

FORAGES AND PASTURE MANAGEMENT

Establishment of Kura Clover No-Tilled into Grass Pastures with Herbicide Sod Suppression and Nitrogen Fertilization

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ABSTRACT

Sod-seeding legumes into grass-dominated pastures improve forage productivity and quality. Identical field experiments were established in May 2001–2002 at two sites in Québec and three in Minnesota. Our objective was to compare the establishment in perennial cool-season grass sods of two sod-seeded cultivars ('Cossack' and 'Endura') of Kura clover (*Trifolium ambiguum* M.B.) against that of red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.) using different herbicide sod suppression intensities [paraquat, 1,1'-dimethyl-4,4'-bipyridinium (0.9 kg a.i. ha⁻¹) and glyphosate [N-(phosphonomethyl) glycine] (0.8 or 3.3 kg a.i. ha⁻¹)], without or with N fertilization (110 kg N ha⁻¹). Establishment year plant density and dry matter (DM) production of both Kura clover cultivars were similar (avg. 90 plants m⁻², 390 kg DM ha⁻¹), but were generally inferior to white clover (avg. 110 plants m⁻², 740 kg DM ha⁻¹) and red clover (avg. 170 plants m⁻², 1450 kg DM ha⁻¹). Paraquat did not sufficiently suppress the sod, resulting in lower legume populations and yields than glyphosate. Sod suppression using glyphosate, however, led to heavy seeding-year weed infestation at two of three sites in Minnesota (avg. 2.2 Mg weed DM ha⁻¹). Sod-seeded Kura clover successfully established with glyphosate; however, its contribution to forage production in the sod-seeding year remained minimal (<0.5 Mg ha⁻¹ at four of five sites). Effects of N fertilization varied with species and herbicides; effects on Kura clover were inconsistent but rarely detrimental, while increasing total forage yields by an average of 40%. It is thus possible to establish Kura clover via sod-seeding; however, its productivity in the seeding year remains minimal.

THE INTRODUCTION of legumes in grass-dominated pastures increases their DM production, forage quality, and seasonal distribution of forage, thus decreasing the need for costly N fertilizer while increasing animal performance and carrying capacity (Seguin, 1998). White clover, red clover, birdsfoot trefoil (*Lotus corniculatus* L.), and alfalfa (*Medicago sativa* L.), the main perennial forage legumes currently used in North America, have limited persistence in pastures and consequently must be reintroduced periodically (Forde et al., 1989). Persistent forage legumes are thus needed to reduce the need and cost for renovation.

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Kura clover is a rhizomatous perennial legume with exceptional persistence under intensive management (Taylor and Smith, 1998). It is also very winter-hardy, adapted to a wide range of edaphic conditions, and has high forage quality compared with other perennial legume species. Relative to alfalfa, at comparable stages of maturity, Kura clover has lower concentrations of neutral detergent fiber, acid detergent fiber, and acid detergent lignin, and higher crude protein and in vitro digestibility (Allinson et al., 1985; Seguin et al., 2002). Establishment problems have limited the widespread use of Kura clover. These are related in part to Kura clover's propensity to devote most of its fixed C to roots and rhizomes during establishment and to its slow nodulation and limited N₂ fixation in the seeding year (Peterson et al., 1994; Seguin et al., 2001).

With its slow establishment but high persistence, Kura clover is best suited for permanent pastures. Permanent pastures are often located on marginal land with soils hard to till, and often contain at least some desirable perennial grass species. Legume sod-seeding is a preferred renovation technique for these pastures. In these situations, the resident vegetation can be suppressed by herbicide before no-till drilling to reduce competition and allow legume establishment. Glyphosate and paraquat have been most frequently used and generally provide good results (Seguin, 1998).

Kura clover was established successfully by sod-seeding in different locations in New Zealand without herbicide application (Moorhead et al., 1994) or following glyphosate application at 1.08 kg a.i. ha⁻¹ (Woodman, 1999). In Minnesota, Cuomo et al. (2001) reported poorer establishment of Kura clover than red clover, birdsfoot trefoil, and alfalfa following sod-seeding with grass suppression using 0.62 kg a.i. ha⁻¹ of glyphosate. However, by the fifth year, sod-seeded Kura clover spread and comprised a greater proportion of the sward than alfalfa, birdsfoot trefoil, and red clover (Cuomo et al., 2003).

Seguin et al. (2001) reported that addition of N to low fertility sandy soils helps Kura clover to establish by increasing the proportion of late nodulating plants that survive to later carry on N₂ fixation. With other legume species (i.e., birdsfoot trefoil, alfalfa, and red clover) in Minnesota, applications of 30 to 60 kg N ha⁻¹

Abbreviations: DM, dry matter; GLYH, glyphosate high dose (3.3 kg a.i. ha⁻¹); GLYL, glyphosate low dose (0.8 kg a.i. ha⁻¹); KC, Kura clover; KCC, Kura clover cv. Cossack; KCE, Kura clover cv. Endura; MN02, Minnesota mixed grass site 2002; MNT01, Minnesota tall grass site 2001; MNS01, Minnesota short grass site 2001; PAR, paraquat (0.9 kg a.i. ha⁻¹); QC01, Québec tall grass site 2001; QC02 Québec tall grass site 2002; RC, red clover; WC, white clover.

before legume sod-seeding in grass-dominated swards increased legume contribution to total herbage yield (West et al., 1980). At 90 kg N ha⁻¹, however, legume presence was reduced. There is no information on the effects of N fertilization on the establishment of sod-seeded Kura clover.

Our objectives were (i) to evaluate the establishment of two cultivars of Kura clover compared with red clover and white clover when sod-seeded into grass-dominated swards, (ii) to compare glyphosate and paraquat as sod suppression treatments, and (iii) to investigate the effect of N fertilization on the establishment of sod-seeded Kura clover.

MATERIALS AND METHODS

Experiments were conducted at two sites in Sainte-Anne-de-Bellevue, Québec (QC), Canada, (45°25' N lat, 73°56' W long) on a St-Benoît light sandy loam (Typic Haplorthods) and three sites at Rosemount, MN, USA (44°43' N lat, 93°06' W long) on a Waukegan fine-silty over sandy-skeletal (mixed mesic Typic Hapludolls). At Sainte-Anne-de-Bellevue, experiments were established in 2001 (QC01) and 2002 (QC02) on sites that were predominantly smooth brome grass (*Bromus inermis* L.) and a soil with pH, P, and K levels of 7.2, 240 kg ha⁻¹, and 260 kg ha⁻¹, respectively. At Rosemount, two experiments were established in 2001: one on a site (MNT01) dominated by smooth brome grass and a soil with pH, P, and K levels of 6.6, 50 kg ha⁻¹, and 355 kg ha⁻¹, respectively, and another on a site (MNS01) dominated by Kentucky bluegrass (*Poa pratense* L.) and a soil with pH, P, and K levels of 6.6, 59 kg ha⁻¹, and 360 kg ha⁻¹, respectively. A third experiment (MN02) was established in 2002 into a smooth brome grass and Kentucky bluegrass mixture with a soil with pH, P, and K levels of 6.4, 71 kg ha⁻¹, and 409 kg ha⁻¹, respectively. Temperature and precipitation data for each experiment were retrieved from nearby weather recording stations (Table 1).

At each site, the experimental design was a randomized complete block with split-split plot restriction and four replications. Main plot treatments were sod-seeded species or cultivars: Kura clover cv. Cossack (KCC), Kura clover cv. Endura (KCE), white clover cv. Shasta (WC), and red clover cv. Scarlett (RC). Subplots were herbicide treatments used to suppress the resident grass population: paraquat (PAR) at 0.9 kg a.i. ha⁻¹ or glyphosate at 0.8 kg a.i. ha⁻¹ (GLYL) or 3.3 kg a.i. ha⁻¹ (GLYH). Sub-subplots (1.6 by 6 m) were seeding year N fertilization levels (0 or 110 kg N ha⁻¹).

Herbicide applications were made 1 to 7 d before sod-seeding using a hand-held sprayer in a solution applied at 200 L ha⁻¹, with a pressure of 241 kPa. Seeds were inoculated with appropriate rhizobial peat-based inoculant (Urban-Labs, St. Joseph, MI) and were drilled directly in the resident grass vegetation using a Tye no-till drill in Minnesota (The Tye Co., Lockney, TX) and a disc-drill no-till seeder in Québec (Fabro, Swift Current, SK, Canada) at rates of 13, 9, and 3 kg ha⁻¹ for KC, RC, and WC, respectively, for equivalent seed numbers per area. Seeding occurred in early May at all sites. In plots receiving N, ammonium nitrate was broadcast at 66 kg N ha⁻¹ applied 1 wk after seeding and 44 kg N ha⁻¹ 6 wk later.

In July of the seeding year, populations of established legume seedlings were determined by counting plants within two or three 0.2-m² quadrats in each plot. Plots were harvested at each site according to forage accumulation, dictated largely by precipitation patterns (Table 1). Number of harvests thus varied among sites with two harvests in QC02; three in QC01, MNT01, and MNS01; and four in MN02. Paraquat treated

Table 1. Monthly precipitation (mm) and average temperature (°C) in Sainte-Anne-de-Bellevue, QC, and Rosemount, MN, from April to October and the 30-yr average (1971–2000).

| Month | Ste. Anne-de-Bellevue, QC | | | Rosemount, MN | | |
|-----------|---------------------------|------|------|---------------|------|------|
| | 2001 | 2002 | Avg. | 2001 | 2002 | Avg. |
| | mm | | | | | |
| April | 14 | 73 | 70 | 145 | 107 | 73 |
| May | 71 | 97 | 71 | 116 | 59 | 102 |
| June | 59 | 67 | 88 | 113 | 261 | 117 |
| July | 37 | 31 | 90 | 26 | 85 | 119 |
| August | 57 | 8 | 100 | 67 | 209 | 118 |
| September | 78 | 64 | 98 | 87 | 150 | 90 |
| October | 79 | 64 | 77 | 34 | 133 | 64 |
| | °C | | | | | |
| April | 7 | 7 | 6 | 8 | 7 | 7 |
| May | 15 | 11 | 13 | 15 | 12 | 14 |
| June | 19 | 17 | 18 | 19 | 21 | 19 |
| July | 19 | 21 | 21 | 23 | 24 | 22 |
| August | 21 | 21 | 20 | 22 | 20 | 20 |
| September | 16 | 17 | 15 | 15 | 18 | 16 |
| October | 10 | 7 | 8 | 9 | 5 | 9 |

plots also had one additional harvest in the spring at all sites. The contribution of sod-seeded clovers, grasses, and weeds were determined visually as a percentage of the total biomass at each harvest. A 0.6 by 4.4 m area was cut in the center of plots at each harvest to a 7-cm stubble height using a flail forage harvester in Québec (Swift Machine & Welding, Swift Current, SK, Canada). A 0.9 by 6.0 m area was similarly harvested in Minnesota (Carter Manufacturing Corp., Brookston, IN). Representative 500-g samples of harvested forage were obtained from each plot, dried in a forced-air oven at 60°C for 48 h, and weighted to determine DM content.

All data were subjected to analysis of variance (ANOVA) using PROC GLM of the SAS software (SAS Inst., 1985) to identify significant ($P < 0.05$) treatment effects and interactions. Data were first analyzed in a combined analysis (McIntosh, 1983) regrouping sites, species/cultivars seeded, herbicide, and N fertilization treatments in a combined split-split-plot design (data not shown). Data from each site were then reanalyzed separately as a split-split plot design using PROC GLM of the SAS software because of the presence of numerous and complex site × treatment interactions. Appropriate LSD values ($P < 0.05$) were used for mean comparisons based on Gomez and Gomez (1984), when F tests were significant at $P < 0.05$.

RESULTS AND DISCUSSION

Climate Data

Temperatures at each site from April through October were near average in 2001 and 2002 (Table 1). Precipitation, however, deviated considerably from 30-yr averages at all sites. Rainfall from April through September at Sainte-Anne-de-Bellevue, QC, was 200 and 188 mm below average for 2001 and 2002, respectively. At Rosemount, MN, rainfall was 92 mm below and 325 mm above average in 2001 and 2002, respectively. Moisture is a key factor influencing the establishment of sod-seeded legumes (Mueller-Warrant and Koch, 1980; Groya and Sheaffer, 1981). Moisture was thus limiting in four environments and optimal in the other.

Sod-Seeded Clover Densities

Sod Suppression

Herbicide sod suppression was the factor with the greatest impact on sod-seeded clover densities through main effects and interactions with N fertilization and/or

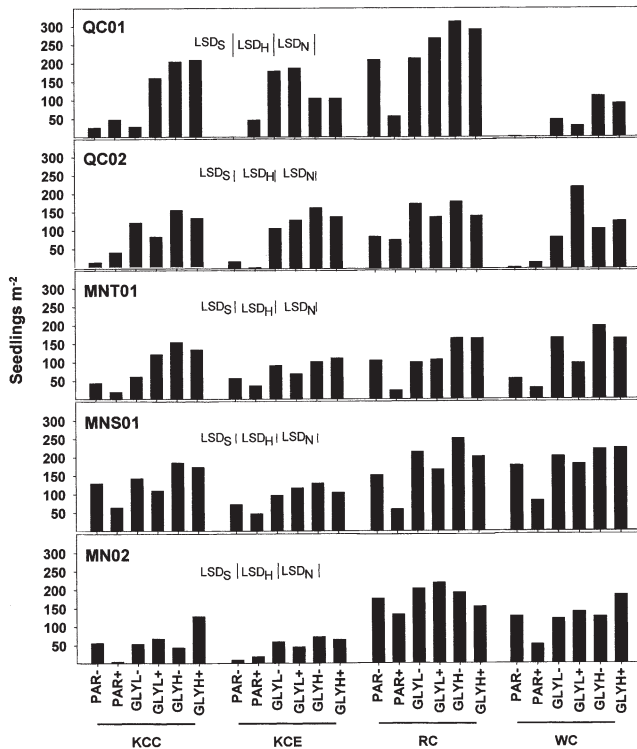


Fig. 1. Density of established seedlings following sod-seeding of clovers into grass swards suppressed using different herbicides, and with or without N fertilization at five sites in Québec and Minnesota. PAR, paraquat (0.9 kg a.i. ha⁻¹); GLYL, glyphosate low dose (0.8 kg a.i. ha⁻¹); GLYH, glyphosate high dose (3.30 kg a.i. ha⁻¹); (-) 0 kg N ha⁻¹; (+) 100 kg N ha⁻¹. KCC, Kura clover cv. Cossack; KCE, Kura clover cv. Endura; MNT01, Minnesota tall grass site 2001; MNS01, Minnesota short grass site 2001; MN02, Minnesota mixed grass site 2002; QC01, Québec tall grass site 2001; QC02 Québec tall grass site 2002; RC, red clover; WC, white clover. LSD_S is used to compare means for same herbicide and N levels; LSD_H is used to compare means for same species and N levels; LSD_N is used to compare means for same species and herbicide levels.

clover species. A positive association between suppression intensity and clover density was observed at all sites (Fig. 1). Clover densities averaged 180% greater in GLYH and 170% greater in GLYL plots than when PAR was used in 38 and 28 of 40 site-species-N treatment combinations, respectively. Clover densities were also greater in GLYH than GLYL plots in 21 of 40 site-species-N treatment combinations; however, the increase was smaller, averaging 44%. Mueller-Warrant and Koch (1983) also reported lower plant densities of sod-seeded alfalfa with paraquat compared with glyphosate. Paraquat, a contact herbicide, exerts short-term control over vegetation, whereas glyphosate, a translocated herbicide, extends its control over a longer period and greater establishment often occurs (Bélanger and Winch, 1985).

Sod-Seeded Clover Species

The clovers introduced influenced plant densities at all sites either through main effects or interactions with N fertilization and/or herbicides. Plant densities of KC and WC were low (avg. 60 plants m⁻²) in PAR-treated plots at all sites (Fig. 1). Exceptions were MNS01, where

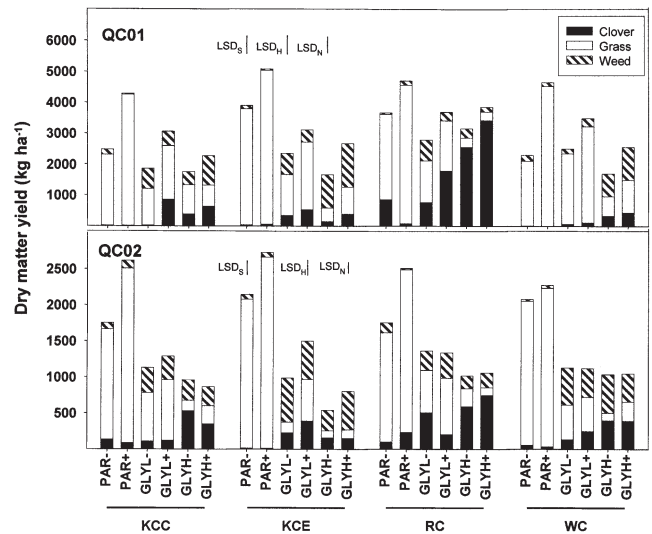


Fig. 2. Forage yields and botanical composition following sod-seeding of clovers into grass swards suppressed using different herbicides, and with or without N fertilization at two sites in Québec. PAR, paraquat (0.9 kg a.i. ha⁻¹); GLYL, glyphosate low dose (0.8 kg a.i. ha⁻¹); GLYH, glyphosate high dose (3.30 kg a.i. ha⁻¹); (-) 0 kg N ha⁻¹; (+) 100 kg N ha⁻¹. KCC, Kura clover cv. Cossack; KCE, Kura clover cv. Endura; QC01, Québec tall grass site 2001; QC02 Québec tall grass site 2002; RC, red clover; WC, white clover. LSD_S is used to compare clover means for same herbicide and N levels; LSD_H is used to compare clover means for same species and N levels; LSD_N is used to compare clover means for same species and herbicide levels. LSD for total, grass, and weed DM production are not indicated on the figure. At QC01, LSD_S were 594, 466, and 268 kg DM ha⁻¹ for total herbage, grass, and weeds DM production, respectively; LSD_H were 652, 495, and 277 kg DM ha⁻¹; and LSD_N were 465, 500, and 297 kg DM ha⁻¹. At QC02, LSD_S were 227, 229, and 124 kg DM ha⁻¹, for total herbage, grass, and weeds DM production, respectively; LSD_H were 246, 240, and 133 kg DM ha⁻¹ and LSD_N were 216, 264, and 88 kg DM ha⁻¹.

KCC and WC averaged 129 and 176 plants m⁻², respectively, and MN02, where WC averaged 126 plants m⁻². Establishment of all species was greater in MNS01, due to less competitiveness of the sward dominated by short grasses, and in MN02, due to optimal moisture conditions. Moisture availability is a key factor when paraquat is used for sod suppression since it provides only short-term suppression of the vegetation. Red clover densities were also low in N fertilized PAR-treated plots (avg. 70 plants m⁻²); however, in non-N fertilized PAR-treated plots, RC densities (avg. 150 plants m⁻²) were greater than KCE (avg. 30 plants m⁻²) across all sites and than KCC (avg. 50 plants m⁻²) and WC (avg. 70 plants m⁻²) in four of five sites. Red clover thus had greater establishment than other clovers when competition was high, though its production in PAR-treated plots remained low in four of five sites (avg. 268 kg DM ha⁻¹) (Fig. 2 and 3). Overall, all species required greater suppression of the resident vegetation than that achieved with PAR to establish a productive seeding-year clover population. However, PAR led to high second year legume DM production in the less competitive short grasses present in MNS01 (unpublished data). Paraquat should therefore not be discarded for legume sod-seeding in all situations.

In GLYL and GLYH treated plots, RC also had

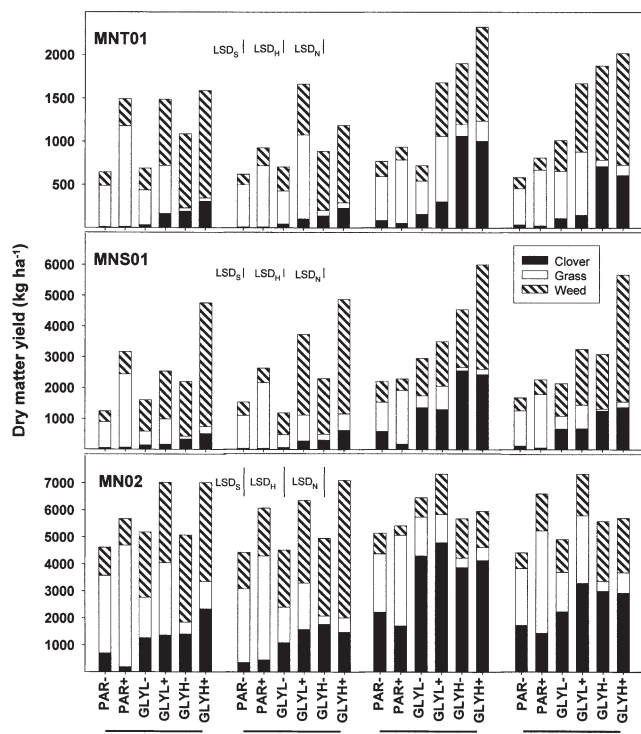


Fig. 3. Forage yields (kg DM ha^{-1}) and botanical composition following sod-seeding of clovers into grass swards suppressed using different herbicides, and with or without N fertilization at three sites in Minnesota. PAR, paraquat ($0.9 \text{ kg a.i. ha}^{-1}$); GLYL, glyphosate low dose ($0.8 \text{ kg a.i. ha}^{-1}$); GLYH, glyphosate high dose ($3.30 \text{ kg a.i. ha}^{-1}$); (-) 0 kg N ha^{-1} ; (+) 100 kg N ha^{-1} . KCC, Kura clover cv. Cossack; KCE, Kura clover cv. Endura; MNT01, Minnesota tall grass site 2001; MNS01, Minnesota short grass site 2001; MN02, Minnesota mixed grass site 2002; RC, red clover; WC, white clover. LSD_s is used to compare clover means for same herbicide and N levels; LSD_h is used to compare clover means for same species and N levels; LSD_N is used to compare clover means for same species and herbicide levels. LSD for total, grass, and weed DM production are not indicated on the figure. At MNT01, LSD_s were 263, 178, and $218 \text{ kg DM ha}^{-1}$, for total herbage, grass, and weeds DM production, respectively; LSD_h were 270, 184, and $177 \text{ kg DM ha}^{-1}$ and LSD_N were 330, 155, and $239 \text{ kg DM ha}^{-1}$. At MNS01, LSD_s were 543, 228, and $463 \text{ kg DM ha}^{-1}$, for total herbage, grass, and weeds DM production, respectively; LSD_h were 549, 209, and $447 \text{ kg DM ha}^{-1}$, and LSD_N were 544, 189, and $444 \text{ kg DM ha}^{-1}$. At MN02, LSD_s were 679, 553, and $705 \text{ kg DM ha}^{-1}$, for total herbage, grass, and weeds DM production, respectively; LSD_h were 654, 550, and $645 \text{ kg DM ha}^{-1}$, and LSD_N were 610, 713, and $631 \text{ kg DM ha}^{-1}$.

greater plant densities than either KCC or KCE (70 and 110% greater, respectively) in 15 of 20 site-herbicide-N treatment combinations. In Québec, where WC was severely affected by drought, there were no consistent differences between KC and WC. However, in Minnesota WC had greater plant densities than both KCC and KCE (60 and 100% greater, respectively) in 11 of 12 site-herbicide-N combinations. White clover and RC had comparable plant densities at the three Minnesota sites and at QC02 in GLYL and GLYH treatments. Red clover, however, had significantly higher plant densities (290% greater) than WC in QC01 in all site-herbicide-N combinations of GLYL and GLYH. The lower WC plant densities observed in QC01 may be attribut-

able to severe drought, WC having been noted for its low drought tolerance (Matches, 1989).

No consistent difference was observed between plant densities of KCE and KCC across sites. Despite generally low plant densities of KC compared with RC and WC, densities observed with glyphosate sod suppression should be sufficient to ensure significant KC contributions to forage yields in post-seeding years. Kura clover plants spread via rhizomes and its contribution to yield increase in post-seeding years (Cuomo et al., 2001, 2003).

Nitrogen Fertilization

Nitrogen fertilization influenced clover densities through interactions with herbicides and/or species at all sites except at QC01, where N had no effect. With PAR, N fertilization reduced clover plant densities in 9 of 20 site-herbicide-species treatment combinations. In the 11 other cases, densities of all clover species were extremely low independent of N applications (Fig. 1). This reduction in clover densities is attributable to an increase in the competitive vigor of resident grasses from N fertilization. With PAR, N fertilization reduced RC densities by 60% in four of five sites. It also reduced plant densities of KCC by 75%, of KCE by 35%, and of WC by 55% on average at all sites except QC02. In GLYL- and GLYH-treated plots, there was no consistent effect of N fertilization on plant densities. Nitrogen fertilization, thus, did not increase the number of surviving Kura clover plants, a phenomenon observed in conventionally seeded stands (Seguin et al., 2001).

Forage Dry Matter Yield and Species Composition Sod Suppression

As for plant densities, herbicide treatment markedly influenced seeding year total forage yield and botanical composition of renovated swards through main effects and interactions with N fertilization and/or species at all sites.

Clover yields in the renovation year increased as intensity of grass suppression increased (Fig. 2 and 3). Herbicide \times species interactions were observed in each of the five sites and were driven by variation in the magnitude of differences among species in GLYH- and GLYL-treated plots compared with PAR-treated ones. Differences were driven by numerically small but proportionately large changes occurring where PAR was used. Across sites, DM production of all clovers in PAR-treated plots remained low, being lower than 1 Mg ha^{-1} , except in MN02, where rainfall was significantly above the 30-yr average. Kura clover, WC, and RC contribution to total yield were on average 3, 9, and 17%, respectively, with PAR. With GLYL, KC, WC, and RC contributions were greater, representing 15, 20, and 40% of the total yield, respectively. Finally, with GLYH, KC, WC, and RC content was greater still, representing 25, 35, and 65% of the total DM yield, respectively.

Others have also reported greater legume establishment and DM production when glyphosate was used

instead of paraquat for sod suppression (e.g., Koch et al., 1987). The high legume proportion we observed with RC in GLYH-treated plots could, however, be considered too high for pasture swards. Establishment should optimally result in no more than 50% succulent legumes in the sward to avoid the incidence of bloat in ruminant animals (Howart et al., 1991). Sheaffer and Swanson (1982) also obtained high RC proportion (>85%) when sod-seeded following applications of glyphosate at high rates (1.7 kg a.i. ha⁻¹).

Grass DM production decreased as suppression intensity increased. It generally remained higher in plots treated with paraquat, a contact herbicide, than when grasses were suppressed with glyphosate (Fig. 2 and 3). Grass production following PAR application was 130% greater than following GLYL in 30 of 32 sites-species-N treatment combinations across all sites except MNT01. The MNT01 site differed from other environments as no differences were observed in grass DM production between PAR and GLYL in seven of eight species-N treatment combinations. Paraquat grass suppression was exceptionally successful at MNT01 and grasses grew little following herbicide application. Grass DM production was on average nearly sixfold higher with PAR than GLYH in all of 40 site-species-N treatment combinations, and 2.5-fold greater on average in GLYL- than GLYH-treated plots in 37 of 40 site-species-N treatment combinations. The lower dose of glyphosate thus allowed greater grass recuperation following application. Across sites, grass production represented 14, 43, and 78% of total DM following GLYH, GLYL, and PAR applications, respectively. This is concordant with observations from Koch et al. (1987) in New Hampshire, who reported that smooth brome grass still dominated stands in which sod was treated with paraquat (0.56 kg a.i. ha⁻¹), whereas glyphosate at high dose (2.24 kg a.i. ha⁻¹) killed 90% or more of the initial stand.

Weed infestation was positively associated with level of sod suppression (Fig. 2 and 3). On average, across sites, PAR, GLYL, and GLYH applications resulted in weed content representing 15, 35, and 50% of total DM, respectively. Weed DM production was on average 340% greater in GLYH than PAR and 80% greater than GLYL-treated plots in 35 and 27 of 40 site-species-N treatment combinations, respectively. Significantly greater weed DM production was also observed with GLYL compared with PAR in 31 of 40 site-species-N treatment combinations. Main weeds in QC01 and QC02 were milkweed (*Asclepias syriaca* L.), Canada thistle [*Cirsium arvense* (L.) Scop.], dandelion (*Taraxacum officinale* Wiggers), and tufted vetch (*Vicia cracca* L.). In Minnesota they were dandelion, Canada thistle, Pennsylvania smartweed (*Polygonum pensylvanicum* L.), barnyardgrass (*Echinochloa crusgalii* L.), and foxtail species (*Setaria* sp.). Weed infestation was especially high in MN02 and MNS01; weed biomass represented 50% of total DM on average in GLYH- and GLYL-treated plots. The summer was exceptionally humid in MN02 and allowed high weed production, while at MNS01 short-grasses dominating the sward were more severely affected by the herbicidal treatments than at

the other sites; weed encroachment followed. Weed biomass was concentrated in the first harvest and generally decreased in subsequent harvests (data not presented). Rioux (1994) also reported severe weed infestation when alfalfa sod-seeding followed broadcast application of glyphosate at high rate (2.5 kg a.i. ha⁻¹) in a smooth brome grass-dominated sward; dandelion represented as much as 45% of total biomass in the second harvest of the seeding year.

Total DM production responded differently to herbicides in Québec and Minnesota. In QC01 and QC02; total DM production was significantly lower (35% lower on avg.) in GLYL than in PAR-treated plots in 13 of 16 site-species-N treatment combinations. It further decreased by 30% in GLYH-treated swards compared with GLYL in 7 of 16 site-species-N treatment combinations (Fig. 2). The midsummer droughts encountered in both years in Québec did not allow forage regrowth to compensate for loss of grass forage caused by herbicides; total production therefore decreased with increased level of suppression. Severe grass suppression often excessively reduces total forage yield in the seeding year (Seguin, 1998). A pasture in West Virginia renovated with red clover and birdsfoot trefoil produced 30% less forage in the seeding year than nonrenovated swards following sod suppression with paraquat (0.84 kg a.i. ha⁻¹) (Bryan, 1985). In Minnesota the trend was reversed with greater (37% greater on avg.) total DM production in 11 of 24 site-species-N treatment combinations in GLYL- than in PAR-treated plots (Fig. 3). It further increased by 50% in 14 of 24 site-species-N treatment combinations from GLYL to GLYH. Increase in total biomass with increasing suppression in Minnesota is attributable to increased clover and weed DM production that compensated for the grass DM production lost to herbicides.

Sod-Seeded Clover Species

Clover species had small, inconsistent effects on total, grass, and weed DM production across sites; but, as expected, it exerted a strong influence on legume yield at all sites through highly significant main effects, but also through interactions with N fertilization and/or herbicides.

Plots seeded with RC had greater legume DM production than other species in 21 of 30 site-herbicide-N treatment combinations. Red clover was the only legume to produce biologically significant legume yields in PAR plots, its contribution to total DM averaging 16%. Kura clover and WC produced <140 kg clover DM ha⁻¹ in PAR-treated plots, except in the unusually humid season of MN02 (Fig. 2 and 3). In GLYL and GLYH treatments, RC contribution to total DM averaged 40 and 60%, respectively. Red clover superiority is attributable to its rapid and aggressive development and early foliage growth, making it particularly well suited for sod-seeding situations (Belzile, 1988).

There were no consistent differences in clover DM production between the two cultivars of KC across sites. Others have reported differences in suitability for sod-

seeding between cultivars of a species (Kunelius and Campbell, 1984). In four of five sites, production of sod-seeded Kura clover remained $<1 \text{ Mg DM ha}^{-1}$ (avg. 10% of total DM) in the seeding year within all treatments. Only the exceptional weather conditions encountered in Minnesota in 2002 allowed KCC and KCE to achieve greater initial production, $>1.5 \text{ Mg DM ha}^{-1}$ (avg. 30% of total DM) in GLYL and GLYH treatments. Kura clover is known to establish slowly and to have lower initial yields when compared with other legumes. Seguin et al. (1999), in Minnesota, reported Kura clover seeding year yields of $<500 \text{ kg DM ha}^{-1}$ when solo-seeded with or without herbicides. In another study conducted in Minnesota, sod-seeded Kura clover occupied only 10% of the sward in its first year of growth (Cuomo et al., 2001).

Legume DM production in WC plots was also minimal, being lower than $0.5 \text{ Mg DM ha}^{-1}$ at both sites in Québec. White clover is particularly sensitive to soil water deficits (Spencer et al., 1975). The drought conditions encountered locally in both years greatly affected WC establishment and growth. At the three sites in Minnesota, WC production was, however, more than twofold greater than KC in 12 of 18 site-herbicide-N treatment combinations. Others have also reported greater first-year production of WC when compared with KC (Spencer et al., 1975; Moss et al., 1996).

Clover species effects on total DM production were inconsistent across sites. There were significant interactions with herbicides and N in QC01 and MNS01, respectively. Clover species did not influence total DM production at QC02, MNT01, or MN02. In QC01 and QC02, low precipitation in midsummer did not allow legumes to sustain DM production. In Minnesota, heavy weed infestations increased total DM production and masked the effects of species on total production.

Clover species did not influence weed DM production in MNS01 and MNT01 but did at other sites through main effects or interactions with herbicide. In the heavily weed-infested plots of MN02, there was significantly greater weed biomass with both cultivars of KC than with WC or RC, for both GLYL and GLYH treatments (Fig. 3). In previous work in Minnesota, high weed infestation occurred in solo-seeded KC plots due to its slow establishment and poor competitive ability (Seguin et al., 1999). Grass production was mainly influenced by herbicide and N treatments. Effects of clover species introduced on grass DM production were weak and inconsistent.

Nitrogen Fertilization

Seeding year N fertilization had limited effects on clover DM production of all species across sites. Legume DM production was not influenced by N in MNT01 and MN02, but was at the other sites through interactions with species and/or herbicides. There were either no effects or positive effects of N on KC production in 19 and 9 of 30 site-species-herbicide treatment combinations, respectively. This contrasts with Seguin et al. (2001), who reported increased KC establishment and

seeding year production following N fertilization when conventionally seeded. Differences between studies may be explained by differences in seeding methods. Nitrogen fertilization likely promotes competition against the establishing legume when sod-seeded, which could in turn reduce or cancel its direct positive effects on clover growth. West et al. (1980) reported that application of N at moderate rates during legume sod-seeding increased legume content, but reduced legume content when N was applied at $>90 \text{ kg N ha}^{-1}$. Fertilization also had little or no effects across sites on WC, and effects on RC were inconsistent. Overall, there was a significant negative effect of N on yield of all clovers in only 7 of 60 site-species-herbicide treatment combinations, mainly in PAR-treated plots. This suggests that N fertilization could be used with glyphosate to increase total forage production without negatively affecting clover yield in the renovation year, though potential carryover effects in postseeding years must be assessed.

Nitrogen \times herbicide interactions influenced grass DM production at all sites. With GLYH, grass yield was not influenced by N fertilization in 19 of 20 site-species combinations. The lack of response to fertilization in GLYH-treated plots is attributable to the excessive suppression resulting in death of the grass resident vegetation. In contrast, a positive grass response to N fertilization was observed in 19 and 13 of 20 site-species treatment combinations in PAR- (avg. increase of 64%) and GLYL-treated plots (avg. increase of 69%), respectively. The proportion of grass in total DM was, however, unaffected by N fertilization, averaging across N treatments 77 and 44% in PAR- and GLYL-treated plots, respectively.

Nitrogen \times herbicide interactions were also observed for weed biomass at all sites in Minnesota. In QC01 and QC02, N had no effect on weed biomass. In Minnesota, N fertilization never increased weed biomass in PAR-treated plots, which were dominated by grasses. However, N doubled weed biomass in GLYL- and GLYH-treated plots in 9 and 7 of 12 site-species treatment combinations, respectively. Nitrogen fertilization, however, did not increase weed proportion in the sward, which represented across sites an average of 35 and 50% of total DM for GLYL- and GLYH-treated plots, respectively.

Finally, N had a significant effect on total DM production at all sites, either through main effects or interactions with herbicide, N increasing total DM production in 43 of 60 site-herbicide-species treatment combinations. Interactions with herbicides were caused at QC02 by a lack of response to N fertilization on total production in GLYL- and GLYH-treated plot while there was a significant effect in PAR-treated plots. Overall, N fertilization increased total seeding year DM production in PAR- (40% increase on avg.), GLYL- (43% increase on avg.), and GLYH- (35% increase on avg.) treated plots in 14, 17, and 12 of 20 site-species-herbicide treatment combinations, respectively.

SUMMARY AND CONCLUSIONS

Intensity of sod suppression had the greatest influence of the factors studied on the establishment of sod-seeded

clovers. Densities and DM production of sod-seeded clovers generally increased as intensity of sod-suppression increased. In PAR-treated plots, only RC produced biologically significant legume yield in the seeding year. When glyphosate was used RC had the greatest establishment and legume production, WC was intermediate, and KC had the least establishment. No differences between WC and KC were, however, observed in Québec. Despite KC's reputation of having low seedling vigor, sod-seeded KC successfully established following suppression of the resident grass vegetation using glyphosate. Although KC production was low, it was still comparable to yields reported when solo-seeded (Seguin et al., 1999). Nitrogen fertilization tended to have negative effects on clover density in PAR-treated plots where it increased grass vigor. It had inconsistent but rarely negative effects on clover density and production in GLYL- and GLYH-treated plots, while increasing total forage yield. Thus, N fertilization could be used as a tool to increase renovation year forage DM yields when sod-seeding clovers with glyphosate, without harming clover establishment. Although glyphosate resulted in best establishment of sod-seeded legumes, it also, however, resulted in severe weed infestation at two sites in Minnesota. Despite the generally lower plant densities and production of KC compared with RC and WC, KC is expected to spread over time via rhizomes by as much as 1 m yr⁻¹ (Taylor and Smith, 1998). Plant densities observed herein with glyphosate sod suppression should therefore be sufficient to ensure significant KC contribution to forage yields in postseeding years; Kura clover's contribution to yield in the renovation year, however, remains minimal.

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