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Review of factors determining legumes sod-seeding outcome during pasture renovation in North America

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Pasture renovation by legumes sod-seeding, which consist in drilling legumes seeds in a grass dominated sward, is a way of increasing both pasture productivity and quality. In North America the use of this method is increasing in popularity. However, results are variable and some problems still persistent. Factors determining the outcome of legumes sod-seeding during pasture renovation are reviewed. Particular attention is given to the role and effects of herbicides, which are generally used to suppress the competition provided by the resident grass vegetation. The use of physical sod suppression methods (eg: mowing or grazing) as an alternative to herbicides is also discussed.
Keywords. Direct sowing, pasture renovation, feed legumes, grass sod, herbicides, North America.

Synthèse des facteurs déterminant le succès de la rénovation de pâturages par semis direct de légumineuses en Amérique du Nord. La rénovation de pâturages *via* l'introduction de légumineuses par semis direct, consistant en un semis sans labour dans une prairie dominée par des graminées, est une méthode qui accroît la productivité et la qualité des pâturages. En Amérique du Nord, l'utilisation de cette méthode croît en popularité. Cependant, les résultats sont variables et certains problèmes persistent. Les facteurs determinant le succès de la rénovation de pâturages par semis direct sont présentés. Une attention particulière est portée au rôle et aux effets des herbicides. Ces derniers sont généralement utilisés afin de réduire la compétition exercée par la végétation résidente de graminées. L'utilisation de méthodes physiques (ex. : fauche ou pâture) afin de réduire l'effet compétitif des graminées est présentée comme alternative à l'utilisation d'herbicide.
Mots-clés. Semis direct, rénovation de pâturages, légumineuse fourragère, graminées, herbicide, Amérique du Nord.

INTRODUCTION

Pasture renovation entails 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.), into a grass dominated pasture. A commonly used method of pasture renovation consists in drilling seeds into the grass sod (sod-seeding). Introduced legumes benefit the pasture in three ways.

– They eliminate the need for application of costly nitrogen fertilizers, due to N_2 fixation by the legumes and transfer of this fixed N to spatially associated grasses, resulting in increased production (Kunelius, 1982; Taylor, Allinson, 1983; Kunelius, Campbell, 1984; Koch *et al*., 1987; George *et al*., 1995; Vough *et al*., 1995)

– They permit the stabilization of forage dry matter production throughout the year, due to differences in seasonal yield distribution between grass and legume species (Robinson, Winch, 1985).

– They increase the quality of forage available to grazing animals (Taylor, Allinson, 1983; Kunelius, Campbell, 1984; Koch *et al*., 1987; Ocumpaugh, 1990).

Although pasture renovation by sod-seeding is a method increasing in popularity, results reported are characterized by their great variability (Rioux, 1994a). As a consequence, factors affecting legume sod-seeding outcome warrant further discussion and investigation.

SUITABILITY OF VARIOUS LEGUMES TO SOD-SEEDING

Leguminous species vary in their suitability to sod-seeding. As underlined by Robinson and Cross (1960), the outcome of legume sod-seeding, depends in part on the inherent ability of the legume species to compete with grass. Tolerance for shading and lack of moisture are of greatest importance. Greatest success to date has been obtained with red clover (Belzile, 1988). Alfalfa (*Medicago sativa* L.), birdsfoot trefoil, hairy vetch (*Vicia villosa* Roth.), white-flowered sweetclover (*Melilotus alba* Medik.), yellow-flowered sweetclover (*Melilotus officinalis* Lam.) and white clover, have also been successfully established with this method (Olsen *et al*., 1981; Kunelius, Campbell, 1984; Blanchet *et al*., 1995). Crownvetch (*Cornilla varia* L.) generally fails to establish with sod-seeding (Olsen *et al*., 1981; Taylor, Allinson, 1983); however Decker *et al*. (1969) and Blanchet *et al*. (1995) reported successful crownvetch sod-seeding. Variability in suitability for sod-seeding, have also been reported for different cultivars of a same species (Kunelius, Campbell, 1984; Schellenberg *et al*., 1994b).

SEEDING OPERATIONS RELATED FACTORS

Seeding date

Sod-seeding can be done in spring or fall. However, adequate moisture is essential for successful sod-seeded legume establishment (Taylor *et al*., 1969; Mueller-Warrant, Koch, 1980). Generally, higher soil moisture levels occur in spring but grass competitiveness is greatest at this time. In summer and fall, grass growth and competitiveness are lower, but soil moisture is also generally low. To take advantage of the better soil moisture status associated with a spring seeding, having adequate control of grass competition is critical (Groya, Sheaffer, 1981; Olsen *et al*., 1981; Evers, 1995a). Usually herbicide is used as the suppressing agent.

Martin *et al*. (1983) observed that spring sod-seeding (late April, early May and late May), resulted in greater alfalfa dry matter (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 crude protein (CP) yields in the seeding year. The best spring seeding date depends on grass suppression level and herbicide used, being late April with paraquat and late May with glyphosate applied in spring. When spraying occurred at seeding, paraquat 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 the best spring seeding date depending on the herbicide used. In addition they showed that when glyphosate (2.1 $kg{\cdot}ha^{-1}$) was applied in mid-October to suppress grass, an early May seeding date gives greater alfalfa DM yields in the seeding year (1,100 $kg{\cdot}ha^{-1}$) and post-seeding year (3,700 $kg{\cdot}ha^{-1}$) compared with a mid-May seeding (800 and 3,200 $kg{\cdot}ha^{-1}$, 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 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, being lower in fall. With fall seeding, 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, in north central and northeastern North America, occur in late spring and early fall, and is dependent of herbicide related factors (eg: type, spraying-seeding interval, etc.).

In southeastern North America, Hoveland *et al*. (1996) reported greater sod-seeded grazing-tolerant alfalfa stands and yields, when seeded in September compared to March; with a pre-seeding paraquat application. These results were attributed to a less effective grass suppression with late winter than fall paraquat application. Also alfalfa was more vulnerable to drought and had a lower ability to compete with the resident vegetation. Zarnstorff *et al*. (1992) reported that under similar conditions, a mid-October application of paraquat will not result in increased legume establishment when seeded in late winter (February or March). Legume establishment was greater when seeded in March compared to February.

Seeding rate

There are presently no specific seeding rate recommendations for legume sod-seeding. Various seeding rates have produced highly variable results. Sheaffer and Swanson (1982) showed that optimum seeding rate depends upon level of competition offered 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 $kg{\cdot}ha^{-1}$ did not affect legume yields in the seeding year. However, with high grass competition increasing the seeding rate to 17.6 $kg{\cdot}ha^{-1}$ significantly increased legume DM yields of red clover at the first harvest and alfalfa at second harvest and for the yearly total. This effect was not carried on 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%; this legume content could result in bloat problems for animals grazing on such pastures. Generally, 30 to 50% of legumes in total forage yield is a desirable content in pastures (Wolfe, 1973; Rhodes *et al*., 1994). Sund *et al*. (1966) suggested that with precise sod-seeding, seeding rates could be decreased if compared with conventional seeding rates (red clover 7 to 3.3 kg·ha^{-1} and alfalfa 12 to 4.4 kg·ha^{-1}). Information is lacking on the subject for other species.

Seeding rates similar or even below those recommended for conventional seeding should be adequate for legume sod-seeding. Recommended seeding rates for legumes in northeastern regions 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).

Seeding depth

Seeding depth is an important factor with legume sod-seeding (Barnhart, Wedin, 1981) because of the small size, and thus very limited nutrients reserves, of the legume seeds (Frame, Newbould, 1986). Campbell (1985) evaluated the influence of seeding depth on the emergence of sod-seeded red clover. 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 (broadcast seeding), 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 seeds under soil surface (12 mm for alfalfa and 6 mm for red clover) provide better establishment, compared to seed placed on the surface. However, with current no-till seeders, it is often difficult to ensure a constant and even seeding depth (Campbell, 1985).

Seeder type

Seeder type used for legume sod-seeding will often have a great impact on success of legume establishment. For example, Welty *et al*. (1981) reported that a John Deere Power-till resulted in 186 seedlings·m^{-2} of alsike clover (*Trifolium hybridum* L.) compared to 33 with a Melroe 701 no-till drill. 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 give adequate legume emergence and establishment. However, results obtained with individual drills can vary.

Resident vegetation

Grass species. Looking at the effect of resident grass species on the establishment and production of sod-seeded legumes is essential, in order to identify desirable grass-legume associations for sod-seeding.

Grass species can affect legume establishment, even when herbicides are used to suppress the grass sod, especially when the grass sod is temporarily suppressed rather than killed, because of grass competitiveness. Eltun *et al*. (1985) showed that both seedling emergence and development are affected by dominant grass species present in a sod suppressed by herbicide. Reduction of legume seedling growth was greater with timothy (*Phleum pratense* L.) than with orchardgrass (*Dactylis glomerata* L.) or Kentucky bluegrass (*Poa pratensis* L). In contrast, 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/quackgrass sward. Groya and Sheaffer (1981) also observed lower alfalfa populations with smooth bromegrass (*Bromus inermis* Leyss.) than with Kentucky bluegrass. Hoveland *et al*. (1997) observed no differences in alfalfa establishment when seeded in orchardgrass, reed canarygrass (*Phalaris arundinacea* L.), endophyte-infected or endophyte-free tall fescue (*Festuca arundinacea* Schreb.). As for the effect on the sod-seeded legume yields, Eltun *et al*. (1985) observed lower alfalfa yields in the seeding year when associated with orchardgrass (780 kg·ha^{-1}) and timothy (830 kg·ha^{-1}) than with Kentucky bluegrass (1,120 kg·ha^{-1}). 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 most case, establishment of various legumes in a range of grass species has been successful (resulting in desirable legume yields) when herbicides were 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, Templeton, 1988), and red clover and alfalfa in smooth bromegrass (Sheaffer, Swanson, 1982).

With physical grass suppression (mowing and/or grazing) total forage and legume yields are even more affected by the grass species present at seeding, due essentially to a greater competition (Taylor, Allinson, 1983). Authors reported lower birdsfoot trefoil yields in orchardgrass and tall fescue than in either smooth bromegrass or timothy. They concluded that for alfalfa and birdsfoot trefoil establishment, orchardgrass was the most competitive grass, and timothy and smooth bromegrass were the least. 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 then orchardgrass or tall fescue for association with birdsfoot trefoil. In post-seeding years, tall fescue sod provided better legume survival by reducing winter heaving. Three years after seeding the differences among various grass–legume mixtures were non-significant.

Grass height. Grass height at seeding and during legume establishment, affects the success of legume introduction by sod-seeding. Mowing or grazing the grass vegetation before 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.* (1981) showed that although cutting grass down to 8 cm before herbicide spraying increased legume stand establishment by 89%, legume yields were reduced by 21%. This was attributed to an inadequate translocation of the herbicide in the grasses. The importance of this effect should be smaller for contact herbicides such as paraquat. There is no mention in the literature of studies looking at the ideal grass height at seeding. Mowing/grazing heights reported for legume sod-seeding studies have been highly variable: 2–3 cm (Taylor, Allinson, 1983), 5 cm (Taylor *et al*., 1969; Mueller, Chamblee, 1984), and 10 cm (Eltun *et al*., 1985).

HERBICIDE RELATED FACTORS

Type of 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 limit legume proportion to 50% of the forage production, to reduce bloat potential (Wolfe, 1973; Rhodes *et al.*, 1994).

Many studies which have addressed sod-seeding of legumes have indicated that glyphosate is the best herbicide to suppress resident vegetation (Martin *et al.*, 1983; Mueller-Warrant, Koch, 1983; Vogel *et al.*, 1983; Leroux, Harvey, 1985) at application rates between 0.6 and 1.7 kg·ha^{-1} (Martin *et al.*, 1983; Mueller-Warrant, Koch, 1983). Glyphosate is 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). Sod-seeded legumes greatly benefit from this severe grass suppression, and as a result it will be the greatest forage yield constituent. An application 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, Swanson, 1982). These results are supported by those of Vogel *et al.* (1983) and Koch *et al.* (1987), where glyphosate application resulted in forage containing 95% to 100% of sod-seeded alfalfa. Bowes and Zentner (1992) reported sod-seeded alfalfa contributing to 76% of total forage yields averaged over 4 years. However, severe grass suppression promotes weed encroachment, and often reduces excessively total forage yields in the seeding year. For example Bryan (1985) reported that total seeding year forage yields of a pasture renovated with red clover or birdsfoot trefoil were 30% less than that of an unseeded control. Forage yield reductions as high as 60% have been reported in the seeding year (Kunelius, Campbell, 1986). Rioux (1994a) reported substantial dandelion (*Taraxacum officinale* Weber) infestation of a smooth bromegrass sward renovated with alfalfa; as much as 45% of the second of two harvests in the renovation year was dandelion.

Other herbicides such as paraquat, glufosinate and sethoxydim also have 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; Rioux, 1994b; Evers, 1995b). Unlike glyphosate, paraquat does not kill grass but rather temporarily suppress it (Koch *et al.*, 1987). This results in lower sod-seeded legume yields and establishment when compared to glyphosate (Martin *et al.*, 1983; Mueller-Warrant, Koch, 1983). Koch *et al.* (1987) reported seeding year forage yields containing 80% of sod-seeded alfalfa with glyphosate, and only 40% with paraquat. Mueller-Warrant and Koch (1983), in New Hampshire, noted a decrease in seedling density with paraquat (115 plants·m^{-2}), when compared to glyphosate (178 plants·m^{-2}). Also, at the first harvest 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 yields in 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 to 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 of geographic origin. 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 the 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 three leaf stage (Martin *et al.*, 1983). Some of the conflicting results may originate from application at a wrong 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 seems undesirable for pastures. According to results presented herein, paraquat would be a better choice for legume sod-seeding. This is supported by Koch *et al*. (1987) who reported that unlike glyphosate, paraquat allowed an increase in forage quality without decreasing the dry matter production, when compared with an unseeded control. Also, they reported a grass:legume yield ratio of 50:50, which is optimal for pastures. Martin *et al.* (1983) determined that paraquat applied at a rate of 0.8 $kg{\cdot}ha^{-1}$ is adequate for pasture renovation in May; this rate resulted in legume yields representing 21 to 50% of the total forage production.

Spraying/Seeding interval

Davies and Davies (1981) showed that there is a significant increase in red clover establishment when the interval between spraying glyphosate at 1.44 $kg{\cdot}ha^{-1}$ and seeding is increased from 7 to 21 days. This was attributed, in part, to the 14 days required for glyphosate to desiccate grass completely. Thus, during this period, competition will persist. These results are 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 seedlings per m^2 with 1 day interval between spraying and seeding to 610 seedlings per m^2 with a 28 day interval. For the first harvest in seeding year, alfalfa yields increased from 960 $kg{\cdot}ha^{-1}$ with a 1 day interval to 1,460 $kg{\cdot}ha^{-1}$ with a 28 day interval.

Mueller-Warrant and Koch (1983) sprayed the grass sod in the fall before 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 resided in the broadleaf weed content. With glyphosate sprayed in fall or spring at a rate of 1.1 $kg{\cdot}ha^{-1}$, the weed content of the 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 benefit from an interval between spraying and seeding. This interval might allow total grass desiccation, leaching or inactivation of allelochemicals potentially released by the resident grass, and thus result in complete suppression of competition and herbicide inactivation. Welty *et al*. (1981) recommended that this interval be of 14 to 28 days.

Herbicide disposition

Broadcasting is the most commonly used method of herbicide application for grass sod suppression in pasture renovation studies. However it is thought that banding herbicide could alleviate some of the problems that are currently associated with legume sod-seeding; being reduced forage yields in the seeding year, weed encroachment and inappropriate grass:legume ratio (Bryan, 1985). Rioux (1994a) looked at 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 *versus* 1.35 $tons{\cdot}ha^{-1}$). In addition, herbicide banding resulted in lower proportions of broadleaf weeds. However alfalfa content, as well as CP and *in vitro* digestible dry matter (IVDDM), were all lower with herbicide banding in one year out of two. Byers and Templeton (1988) reported lower total forage production (1,256 *versus* 1,470 $kg{\cdot}ha^{-1}$), sod-seeded alfalfa yields (144 *versus* 373 $kg{\cdot}ha^{-1}$), digestible dry matter (DDM) (810 *versus* 975 $kg{\cdot}ha^{-1}$), CP (155 *versus* 218 $kg{\cdot}ha^{-1}$) and similar weed yields (24 *versus* 34 $kg{\cdot}ha^{-1}$) with herbicide banding compared with broadcasting. The percentage of alfalfa in total forage production was only 11%. Schellenberg *et al*. (1994a) observed increased alfalfa establishment with an increase in width of grass suppression up to 75 cm. However, Taylor *et al*. (1969) reported no effect of herbicide band width on alfalfa establishment (germination and seedling growth). Thus, benefits of banding herbicides may be limited.

AN ALTERNATIVE TO HERBICIDE: PHYSICAL SOD SUPPRESSION

Although sod-seeding with herbicide sod suppression is often successful, several disadvantages still subsist. 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 primary goal 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), might represent an 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 successful in several studies (Olsen *et al*., 1981; Kunelius *et al*. 1982; Taylor and Allinson, 1983; Seguin and Peterson, 1997). Herbicide and physical methods of grass suppression may result in similar sod-seeded legumes establishment (Seguin, Peterson, 1997). 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. Taylor and Allinson (1983) showed that red clover sod-seeding with physical grass sod suppression increased total dry matter yields compared with an unseeded control. Suppression methods consisting in mowing sward every 2 or 4 weeks for 8 weeks, did not differ in effectiveness. Kunelius *et al*. (1982) showed that intensive management of the resident vegetation during establishment of sod-seeded legumes can yield benefits compared with methods relying on herbicides. In the seeding year, mowing the vegetation down to 4 cm when it reached 12 cm, as a sod suppression method, 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 a rate of 1.1 $kg·ha^{-1}$. Also in the post-seeding year, grass suppression by mowing resulted in lower broadleaf weed yields (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 with herbicide. Rioux (1994a) also reported higher total forage production when alfalfa was sod-seeded without herbicides (5.5 $tons·ha^{-1}$) than with banded herbicides (2.3 $tons·ha^{-1}$). There are also indications that physical sod suppression methods will result in increased CP and DDM (digestible dry matter) yields in both renovation and post renovation years (Taylor, Allinson, 1983). Also, Rioux (1994a) reported similar forage CP and IVDDM yields with legumes sod-seeding following herbicide and physical grass suppression.

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 greater with herbicide suppression (187 $kg·ha^{-1}$) than with physical suppression (125 $kg·ha^{-1}$). Also, there were no differences in the weed content or alfalfa yields.

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

REGIONS USING LEGUME SOD-SEEDING AS A METHOD OF PASTURE RENOVATION

North American regions where legume sod-seeding is now used as a method of pasture renovation include: eastern (Atlantic provinces, Québec, and Ontario), and central Canada (Saskatchewan); and north-eastern (Connecticut, Delaware, Maryland, New Hampshire, New York, Ohio, Pennsylvania, and West Virginia), north central (Iowa, Minnesota, and South Dakota), and south-eastern USA (Georgia and North Carolina). North-eastern temperate continental and south-eastern subtropical wet climates best support legume sod-seeding among these regions. North-eastern regions are characterized by freeze-free period of 115 to 200 days, total annual precipitation of 800 to 1,300 mm and wide temperature ranges. Southeastern regions have total annual precipitation of 1,250 mm or more; these together with relatively high temperatures contribute to soils generally low in organic matter, nutrients and pH, compared to north-eastern regions.

Legume sod-seeding is a method of pasture renovation generally recommended for soils prone to erosion. However it has given satisfactory results in a wide range of soils and topographic conditions. The present review has demonstrated that legume sod-seeding can be successful in a range of soils, resident vegetation, and climatic conditions. As mentioned earlier, independent of the region, the most important environmental condition for successful legume sod-seeding seems to consist in adequate soil moisture during legume establishment (Groya, Sheaffer, 1981;

Hoveland *et al*., 1996). This might explain why best results are generally reported in eastern regions, and not in the semi-arid central ones. However there is a lack of research on the effects of environmental variables on legume sod-seeding.

CONCLUSION

Pasture renovation by legumes sod-seeding is a method increasing in popularity in North America. If the use of this method is to be spread to other regions such as Europe, its reliability is to be improved. Some key factors determining the outcome of legume sod-seeding seem to reside in the seeding conditions and the effect of the herbicide on these. The most important factor resides in achieving a sufficient reduction of the competition provided by the resident grass sod. Herbicide is an effective suppressing agent however its use is associated to problems such as: reduced forage yields, weed encroachment and inappropriate grass:legume ratio. Potential solutions to these include using a herbicide providing temporary grass suppression, or using physical sod suppression methods such as grazing or mowing.

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