after each defoliation event, forage material was removed.

Seeding was carried out using a Great Plains no-till seeder, to a depth of 5 mm, on June 1, 1995. Seeding rates were 7 and 2 kg ha^{-1} for red clover and white clover, respectively. For the physical sod suppression subplots, three defoliations occurred: the first at seeding and the later two during legume establishment. Suppression via sheep grazing was imposed from May 23 to 31, from June 12 to 20, and from July 3 to 8, 1995. This range in dates reflects sheep numbers sufficient to graze one block at a time. Defoliation of the mowed subplots occurred near the middle of these intervals as weather allowed. The other subplots were defoliated once during legume establishment on July 6, 1995. Following legume establishment, forage was harvested once on August 8, 1995.

4.3.3 Analyses and Measurements

Forage quality was determined twice in the seeding year: at the 8 August harvest and at the end of season (October 1, 1995). For the August harvest, four samples were obtained from representative areas in each subplot. These were bulked, and a 500 g fresh subsample was taken and dried at 70°C for 24 h. Dry forage samples were ground to pass a 1-mm screen of a shear mill (Wiley Mill, Philadelphia, PA) for forage quality analyses. At the end of season, samples were obtained from four 0.25 m^2 rectangle quadrats in each subplot, following a stratified random sampling procedure (Gomez and Gomez, 1984 p. 540-541). The samples were then bulked, dried and ground as described before.

Forage quality analyses were performed at the William H. Miner Agricultural Research Institute (Chazy, NY). Neutral detergent fiber (NDF), acid detergent fiber (ADF) and in vitro true digestibility (IVTD) were determined on duplicate samples from each harvest and subplot by the methods of Goering and Van Soest (1970). NDF is negatively related to forage intake and ADF to forage digestibility (Mott and Moore, 1985). Analyses were performed using an ANKOM 200 fiber analyzer (Ankom Technology Corporation, Buffalo. NY). The fermentation step for IVTD also required the use of a DAISY II incubator (Ankom technology corporation, Buffalo, NY). All values reported are on a dry matter basis. In addition, relative feeding value (RFV) was determinated from the values obtained for NDF and ADF (Brothers et al., 1994).

4.3.4 Statistical Analysis

Data were analysed using the GLM procedure of the SAS Institute, Inc (SAS, 1988). Analysis of variance was used to detect mainplot by subplot interactions, and mainplot and subplot main effects. When the F-tests were significant at $p \leq 0.05$, means were separated using Duncan's multiple range test. Single degree of freedom contrasts were also used to carry out preplanned comparisons of specific subplot combinations. Because these were of a priori interest, they were made regardless of significance of effects in analysis of variance (Steel and Torrie, 1980, p. 172-174). Before performing the analysis of variance, every data set was tested for normality and homoscedasticity.

4.4 RESULTS AND DISCUSSION

4.4.1 Sod Suppression Effects on Forage Quality

Clover species by suppression methods interactions and clover species effects were non significant at both dates. There were no differences in NDF, ADF concentrations, and IVTD among unseeded, seeded but not suppressed, and mowed treatments except for mowing to 5 cm which resulted in higher IVTD (Table 4.1). At the August harvest, forage from grazed and herbicide suppressed treatments had lower NDF concentrations, than with mowing or the controls (unseeded and no suppression). However, only grazed treatments had lower ADF concentrations and higher IVTD. At the end of season, grazed and herbicide suppression treatments resulted in better forage quality (ie: lower NDF and ADF concentrations, and higher IVTD) than the controls; except for grazed to 10 cm which failed to lower NDF concentration. At both dates, contrasts demonstrated that sod suppression resulted in better forage quality. This increase in forage quality was likely due to the presence of sod-seeded clover as well as differences in sward defoliation frequencies. Indeed, subplots submitted to physical sod suppression had two more defoliations than other treatments. This resulted in less fibrous forage since fiber content increases with maturity (Cherney et al., 1993) and may have been the cause of higher forage quality of some of the sods physically suppressed. Turner et al. (1996) reported that more frequent defoliation of monoculture grass swards early in the season result in lower NDF and ADF values. The relationship between defoliation frequencies and forage quality response seems to be further supported by the low clover content in the August harvest, in all treatments (Seguin and Peterson, 1997) but also by the fact that the herbicide suppression treatment which had the same number of defoliations as controls, only showed lower percentage NDF, when compared with these later at the August harvest. However, at the end of season, when the clover contribution to total forage mass was much higher, as mentioned earlier, herbicide suppression resulted in improved forage quality for all the parameters analysed compared with controls. Physical suppression resulted in lower NDF concentration than herbicide suppression at both dates; while the reverse was observed for ADF concentration and IVTD at the last harvest. Also, suppression via grazing resulted in better forage quality at the August harvest than mowing; while at the end of season it resulted only in higher IVTD.

4.4.2 Sod Suppression Effects on Forage Relative Feeding Value

At both dates, clover species by suppression method interactions and clover species effects were non significant. At both dates, there were no differences in the forage RFV of the unseeded and no suppression treatments (Table 4.2). At the August harvest, grazing and herbicide suppression produced forage of greater RFV than the controls. At the end of season, this was only observed with herbicide suppression and grazing to 5 cm treatments. Suppression of the sod resulted in higher forage RFV at both dates, while at the last harvest, grazing resulted in higher RFV than mowing, and at the end of season, forage RFV with herbicide suppression was higher than with physical suppression. These results further support the hypothesis that increased forage quality observed with physical sod suppression might be due to the defoliation frequency rather than to clover introduction itself. As for the increase in RFV observed with herbicide suppression, it might be a result of clover introduction, but also of the high weed content that was observed with herbicide suppression. Some of the weeds that were present (eg: dandelion (*Taraxacum officinale* Weber)) are known to have a high nutritional quality.

4.5 CONCLUSION

Improvement in forage quality might result from pasture renovation by legume sod-seeding. However, whereas the improved forage quality with herbicide suppression seems to be a direct consequence of the renovation process; with physical suppression, improved forage quality in the renovation year might be due in part to the more intensive defoliation to which the sod is submitted during the legume establishment phase.

4.6 ACKNOWLEDGMENTS

The senior author was supported by the Fonds pour la Formation de Chercheurs et l'Aide à la Recherche du Quebec. The authors acknowledge the technical assistance of W. Asbil, S. Couture, M. Lira jr., F. Karimian., J. Straughton and S. Willox.

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4.8 TABLES

Table 4.1 Concentrations of neutral detergent fiber (NDF), acid detergent fiber (ADF), and in vitro true digestibility (IVTD) of forage in the renovation year, averaged over red and white clover.

Suppression method†	Last harvest (8 Aug. 1995)			End of the season (1 Oct. 1995)		
	NDF	ADF	IVTD	NDF	ADF	IVTD
			% of dry matter			
Mow to 5 cm	54.4 ab‡	27.9 ab	86.4 bc	52.7 ab	29.8 ab	77.6 bc
Mow to 10 cm	54.3 ab	28.2 ab	85.6 cd	52.3 ab	30.0 ab	77.8 bc
Graze to 5 cm	52.0 c	26.9 c	88.6 a	51.6 b	28.9 b	80.8 a
Graze to 10 cm	52.6 bc	27.3 bc	87.4 ab	52.3 ab	28.7 b	79.1 ab
Herbicide	51.3 c	28.7 a	85.2 cd	47.2 c	28.8 b	79.4 ab
No suppression	54.7 a	28.8 a	84.6 d	54.8 a	31.4 a	75.5 cd
Unseeded	54.8 a	28.7 a	84.6 d	54.8 a	31.6 a	75.0 d
Contrasts						
Suppression Vs. No suppression	*	**	***	***	**	***
Physical Vs. Herbicide	**	**	**	***	NS	NS
Mow Vs. Graze	**	**	***	NS	NS	**
CV, %	4	3	2	5	7	3

NS,*,**,*** Not significant or, significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

†For mow and graze, the grass sward was defoliated to 5 or 10 cm residual height at seeding and during the first two months of legume establishment, when the sward reached 25 to 35 cm.

‡Within columns, means followed by the same letter are not significantly different at the 5% level.

Table 4.2 Forage relative feeding value (RFV) in the renovation year, averaged over red and white clover.

Suppression method†	Last harvest (8 Aug. 1995)	End of the season (1 Oct. 1995)
	RFV	
Mow to 5 cm	115 bc‡	118 bc
Mow to 10 cm	115 bc	117 bc
Graze to 5 cm	122 a	120 b
Graze to 10 cm	120 ab	119 bc
Herbicide	121 a	132 a
No suppression	113 c	110 c
Unseeded	113 c	110 c
Contrasts		
Suppression Vs. No suppression	**	**
Physical Vs. Herbicide	NS	***
Mow Vs. Graze	**	NS
CV, %	4	8

NS,**,*** Not significant or, significant at the 0.01 and 0.001 probability levels, respectively.

†For mow and graze, the grass sward was defoliated to 5 or 10 cm residual height at seeding and during the first two months of legume establishment, when the sward reached 25 to 35 cm.

‡Within columns, means followed by the same letter are not significantly different at the 5% level.

5.0 GENERAL DISCUSSION AND CONCLUSIONS

The main goal of the work presented herein was to develop alternatives to the use of herbicide as a sod suppression method during pasture renovation by legume sod-seeding, in order to overcome some of the problems that are associated with the use of herbicide. The physical suppression methods tested (mowing and sheep grazing) have both demonstrated potential, resulting in similar sod-seeded legume establishment than herbicide suppression. There are clear indications that severity of the physical sod suppression, will be a key factor for ensuring proper legume development. Indeed, increases in the severity of defoliation resulted in increases as high as 360% in the clover plant population, and only the more severe physical suppression methods, involving defoliation to 5 cm, resulted in clover yields above those obtained with the controls. Clover mass at the end of the season (October) was as much as 7 times greater with herbicide than with the more intensive physical suppression methods. However, problems usually encountered during pasture renovation with herbicide sod suppression, such as weed infestation and total forage yield reduction in the renovation year, were not reported with physical suppression. Unlike herbicides, physical suppression methods were able to maintain the total forage production in the renovation year equivalent to that obtained with an unrenovated control; in some cases production was even increased (by as much as 829 kg ha^{-1}), although these increases were not statistically significant. Herbicide suppression resulted in 46% less total forage yield in the renovation year than the unseeded control.

However, when the effect of the sod suppression method on forage quality was assessed, results tended to indicate that clover yields with physical suppression methods might be too low to result in increased forage quality when compared with an unrenovated control. Increases in forage quality that were observed following physical sod suppression involving grazing, were attributed to the more frequent defoliation to which the sod was submitted compared with the unrenovated control.

Although results presented herein demonstrate the potential of physical sod suppression methods as an alternative to herbicide, as demonstrated by the high clover establishment; proposed physical suppression methods do not suppress resident vegetation enough, thus leading to slow legume development and relatively poor legume yields in the renovation year. More frequent physical defoliation of the sod, or a better knowledge of the effects of physical suppression methods on sod physiology, especially on sod regrowth potential should lead to the improvement of the proposed methods.

6.0 RECOMMENDATIONS FOR FUTURE RESEARCH

Future research could include:

1. Determination of the total non-structural carbohydrate reserves and other regrowth potential related reserves (N reserves).
2. Evaluation of physical suppression methods consisting of severe (to 5 cm) and frequent (3, 4, or 5 times) defoliations.
3. Evaluation of the proposed physical suppression methods over the long term.

7.0 APPENDIX

Table 7.1 Monthly precipitation and temperature at Ste-Anne-de-Bellevue, Quebec, April to October, 1995 and 1996, and the 30 year average (1961-1990).

Period	Total Precipitation			Mean monthly temperature		
	1995	1996	30-yr avg.	1995	1996	30-yr avg.
		mm			°C	
April	75	139	75	3.9	4.7	5.7
May	81	82	67	12.9	12.2	12.9
June	73	90	83	20.2	18.3	18.0
July	152	104	86	21.6	20.0	20.8
August	139	29	100	20.3	20.1	19.4
September	86	113	87	13.2	15.9	14.5
October	207	76	73	10.9	8.2	8.3
Growing season						
(May-Oct.)	738	494	496	16.5	15.8	15.7

Table 7.2 Sward height before and after each physical sod suppression event.

Suppression method†	First defoliation		Second defoliation		Third defoliation	
	Before	After	Before	After	Before	After
			cm			
Site A						
Mow to 5 cm	-‡	6.9 c§	18.8 b	6.6 b	22.2 bc	11.8 a
Mow to 10 cm	-	12.3 b	24.3 a	11.0 a	27.2 a	11.6 ab
Graze to 5 cm	-	9.0 c	24.0 a	8.0 b	21.1 c	8.0 c
Graze to 10 cm	-	15.3 a	23.7 a	10.0 a	26.8 ab	10.2 b
Site B						
Mow to 5 cm + fall	25.2 bc	5.1 b	28.6 c	5.4 c	36.3 b	12.7 c
Mow to 5 cm	32.0 a	5.8 b	34.2 bc	5.0 c	40.1 ab	12.4 c
Mow to 10 cm	29.6 ab	10.8 a	41.5 a	9.9 a	44.3 a	12.4 c
Graze to 5 cm + fall	20.6 c	6.8 b	32.2 bc	6.7 bc	36.6 b	16.3 bc
Graze to 5 cm	22.3 c	6.0 b	32.2 bc	7.7 ab	45.0 a	23.8 a
Graze to 10 cm	23.8 bc	11.0 a	34.6 b	9.1 a	44.0 a	19.6 ab

†For mow and graze, the grass sward was defoliated to 5 or 10 cm residual height at seeding and during the first two months of legume establishment, when the sward reached 25 to 35 cm; + fall, included an additional defoliation to 5 cm the fall prior to renovation.
‡Values not recorded.
§Within columns and sites, means followed by the same letter are not significantly different at the 5% level.

Table 7.3 Characteristics of the sward at seeding.

Suppression method†	Sward height		Mass of vegetation present	
	Site A	Site B	Site A	Site B
	cm		kg ha^{-1}	
Mow to 5 cm + fall		5.1 c‡		862 c
Mow to 5 cm	6.9 e	5.8 c	2066 c	1202 c
Mow to 10 cm	12.3 d	10.8 b	3665 b	2680 b
Graze to 5 cm + fall		6.8 c		1179 c
Graze to 5 cm	9.0 e	6.0 c	2133 c	2055 b
Graze to 10 cm	15.3 c	11.0 b	3166 b	2515 b
Herbicide	8.7 e	5.5 c	3486 b	3615 a
No suppression	19.6 b	29.4 a	4440 a	3918 a
Unseeded	23.5 a	31.6 a	-§	4337 a

† For mow and graze, the grass sward was defoliated to 5 or 10 cm residual height at seeding and during the first two months of the legume establishment, when the sward reached 25 to 35 cm; + fall, included an additional defoliation to 5 cm during the fall prior to renovation.
‡ Within columns, means followed by the same letter are not significantly different at the 5% level.
§ Value not recorded.

Table 7.4 Detailed botanical composition of renovated sods at the last harvest and end of the season of the renovation year (site A).

	Last harvest (8 August, 1995)					End of the season (1 October, 1995)				
Treatment	Clover	Short grasses	Tall grasses	Weeds	Other legume	Clover	Short grasses	Tall grasses	Weeds	Other legume
					%†					
Suppression method (S)‡										
Mow to 5 cm	2.2 ab§	11.0 a	60.8 a	2.7 a	19.4 ab	16.6 a	19.7 a	50.2 a	2.5 b	7.6 a
Mow to 10 cm	1.6 abc	11.4 a	65.8 a	4.6 a	11.8 b	7.2 bc	24.0 a	51.6 a	7.3 ab	6.2 a
Graze to 5 cm	2.4 ab	7.6 a	71.8 a	4.9 a	7.9 b	12.3 ab	22.8 a	54.3 a	2.8 b	3.8 a
Graze to 10 cm	0.6 bcd	12.7 a	66.0 a	4.8 a	9.3 b	3.8 c	23.0 a	60.2 a	1.5 b	6.5 a
Herbicide	3.0 a	0.6 b	47.0 a	10.5 a	30.2 a	18.0 a	2.2 b	42.4 a	16.2 a	12.8 a
No suppression	0.3 cd	12.2 a	65.4 a	1.9 a	18.0 ab	3.2 c	25.5 a	56.1 a	3.9 b	8.1 a
Unseeded	0 d	11.1 a	73.4 a	3.8 a	7.9 b	0 d	27.5 a	53.6 a	4.6 b	10.2 a
Contrasts										
Suppression Vs. No suppression	**	NS	NS	NS	NS	**	NS	NS	NS	NS
Physical Vs. Herbicide	NS	***	**	*	NS	*	***	NS	***	*
Mow Vs. Graze	NS	NS	NS	NS	***	NS	NS	NS	NS	NS

Table 7.4 (Continued) Detailed botanical composition of renovated sods at the last harvest and end of the season of the renovation year (site A).

	Last harvest (8 August, 1995)					End of the season (1 October, 1995)				
Treatment	Clover	Short grasses	Tall grasses	Weeds	Other legume	Clover	Short grasses	Tall grasses	Weeds	Other legume
					%†					
Clover species (C)										
Red clover	1.8 a	6.6 b	66.3 a	5.1 a	13.5 a	10.0 a	19.6 a	50.2 a	5.0 a	7.6 a
White clover	0.8 a	11.2 a	62.4 a	3.9 a	14.6 a	4.9 a	21.7 a	55.0 a	4.7 a	7.5 a
S x C interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS,*,**,*** Not significant or, significant at the 0.05, 0.01 and 0.001 probability levels, respectively.
† The sum of percent of each component at a given date may not be equal to 100, due to the use of data transformation during statistical analysis.
‡ For mow and graze, the grass sward was defoliated to 5 or 10 cm residual height at seeding and during the first two months of legume establishment, when the sward reached 25 to 35 cm.
§ Within columns, means followed by the same letter are not significantly different at the 5% level.

Table 7.5 Detailed botanical composition of renovated sods at last harvest and end of season of the renovation year (site B).

Treatment	Last harvest (27 August, 1996) Clover	Short grasses	Tall grasses	Weeds	Other legume	End of the season (October 7, 1996) Clover	Short grasses	Tall grasses	Weeds	Other legume
					%†					
Suppression method (S)‡										
Mow to 5 cm + fall	12.1 b§	10.0 a	65.8 b	1.7 a	1.6 b	7.7 b	19.6 ab	60.1 c	3.1 b	0.7 bc
Mow to 5 cm	9.4 bc	7.8 a	70.6 b	1.2 a	2.9 ab	4.8 bc	17.0 ab	69.3 bc	1.2 bc	1.2 b
Mow to 10 cm	3.1 cd	8.8 a	83.8 ab	0.8 a	1.0 b	1.9 cd	18.6 ab	70.8 bc	2.0 bc	0.8 bc
Graze to 5 cm + fall	9.0 bc	8.5 a	73.9 b	1.9 a	1.3 b	7.3 b	28.8 a	55.2 cd	1.8 bc	0.3 bc
Graze to 5 cm	2.7 cd	4.5 a	82.4 ab	3.6 a	1.1 b	3.1 c	16.0 ab	73.1 abc	0.5 c	0.6 bc
Graze to 10 cm	0.9 d	7.5 a	85.0 ab	2.0 a	0.9 b	1.7 cd	29.3 a	63.1 bc	1.0 bc	0.3 bc
Herbicide	44.8 a	2.0 a	36.1 c	4.2 a	6.2 a	46.5 a	1.1 c	38.8 d	6.9 a	3.6 a
No suppression	0.3 d	1.9 a	95.2 a	1.2 a	0.6 b	0 d	5.6 bc	89.9 a	0.2 c	0.1 c
Unseeded	0 d	6.0 a	92.2 a	0 a	0.8 b	0 d	12.2 ab	82.1 ab	0.2 c	0.4 bc
Contrasts										
Suppression Vs. No suppression	***	NS	***	NS	NS	***	*	***	**	*
Physical Vs. Herbicide	***	*	***	NS	***	***	***	***	***	***
Mow Vs. Graze	*	NS	NS	NS	NS	NS	NS	NS	NS	*

Table 7.5 (Continued) Detailed botanical composition of renovated sods at the last harvest and end of the season of the renovation

Treatment	Last harvest (27 August, 1996)					End of the season (October 7, 1996)				
	Clover	Short grasses	Tall grasses	Weeds	Other legume	Clover	Short grasses	Tall grasses	Weeds	Other legume
	%†									
Clover species (C)										
Red clover	9.1 a	5.8 a	75.5 a	1.5 a	1.2 a	6.8 a	15.1 a	65.5 a	1.3 a	0.8 a
White clover	3.5 b	6.5 a	80.1 a	1.7 a	2.0 a	3.5 b	14.6 a	68.3 a	1.9 a	0.8 a
S x C interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

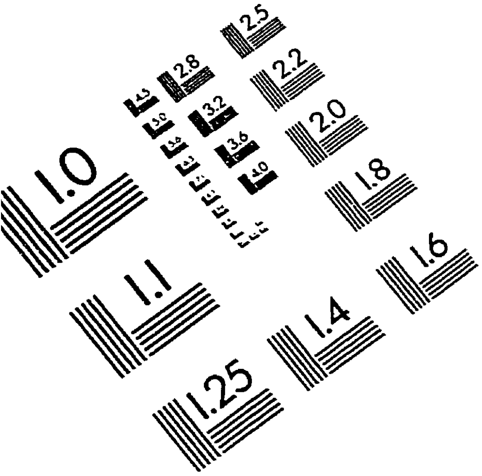
NS,*,**,*** Not significant or, significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

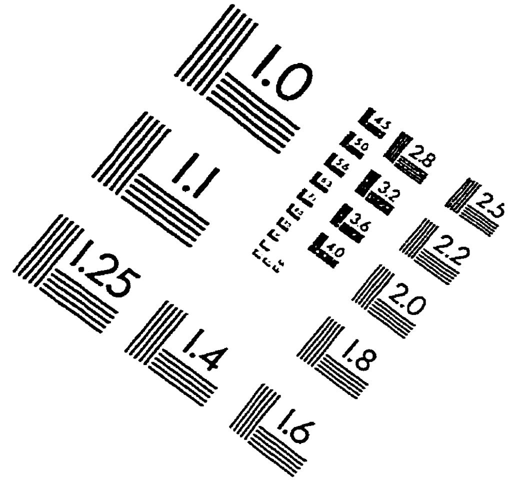
† The sum of percent of each component at a given date may not be equal to 100, due to the use of data transformation during statistical analysis.

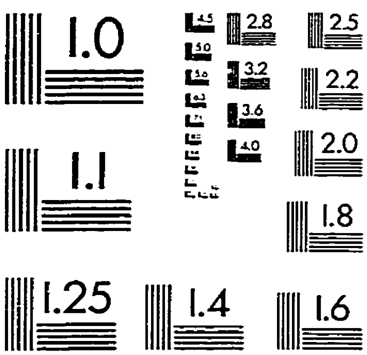
‡ For mow and graze, the grass sward was defoliated to 5 or 10 cm residual height at seeding and during the first two months of legume establishment, when the sward reached 25 to 35 cm; + fall, included an additional defoliation to 5 cm during the fall prior to renovation.

§ Within columns, means followed by the same letter are not significantly different at the 5% level.

IMAGE EVALUATION
TEST TARGET (QA-3)

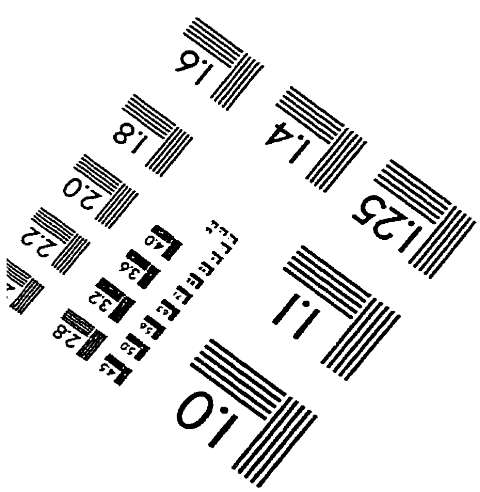


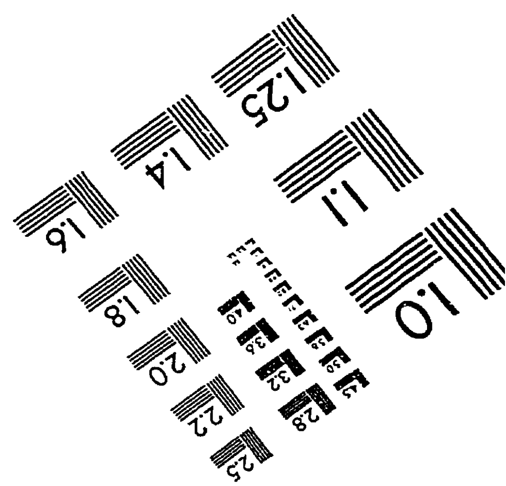




150mm

6″





APPLIED IMAGE, Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989