

Forage Yield and Species Composition in Years following Kura Clover Sod-Seeding into Grass Swards

Guillaume Laberge, Philippe Seguin,* Paul R. Peterson, Craig C. Sheaffer, and Nancy J. Ehlke

ABSTRACT

Sod-seeding legumes into grass pastures improves forage productivity and quality, but legumes currently used lack persistence. Field experiments were established in Québec and Minnesota to compare postseeding year performance of two cultivars ('Cossack' and 'Endura') of Kura clover (*Trifolium ambiguum* M. Bieb.) against that of red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.) sod-seeded using different intensities of herbicide sod suppression [paraquat (0.9 kg a.i. ha⁻¹) and glyphosate (0.8 or 3.3 kg a.i. ha⁻¹)] with or without seeding year N fertilization (110 kg N ha⁻¹). Red clover had the greatest yield and contribution to total forage yield in the first postseeding year [avg. 2.7 Mg dry matter (DM) ha⁻¹, 50% clover], white clover (WC) was intermediate (avg. 1.5 Mg DM ha⁻¹, 32% clover), and Kura clover (KC) ranked last (avg. 1.2 Mg DM ha⁻¹, 27% clover). Yields of KC were, however, similar to WC in three of five sites. Clover yields and content in the first postseeding year were positively associated with intensity of sod suppression. Kura clover content increased over time; at the first harvest of the second postseeding year, it had greater clover yield and content (avg. 750 kg DM ha⁻¹, 45% clover) than red clover (avg. 160 kg DM ha⁻¹, 25% clover) and WC (avg. 60 kg DM ha⁻¹, 11% clover). Seeding year N fertilization, which enhanced seeding year yields, had inconsistent effects on postseeding year yield and botanical composition but rarely had negative effects on clover. Kura clover can be established in permanent pastures via sod-seeding.

THE INTRODUCTION of legumes into grass-dominated pastures improves forage yield, quality, and seasonal distribution while decreasing reliance on commercial N fertilizers (Sleugh et al., 2000; Zemenchik et al., 2001). Forage legume species most commonly used in North American pastures [i.e., WC, red clover (RC), birdsfoot trefoil (*Lotus corniculatus* L.), and alfalfa (*Medicago sativa* L.)] often fail to persist more than a few years under grazing and must be periodically reintroduced (Forde et al., 1989). There is thus a need for truly perennial forage legume species.

Kura clover is a forage legume that produces a large network of roots and rhizomes, which enables it to persist under frequent defoliation and climatic extremes (Peterson et al., 1994a, 1994b). Exceptional persistence and high forage quality make KC a potential forage legume for use in permanent pastures, which are often located on marginal land with soils hard to till (Laberge

and Seguin, 2005). In these situations, legume sod-seeding is a recommended renovation strategy to improve grass-dominated swards. Legumes are generally seeded following partial suppression of grasses using herbicide to reduce their competitiveness and allow legume establishment (Seguin, 1998).

Kura clover has been successfully established by sod-seeding in a range of environments. In New Zealand, KC established following herbicide sod suppression with glyphosate (1.08 kg a.i. ha⁻¹) (Woodman, 1999) and even without herbicide suppression (Moorhead et al., 1994). In Minnesota (MN), Cuomo et al. (2001) established KC by sod-seeding following application of glyphosate (0.62 kg a.i. ha⁻¹) to suppress the resident grass population. When different herbicide suppression levels were compared in Québec (QC) and MN (Laberge et al., 2005), the contact herbicide paraquat (PAR) did not suppress grasses sufficiently for KC to establish. Best results were obtained using a moderate dose of glyphosate (0.8 kg a.i. ha⁻¹); applying a higher dose (3.3 kg a.i. ha⁻¹) generally led to greater establishment but also to excessive grass suppression and weed encroachment. Nitrogen fertilization increased establishment of KC when solo-seeded (Seguin et al., 2001); however, no consistent positive effects of N fertilization on KC establishment were observed when sod-seeded (Laberge et al., 2005).

Establishment of KC is typically slow. It initially produces lower yields than other commonly used legumes, but its proportion in swards increases over time. This trend has been observed with conventional as well as sod-seeding (Sheaffer and Marten, 1991; Cuomo et al., 2003). By the fifth year after sod-seeding in MN, KC spread to occupy a greater proportion of the sward than alfalfa, birdsfoot trefoil, and RC (Cuomo et al., 2003). Establishment of KC by sod-seeding is therefore possible, but there is limited information on the impact of sod-seeding strategies on KC stand dynamics in postseeding years.

This study was conducted to evaluate sward composition and yield evolution of sod-seeded KC in postseeding years. Specifically, our objectives were to: (i) compare postseeding years performance of two cultivars of sod-seeded KC with WC and RC, (ii) evaluate the influence of herbicide sod suppression treatments before

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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 cultivar Cossack; KCE, Kura clover cultivar Endura; MN, Minnesota; MN Mixed Grass 02, Minnesota mixed-grass site seeded in 2002; MN Shortgrass 01, Minnesota shortgrass site seeded in 2001; MN Tallgrass 01, Minnesota tallgrass site seeded in 2001; PAR, paraquat (0.9 kg a.i. ha⁻¹); QC, Québec; QC Tallgrass 01, Québec tallgrass site seeded in 2001; QC Tallgrass 02, Québec tallgrass site seeded in 2002; RC, red clover; WC, white clover.

seeding, and (iii) evaluate possible residual effects of N fertilization during the seeding year on postseeding years sward composition and forage yield.

MATERIALS AND METHODS

Site Description

Experiments were conducted at Sainte-Anne-de-Bellevue, QC, Canada (45°25' N, 73°56' W) and Rosemount, MN, USA (44°43' N, 93°06' W) in a total of five environments. Soils were a St-Benoît light sandy loam (Typic Haplorthod) at Sainte-Anne-de-Bellevue and a Waukegan fine-silty over sandy-skeletal (mixed mesic Typic Hapludoll) at Rosemount. At Sainte-Anne-de-Bellevue, one site was established in 2001 (QC Tallgrass 01) and a second one in 2002 (QC Tallgrass 02). Before sod-seeding, both sites were dominated by smooth brome grass (*Bromus inermis* L.). At Rosemount, two experiments were established in 2001, one on a site initially dominated by tallgrasses (MN Tallgrass 01, predominantly smooth brome grass), the other on a site dominated by shortgrass species [MN Shortgrass 01, predominantly Kentucky bluegrass (*Poa pratensis* L.)]. A third experiment was established at Rosemount in 2002 on a site dominated by a mixture of tall- and shortgrasses (MN Mixed Grass 02, predominantly smooth brome grass and Kentucky bluegrass). Soil fertility at the different sites was reported in Laberge et al. (2005). Temperature and precipitation data for each environment were retrieved from nearby weather-recording stations (Table 1).

Field Management and Experimental Design

At each site, the experimental design was a randomized complete block design with split-split-plot restriction and four replications. Main-plot treatments were sod-seeded species or cultivars: Kura clover 'Cossack' (KCC), Kura clover 'Endura' (KCE), WC 'Shasta', and RC 'Scarlett'. Subplots were herbicide treatments used to suppress the resident grass population before seeding: 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 N fertilization levels (0 or 110 kg N ha⁻¹). Nitrogen was applied only in the seeding year in split applications.

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 (Urbana-Labs, St. Joseph, MI) and were drilled directly into the resident grass vegetation using a Tye no-till drill in MN (The Tye Co., Lockney, TX) and a disc-drill no-till seeder in QC (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.

Plots were harvested two to three times in the seeding year depending on the site. Details are given in Laberge et al. (2005). In the first postseeding year, plots were harvested according to forage accumulation at each site, dictated largely by precipitation patterns (Table 1). Harvests were done when herbage reached approximately 30 to 40 cm in height. Number of harvests thus varied among sites with three harvests at QC Tallgrass 01 (29 May, 4 July, and 7 Aug. 2002), QC Tallgrass 02 (24 May, 8 July, and 19 Sept. 2003), and MN Mixed Grass 02 (30 May, 1 July, and 29 July 2003) and four at MN Tallgrass 01 and MN Shortgrass 01 (both on 5 June, 1 July, 5 Aug., and 11 Oct. 2002). A final harvest was done in the spring of the second postseeding year at QC Tallgrass 01 (24 May 2003), MN Tallgrass 01, and MN Shortgrass 01 (both on 1 June 2003). 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 QC (Swift Machine & Welding, Swift Current, SK, Canada). A 0.9- by 6.0-m area was similarly harvested in MN (Carter Manufacturing Corp. Inc., Brookston, IN). The contribution of sod-seeded clovers, grasses, and weeds were determined visually as a percentage of the total biomass at each harvest. 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 weighed to determine DM content.

Table 1. Monthly precipitation and average air temperature during experimentation and the 30-yr average (1971–2000).

| | Ste-Anne-de-Bellevue, QC | | | | Rosemount, MN | | | |
|-----------|--------------------------|------|------|---------|---------------|------|------|---------|
| | 2001 | 2002 | 2003 | Average | 2001 | 2002 | 2003 | Average |
| | mm | | | | | | | |
| January | – | 34 | 17 | 74 | – | 16 | 13 | 31 |
| February | – | 41 | 5 | 23 | – | 19 | 20 | 22 |
| March | – | 84 | 85 | 42 | – | 54 | 50 | 57 |
| April | 14 | 73 | 74 | 70 | 145 | 107 | 70 | 73 |
| May | 71 | 97 | 117 | 71 | 116 | 59 | 182 | 102 |
| June | 59 | 68 | 72 | 88 | 113 | 261 | 81 | 117 |
| July | 37 | 31 | 55 | 90 | 26 | 85 | 100 | 119 |
| August | 57 | 9 | 80 | 100 | 67 | 209 | 56 | 118 |
| September | 78 | 64 | 105 | 98 | 87 | 150 | 52 | 89 |
| October | 79 | 64 | 156 | 77 | 34 | 133 | 19 | 64 |
| November | 84 | 96 | – | 22 | 78 | 3 | – | 57 |
| December | 54 | 34 | – | 15 | 16 | 11 | – | 29 |
| | °C | | | | | | | |
| January | – | –4 | –13 | –9 | – | –6 | –9 | –11 |
| February | – | –5 | –11 | –7 | – | –3 | –9 | –7 |
| March | – | –2 | –4 | –1 | – | –5 | 0 | 0 |
| April | 7 | 7 | 5 | 6 | 8 | 7 | 8 | 7 |
| May | 15 | 11 | 14 | 13 | 15 | 12 | 14 | 14 |
| June | 19 | 17 | 19 | 18 | 19 | 21 | 19 | 19 |
| July | 19 | 21 | 22 | 21 | 23 | 24 | 22 | 22 |
| August | 21 | 21 | 22 | 20 | 22 | 20 | 23 | 20 |
| September | 16 | 17 | 18 | 15 | 15 | 18 | 16 | 16 |
| October | 10 | 7 | 8 | 8 | 8 | 5 | 11 | 9 |
| November | 5 | 1 | – | 2 | 8 | 0 | – | 0 |
| December | 0 | –5 | – | –5 | –3 | –3 | – | –8 |

Statistical Analyses

All data were subjected to analysis of variance (ANOVA) using PROC GLM of the SAS software (SAS Inst., 1985) to identify significant treatment effects and interactions. Data were first analyzed in a combined analysis (McIntosh, 1983), regrouping sites, species/cultivars seeded (main plots), herbicide treatments (subplots), and N fertilization (sub-subplots) in a combined split-split-plot design (data not shown). Results from each site were then reanalyzed separately because of the presence of numerous and complex site \times treatment interactions. Experiments at each site were thus analyzed as a split-split-plot design using PROC GLM of the SAS software (SAS Inst., 1985). Appropriate LSD values ($P < 0.05$) were calculated and used for mean comparisons based on Gomez and Gomez (1984) when F tests were significant at $P < 0.05$. Pearson product-moment correlation coefficients were calculated using PROC CORR in SAS to describe the relationship between variables.

RESULTS AND DISCUSSION

Climate Data

Temperatures at each site from April through October were near average in 2002 and 2003 (Table 1). Precipitation, however, deviated considerably from the 30-yr average at all sites. At Sainte-Anne-de-Bellevue, rainfall was 188 mm below average from April through September 2002 and 70 mm below average during June, July, and August 2003. In Rosemount, precipitation from April through September was 325 mm above average in 2002 and 210 mm below average in 2003. Moisture was thus limited in four environments and optimal in the other. Consequently, large differences in forage production were observed among sites; total-season forage yield ranged from 2 to 9 Mg DM ha⁻¹ (Fig. 1 and 2). In addition, the early winter of 2002–2003 in MN had below-average snow cover and thus winter injury potential.

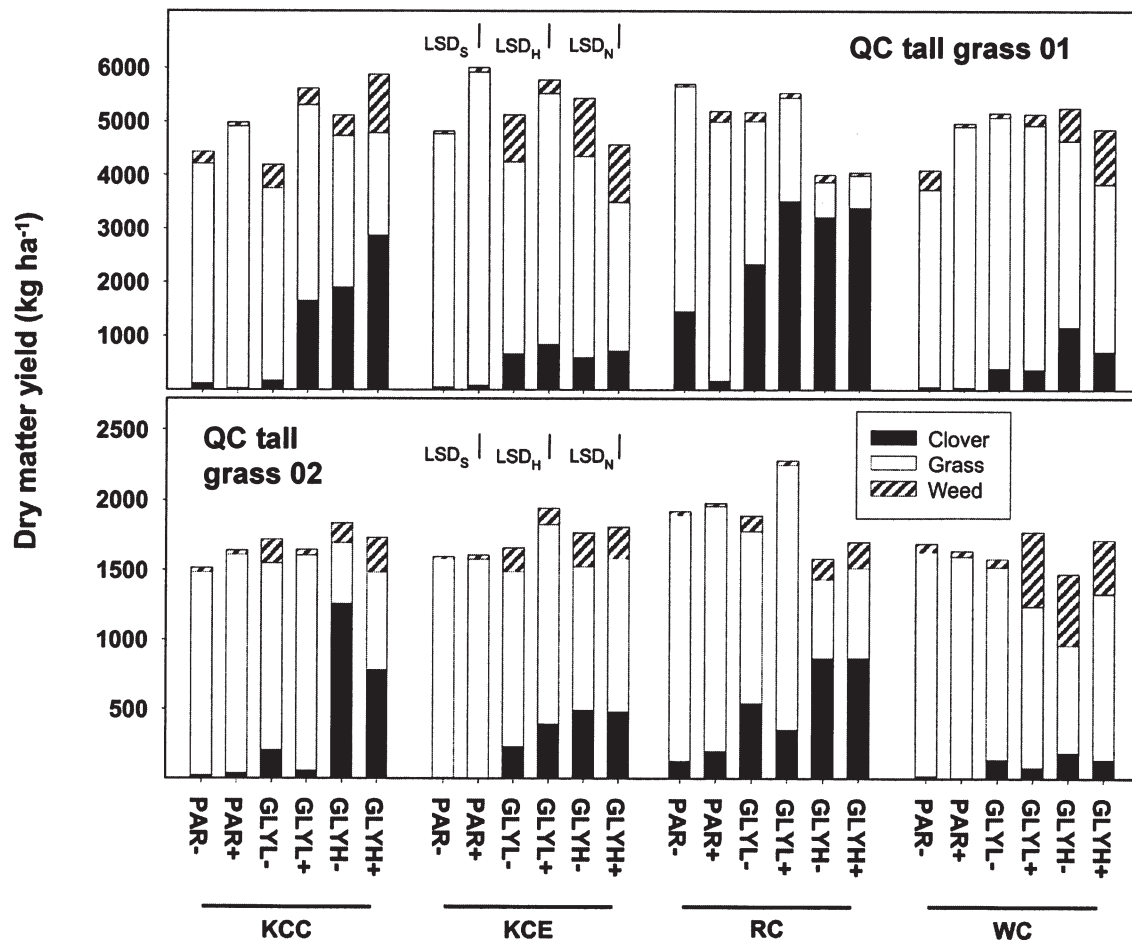


Fig. 1. Total season forage yields and botanical composition in the first postseeding year following sod-seeding of clovers into grass swards suppressed using different herbicides and with or without seeding year N fertilization at two sites in Québec (QC). PAR, paraquat (0.9 kg a.i. ha⁻¹); GLYL, glyphosate 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; + = 110 kg N ha⁻¹; KCC, Kura clover cultivar Cossack; KCE, Kura clover cultivar Endura; QC Tallgrass 01, Québec tallgrass site seeded in 2001; QC Tallgrass 02, Québec tallgrass site seeded in 2002; RC, red clover; WC, white clover. LSD_s is used to compare clover yield means within the same herbicide and N levels; LSD_H is used to compare clover yield means within the same species and herbicide levels. LSD_s is used to compare clover yield means within the same species and N levels; LSD_N is used to compare clover yield means within the same species and herbicide levels. LSDs for total herbage, grass, and weed yields are not indicated on the figure. At QC Tallgrass 01, LSD_s was 583, 630, and 294 kg dry matter (DM) ha⁻¹ for total herbage, grass, and weed yields, respectively; corresponding LSD_H was 618, 650, and 280 kg DM ha⁻¹; and corresponding LSD_N was 530, 675, and 258 kg DM ha⁻¹. At QC Tallgrass 02, LSD_s was 165, 231, and 114 kg DM ha⁻¹ for total herbage, grass, and weed yields, respectively; corresponding LSD_H was 167, 238, and 110 kg DM ha⁻¹; and corresponding LSD_N was 115, 190, and 118 kg DM ha⁻¹.

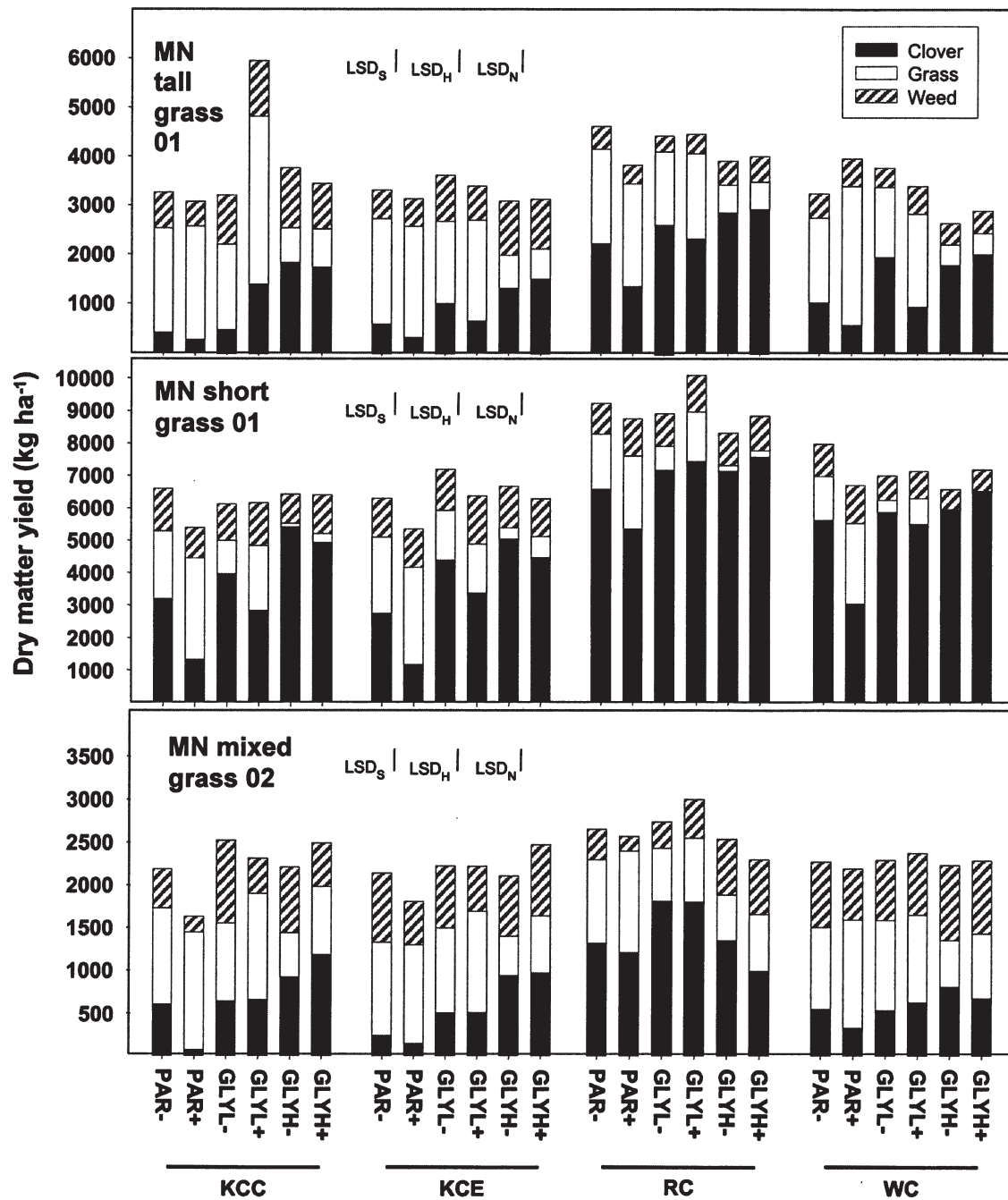


Fig. 2. Total season forage yields and botanical composition in the first postseeding year following sod-seeding of clovers into grass swards suppressed using different herbicides and with or without seeding year N fertilization at three sites in Minnesota. PAR, paraquat (0.9 kg a.i. ha⁻¹); GLYL, glyphosate 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; + = 110 kg N ha⁻¹; KCC, Kura clover cultivar Cossack; KCE, Kura clover cultivar Endura; MN Tallgrass 01, Minnesota tallgrass site seeded in 2001; MN Shortgrass 01, Minnesota shortgrass site seeded in 2001; MN Mixed Grass 02, Minnesota mixed grass site seeded in 2002; RC, red clover; WC, white clover. LSD_S is used to compare clover means within the same herbicide and N levels; LSD_H is used to compare clover means within the same species and N levels; LSD_N is used to compare clover means within the same species and herbicide levels. LSDs for total, grass, and weed dry matter (DM) production are not indicated on the figure. At MN Tallgrass 01, LSD_S was 848, 541, and 213 kg DM ha⁻¹ for total herbage, grass, and weed DM production, respectively; corresponding LSD_H was 911, 536, and 196 kg DM ha⁻¹; and corresponding LSD_N was 801, 585, and 237 kg DM ha⁻¹. At MN Shortgrass 01, LSD_S was 679, 294, and 206 kg DM ha⁻¹ for total herbage, grass, and weed DM production, respectively; corresponding LSD_H was 456, 285, and 192 kg DM ha⁻¹; and corresponding LSD_N was 495, 244, and 157 kg DM ha⁻¹. At MN Mixed Grass 02, LSD_S was 313, 165, and 154 kg DM ha⁻¹ for total herbage, grass, and weed DM production, respectively; corresponding LSD_H was 282, 169, and 154 kg DM ha⁻¹; and corresponding LSD_N was 281, 169, and 122 kg DM ha⁻¹.

Forage Yield and Botanical Composition in the First Postseeding Year

Of seeding year treatments, species and herbicide sod suppression had the greatest effects on total herbage, clover, grass, and weed DM yields the year after seeding through both main effects and interactions. Seeding year N fertilization influenced yields and botanical composition mainly through interactions with species and herbicide treatments, and these were inconsistent across sites. Treatment responses varied with sites, but strongest effects were on clover yield, which influenced other variables through impacts on botanical composition.

Sod-Seeded Clover Species

Species of clover introduced had strong effects on clover yields in the first postseeding year at all sites through main effects and interactions with seeding year herbicide and/or N fertilization treatments. At all sites but QC Tallgrass 02, clover yield of RC was significantly greater than KC and WC in 22 of 24 site–herbicide–N treatment combinations (Fig. 1 and 2). Across seeding year N and herbicide treatments, RC yields were 100 and 60% greater than KC and WC in the first postseeding year, respectively. The contribution of clover to total forage yield averaged 60, 40, and 30% for RC, WC, and KC, respectively. In contrast, yield of all clovers was extremely low at QC Tallgrass 02, most likely due to rainfall that was significantly below the 30-yr average in both the seeding and postseeding years. Still, there was a strong herbicide \times species interaction; KCC and RC produced greater clover yield than KCE and WC in GLYH treatments while smaller differences among clovers occurred at lesser suppression levels (i.e., GLYL and PAR).

Differences in clover yields between KC and WC varied, and two contrasting trends were observed. At MN Tallgrass 01 and MN Shortgrass 01, environments in which precipitation was above the 30-yr average, WC generally outyielded KC. White clover yields were 70 and 60% greater than KCC and KCE in 7 and 9 of 12 site–herbicide–N treatment combinations, respectively. White clover and KC comprised 60 and 42% of total forage yields, respectively. Similar trends were observed in these environments in the seeding year (Laberge et al., 2005). In contrast, at QC Tallgrass 01, QC Tallgrass 02, and MN Mixed Grass 02, WC and KC yields did not differ in 12 of 18 site–herbicide–N treatment combinations; at these sites, KCC, KCE, and WC comprised 24, 17, and 15% of the total forage yield, respectively, in the first postseeding year. Poor initial establishment of WC due to severe moisture deficits in the seeding and postseeding years may explain its low yield in QC. At MN Mixed Grass 02, KC and WC both produced well, but KC cultivars produced less yield than WC in the seeding year (Laberge et al., 2005). Kura clover thus increased its contribution to yield to equal that of WC within 1 yr at MN Mixed Grass 02 (Fig. 2).

Kura clover cultivars had similar clover yields in 19 of 30 site–herbicide–N treatment combinations. Differences between cultivars were generally inconsistent across

sites with the exception of QC Tallgrass 01 and QC Tallgrass 02 where, within the GLYH-treated plots, KCC yields (1700 kg DM ha⁻¹, 50% clover) were more than twice those of KCE (600 kg DM ha⁻¹, 20% clover). This contrasts with a lack of consistent difference between these cultivars during the seeding year in these environments (Laberge et al., 2005). Greater yields of KCC compared with KCE have been observed in postseeding years of conventionally seeded cultivar trials conducted in QC (Seguin and Drapeau, unpublished, 2005). Differences between cultivars may reflect differences in DM partitioning or competitive abilities during establishment in northern environments. In Kentucky, however, these cultivars were similar in forage yield and ground cover during their first 4 yr of growth (Taylor et al., 1999).

Despite lower clover yields than RC, KC yields increased in the first postseeding year compared with the seeding year. Differences in clover yield between RC and KC (or WC) were less pronounced in the first postseeding year than during the seeding year. This may be explained by the abilities of KC and WC to propagate vegetatively. In contrast, RC is known for its aggressive early growth and easy establishment but limited persistence (Seguin, 1998). Across sites and N treatments, KC averaged 1.9 and 1.2 Mg DM ha⁻¹ in GLYH- (avg. 51% clover) and GLYL- (avg. 34% clover) treated plots, respectively, in the first postseeding year. Kura clover yields reached as much as 5 Mg DM ha⁻¹ in GLYH plots of MN Shortgrass 01. In contrast, KC yield during the seeding year was <1 Mg DM ha⁻¹ in four of five sites, with clover representing only 25 and 15% of total forage yield in GLYH- and GLYL-treated plots, respectively (Laberge et al., 2005).

Sod Suppression

Suppression treatments before sod-seeding had strong effects on clover yields in the first postseeding year at all sites through main effects and interactions with clover species and/or N fertilization. However, main effects and interactions were inconsistent across sites. As in the seeding year (Laberge et al., 2005), clover DM production was positively associated with grass suppression intensity. Across sites, clover yield was 75% greater in GLYL- than PAR-treated plots in 34 of 40 site–species–N treatment combinations and 37% greater in GLYH- than GLYL-treated plots in 21 of 40 site–species–N treatment combinations. In QC, in most cases, PAR resulted in biologically insignificant clover yields. Overall, differences among herbicide suppression treatments were less pronounced the year after seeding than in the seeding year when clover yields averaged 128% greater in GLYH- than GLYL-treated plots (Laberge et al., 2005).

The high legume content of the sward obtained in some treatments may be too high for pastures. It is generally recommended that succulent legumes occupy less than 50% of the sward to reduce risks of bloating in ruminant animals (Howarth et al., 1991). In the first postseeding year, RC produced more than 50% of total forage yield in GLYL- and GLYH-treated plots in 17 of 20 site–N

treatment combinations. Kura clover exceeded 50% in GLYH-treated plots in 15 of 20 site–N treatment combinations. Optimal legume/grass ratios (i.e., 30 to 50%) were obtained with both KC and WC in GLYL-treated plots. In the less competitive sward at MN Shortgrass 01, however, all herbicide treatments led to excessive clover content in the first postseeding year.

Total Forage and Grass Yields

There were few consistent treatment effects on total forage yield at both sites in QC due to limited available moisture (Table 1). In MN, differences among species and sod suppression treatments reflected and paralleled clover yield responses. Clover yield and contribution to total forage yields were positively correlated with total forage yields ($r = 0.69$, $P < 0.0001$ and $r = 0.42$, $P < 0.0001$, respectively). Effects of sod-seeded clover species on grass yield were, however, inconsistent across sites. Grasses were mainly influenced by herbicide treatments. Grass yield and contribution to total forage yield were negatively associated with intensity of sod suppression. Grass content averaged 70, 50, and 30% of first postseeding year total forage yields in PAR, GLYL, and GLYH plots, respectively. These results parallel those observed in the seeding year (Laberge et al., 2005). Greater clover percentage and lower grass percentage were achieved at MN Shortgrass 01 than at any other site, with 66% clover and 18% grasses averaged over all treatments, versus 40 and 40%, respectively, at MN Tallgrass 01. The shortgrass species present at the onset of experimentation at MN Shortgrass 01 (mainly Kentucky bluegrass) were more affected by herbicide suppression and less competitive toward the legume component than tallgrass species such as smooth bromegrass found at MN Tallgrass 01 and at the other sites.

Weeds

Weed yield was inconsistently affected across sites by species seeded and seeding year herbicide and N fertilization treatments. Only in QC were consistent effects observed with greater weed production in GLYH- than PAR-treated plots in 13 of 16 site–species–N treatment combinations. Postseeding year weed yield varied greatly among sites, ranging from an average of 1 Mg DM ha⁻¹ weeds in most treatments in the less competitive shortgrasses sward at MN Shortgrass 01 (avg. 12% of total forage yield) to less than 250 kg DM ha⁻¹ in QC Tallgrass 02 (avg. 9% of total forage yield). Weed encroachment has frequently been reported as a problem following herbicide sod suppression (Rioux, 1994; Seguin, 1998). Across sites and treatments, weed contribution to total DM production was lower in the first postseeding year (avg. 15%) than in the seeding year (avg. 35%) (Laberge et al., 2005). Thus, somewhat high seeding year weed content with herbicide sod suppression during pasture renovation may be a short-term phenomenon until the seeded clover fully establishes and the suppressed sod fully recovers.

Residual Effect of Seeding Year Nitrogen Fertilization

Seeding year N fertilization had inconsistent effects across sites and treatments on sward components and forage production in the first postseeding year. Seeding year N fertilization had negative effects on total forage production in only 9 of 60 site–species–herbicide treatment combinations and increased it in 16 others. It had negative impacts on clover yield in 19 of 60 site–species–herbicide treatment combinations and increased it in six others. But in 35 of 60 cases, seeding year N fertilization affected neither total forage nor clover yields the year after seeding.

Yield and Composition of the First Harvest of the Second Postseeding Year

Herbicide × clover species interactions most strongly affected clover yield in each of the three sites sampled at the first harvest in the second postseeding year. Interactions reflected a lack of difference in clover yield among herbicide treatments for WC and RC plots, for which clover yields were low, contrasting with large differences among herbicide treatments in the relatively more productive KC plots where clover yields were generally greater with glyphosate treatments than PAR. Seeding year N treatments had residual effects that were highly inconsistent and affected variables mainly through interactions with herbicide and clover species.

Sod-Seeded Clover Species

Across sites, both cultivars of KC had greater clover yields than RC (fourfold greater) and WC (10-fold greater) in 13 and 15 of 18 site–herbicide–N treatment combinations, respectively (Fig. 3). Red clover and WC had similar clover yields in 17 of 18 site–herbicide–N treatment combinations. There were no consistent differences between the two KC cultivars at MN Tallgrass 01 and MN Shortgrass 01. However, as in the first postseeding year, at QC Tallgrass 01, KCC produced 2.5-fold greater clover yield than KCE in GLYH-treated plots. Differences in second postseeding year clover yields between seeded clover species were greatest in MN Tallgrass 01 and MN Shortgrass 01. At these two sites, across seeding year herbicide and N treatments, KC, RC, and WC yields averaged 900, 200, and 100 kg DM ha⁻¹, respectively, representing 55, 30, and 15% of total forage yield. Overall, clover yields were lower in QC Tallgrass 01 where KCC and KCE yielded 200 and 100 kg DM ha⁻¹, respectively, which represented 20 and 15% of total forage yields. In contrast, RC and WC yields were generally biologically insignificant, averaging <50 kg DM ha⁻¹ across treatments and representing 8 and 2% of total forage yield, respectively. The rainfall in the first postseeding year at QC Tallgrass 01 was 210 mm below the 30-yr average from April through September (Table 1); this probably had residual effects on yields at the first harvest of the second postseeding year.

Kura clover contribution to total forage yields was influenced by species of grasses present. Kura clover represented 70% of the total forage yield in the short-

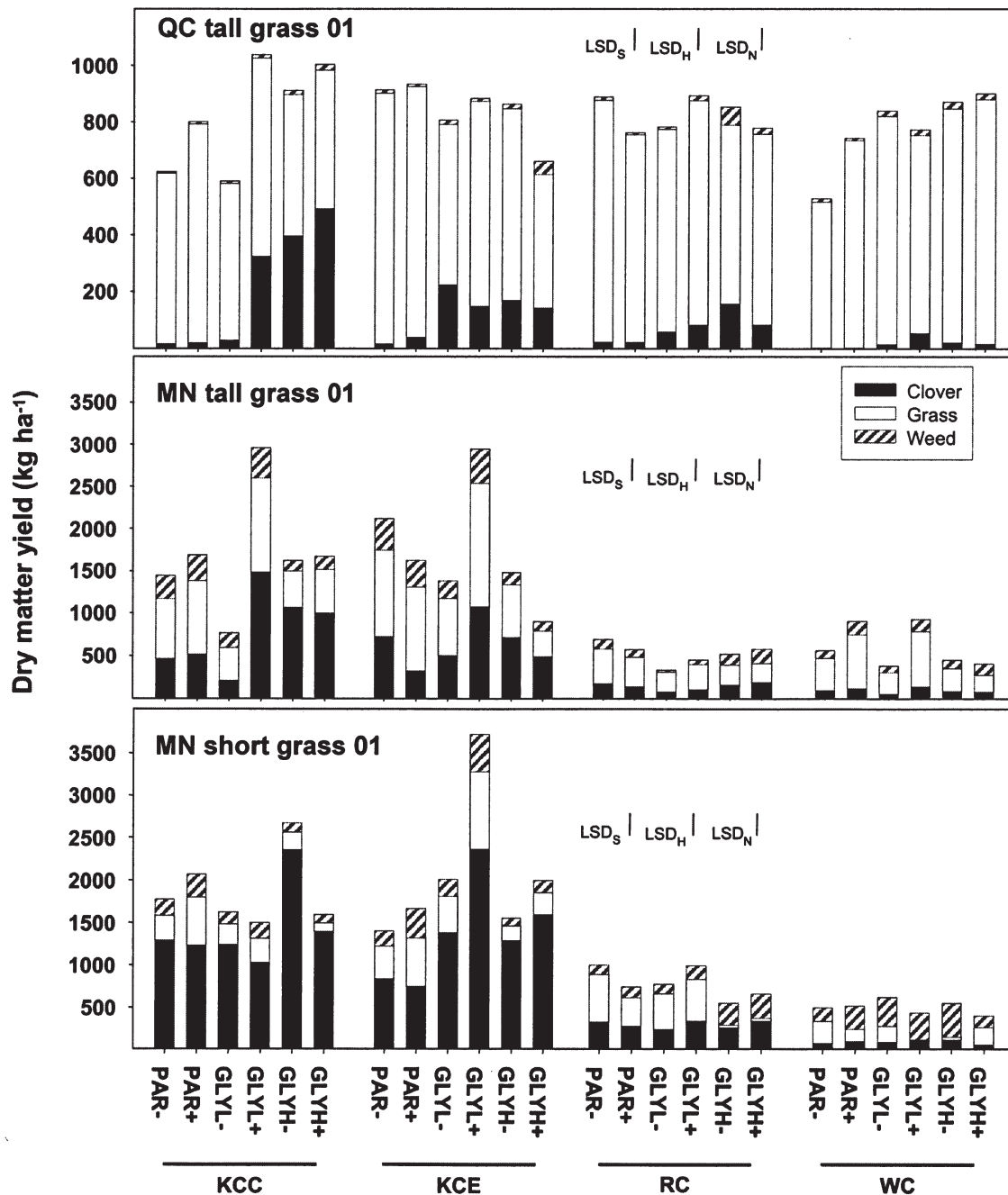


Fig. 3. First-harvest forage yields and botanical composition for the second postseeding year following sod-seeding of clovers into grass swards suppressed using different herbicides and with or without seeding year N fertilization at three sites in Québec and Minnesota. PAR, paraquat (0.9 kg a.i. ha⁻¹); 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; + = 110 kg N ha⁻¹; KCC, Kura clover cultivar Cossack; KCE, Kura clover cultivar Endura; MN Tallgrass 01, Minnesota tallgrass site seeded in 2001; MN Shortgrass 01, Minnesota shortgrass site seeded in 2001; QC Tallgrass 01, Québec tallgrass site seeded in 2001; RC, red clover; WC, white clover. LSD_S is used to compare clover means within the same herbicide and N levels; LSD_H is used to compare clover means within the same species and N levels; LSD_N is used to compare clover means within the same species and herbicide levels. LSDs for total, grass, and weed dry matter (DM) production are not indicated on the figure. At QC Tallgrass 01, LSD_S was 119, 108, and 16 kg DM ha⁻¹ for total herbage, grass, and weed DM production, respectively; corresponding LSD_H was 123, 111, and 17 kg DM ha⁻¹; and corresponding LSD_N was 109, 108, and 15 kg DM ha⁻¹. At MN Tallgrass 01, LSD_S was 314, 158, and 65 kg DM ha⁻¹ for total herbage, grass, and weed DM production, respectively; corresponding LSD_H was 341, 90, and 75 kg DM ha⁻¹; and corresponding LSD_N was 319, 160, and 51 kg DM ha⁻¹. At MN Shortgrass 01, LSD_S was 361, 95, and 85 kg DM ha⁻¹ for total herbage, grass, and weed DM production, respectively; corresponding LSD_H were 341, 90, and 75 kg DM ha⁻¹; and corresponding LSD_N was 335, 88, and 59 kg DM ha⁻¹.

grasses (predominantly Kentucky bluegrass) of MN Shortgrass 01. In contrast, it represented 20 and 40% of total forage yield at QC Tallgrass 01 and MN Tallgrass 01, respectively. In both of these environments, the grass

population was dominated by tall species (predominantly smooth bromegrass). These results are in agreement with Zemenchik et al. (2001), who reported that KC is more competitive in mixtures with shortgrasses

compared with mixtures with taller grasses. This was attributed to the ability of KC to position leaves near the top of the canopy when mixed with Kentucky bluegrass, something rarely observed in mixtures with taller grass species such as smooth bromegrass. It is possible that consequently, KC mixed with Kentucky bluegrass received more photosynthetically active radiation than if mixed with tallgrass species, making it more competitive.

The greater yield of KC at the first harvest of the second postseeding year is in part due to its rapid development in the spring once established. Kura clover yields are generally greatest at the first harvest or grazing period and then decrease during the season (Peterson et al., 1994a; Seguin et al., 2000). In QC, KC has been reported to start growing in the spring even before grasses (Laberge and Seguin, 2005). In contrast, RC and WC achieve optimal production and growth at slightly higher temperature, later in the season (Haynes, 1980). Kura clover superiority in the spring of the second postseeding year, however, also reflects its characteristic slow development in initial years coupled with exceptional persistence (Cuomo et al., 2003). At the first harvest of the first postseeding year (data not presented), RC produced greater yields than KC at all sites, and WC had greater yields than KC in MN (avg. 1300, 330, and 300 kg DM ha⁻¹ for RC, WC, and KC respectively). This trend was thus completely reversed at the first harvest of the second postseeding year. Another reason for the relatively superior yield of KC at MN Shortgrass 01 and MN Tallgrass 01 was winter injury to RC and WC. The early winter of 2002–2003 had below-average snowfall that resulted in cold injury to RC and WC stands without injuring KC. Other RC or WC cultivars may have responded differently.

Our results are in agreement with other studies. It has been previously reported that sod-seeded KC at one site in MN occupied only 10% of the sward during the seeding year and then later increased to more than 50% in the second postseeding year (Cuomo et al., 2001, 2003). In New Zealand, associations of WC with different grasses had higher legume content (40%) than associations of these same grasses with KC (15%) 10 months after seeding. However, after 28 months, KC occupied a greater percentage of the sward (17%) than WC (5%) (Moss et al., 1996).

Total Forage Yield

Total forage yield at the first harvest of the second postseeding year was influenced by three-way interactions among clover species seeded and seeding year herbicide suppression and N fertilization treatments at MN Tallgrass 01 and MN Shortgrass 01. In contrast, at QC Tallgrass 01, there were few consistent treatment effects. Interactions observed in MN mainly reflected larger differences in rankings of herbicide and N treatments in KCC and KCE plots compared with RC and WC. At the first harvest of the second postseeding year, total forage yield was on average threefold greater where KCC and KCE had been introduced than RC and WC in all of 12 site–herbicide–N treatment combi-

nations. This differs dramatically with the situation at the first harvest of the first postseeding year where yields were often lower with KC (data not presented). Grass DM yield was positively correlated with overall clover DM yield in MN ($r = 0.26$; $P < 0.001$) and was thus greater where KCC and KCE had been introduced compared with WC and RC in 8 of 12 site–herbicide–N treatment combinations. This effect also contributed to overall higher total forage production in plots sod-seeded with KC. This positive correlation most likely reflects N transfer from clovers to the associated grasses, which increased grass yields and hence total forage yields.

Residual Effect of Seeding Year Nitrogen Fertilization

Strong residual responses to seeding year N fertilization were observed in some cases. Clover and total forage yields of both KC cultivars were substantially greater in MN Tallgrass 01 where N had been added in GLYL-treated plots (avg. 2.5-fold increase in clover yield and 1.75-fold increase in total forage yield over unfertilized treatments). Similar responses to N fertilization were observed in GLYL-treated plots with KCC in QC Tallgrass 01 and with KCE in MN Shortgrass 01. These results may reflect increased vigor of KC as a result of seeding year N fertilization in swards where suppression was moderate. Nitrogen fertilization enhanced seeding year KC yields in tilled seedbeds as its N₂ fixation potential is generally limited by a slow nodulation (Seguin et al., 2001). In the present trial, N fertilization in the seeding year may have stimulated belowground biomass accumulation, which could have resulted in increased vigor of plants and hence increased herbage production over time. Nitrogen fertilization during sod seeding will, however, also promote grass growth and competition. This may explain some of the variation in the response to N we observed and might be a matter of balance between increased KC vigor and increased grass competition. Outcome depends on the level of grass suppression, species present, and defoliation frequency and intensity. Seeding year N fertilization indeed led to highly variable results in postseeding years but, as in the seeding year (Laberge et al., 2005), rarely had a negative impact on clover or total forage yields. By the spring of the second postseeding year, seeding year N fertilization had no effect on clover content in 27 of 36 site–herbicide–species treatment combinations, decreased clover content in six cases, and increased it in three other cases. Thus, applying N during the seeding year may be a viable option to enhance renovation year yields without detrimental long-term effects on clover content.

Weeds

Effects of treatments on weed yield at the first harvest of the second postseeding year were inconsistent across sites. As in the first postseeding year, they were mainly site-dependent phenomenon. There were practically no weeds in plots at QC Tallgrass 01 (<2% of total forage yield). In MN, weeds also produced little biomass, and differences among treatments were inconsistent. However, because of low total forage yield in RC and WC

plots, weeds were still an important component of these low-producing swards (avg. 22 and 35% clover with RC and WC, respectively). These weeds encroached in openings where previously thick RC and WC stands had been thinned by winter injury over the 2002–2003 winter.

SUMMARY AND CONCLUSIONS

Clover species introduced and herbicide suppression had the greatest effects on postseeding year botanical composition and forage yields. Clover contribution to total forage yields in postseeding years increased as intensity of herbicide sod suppression at seeding increased from PAR to GLYH treatments. In the first postseeding year, RC generally had the greatest clover yield and contribution to total forage yield, WC was intermediate, and KC often ranked last. However, WC and KC had similar clover yields in three of five sites. Kura clover became the highest-yielding species by the first harvest of the second postseeding year. Total forage yields were also higher in MN where KC had been sod-seeded compared with WC and RC. Generally, KC performed better when sod-seeded in shortgrass sod than tallgrass. Differences were attributed to less competition for light when seeded in shortgrass sod.

Experiments demonstrated that KC could be successfully established by sod-seeding with moderate sod suppression with herbicide to become a productive sward component. Despite a low proportion of KC during the seeding year (avg. 18% clover) (Laberge et al., 2005), its presence in the sward increased to occupy on average 45% of the sward in the spring of the second postseeding year. Intensity of herbicide suppression of the resident grasses before sod-seeding continued to influence clover content in swards in postseeding years. Finally, effects of N fertilization on clover, sward productivity, and botanical composition of the swards were inconsistent but rarely negatively impacted clover yields and contribution to total forage yields. Thus, applying N fertilizer during the year can enhance total renovation year yields without significant negative effects on clover content in postseeding years.

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