Barley and triticale underseeded with a kura clover living mulch: Effects on weed pressure, disease incidence, silage yield, and forage quality

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Kosinski, S. M., King, J. R., Harker, K. N., Turkington, T. K. and Spaner, D. 2011. **Barley and triticale underseeded with a kura clover living mulch: Effects on weed pressure, disease incidence, silage yield, and forage quality**. Can. J. Plant Sci. **91**: 677–687. Our objective was to evaluate the effects of seeding barley (*Hordeum vulgare* L.) and triticale (×*Triticosecale wittmack*) into a living mulch of kura clover (*Trifolium ambiguum* M. Bieb.) on weed pressure, barley leaf disease levels, silage yield, and forage quality. Field studies were conducted at two locations in the Parkland region of Alberta, Canada, in 2006 and 2007. Barley and triticale were seeded, at three different soil nitrogen levels, into an established living mulch of kura clover that was either unsuppressed or chemically suppressed with glyphosate at 0.41 kg a.i. ha^{-1} prior to cereal seeding. Barley and triticale sole crops were also included for comparison. The presence of the suppressed and unsuppressed kura clover living mulches significantly decreased weed pressure in 2007 and barley leaf disease incidence in 2006 and 2007. Silage DM yield of the cereal sole crops ranged from 5.18 to 7.02 Mg ha^{-1}, compared with yields of 4.57 to 5.21 Mg ha^{-1} from the unsuppressed living mulch treatments and from 3.95 to 6.00 Mg ha^{-1} from the suppressed living mulch treatments. The kura clover increased the relative feed value of the silage. Based on these results, there is the potential for a suppressed kura clover living mulch to be utilized for cereal silage production in Alberta.

Key words: Living mulch, kura clover, weed suppression, disease incidence, species composition, forage quality

Kosinski, S. M., King, J. R., Harker, K. N., Turkington, T. K. et Spaner, D. 2011. **Semis d'orge et de triticale sur paillage vivant de trèfle du Caucase: effets sur la concurrence des adventices, l'incidence de la maladie, le rendement en ensilage et la qualité du fourrage**. Can. J. Plant Sci. **91**: 677–687. Les auteurs voulaient vérifier quels effets l'ensemencement d'orge (*Hordeum vulgare* L.) et de triticale (×*Triticosecale wittmack*) sur un paillis vivant de trèfle du Caucase (*Trifolium ambiguum* M. Bieb.) aurait sur la concurrence des adventices, l'intensité des maladies foliaires de l'orge, le rendement en ensilage et la qualité du fourrage. Pour cela, ils ont entrepris deux études sur le terrain à deux endroits dans la région des prairies-parcs de l'Alberta, au Canada, en 2006 et 2007. Ils ont semé de l'orge et de la triticale à trois différents dosages d'azote du sol, sur un tapis de trèfle du Caucase qu'ils ont laissé intact ou détruit avec l'application de 0,41 kg de matière active de glyphosate par hectare avant les semis. Des cultures d'orge et de triticale seuls ont été utilisées aux fins de comparaison. La présence du paillis de trèfle du Caucase vivant ou mort a réduit significativement la concurrence des mauvaises herbes en 2007 et l'incidence des maladies foliaires de l'orge en 2006 et 2007. Le rendement en matière sèche pour l'ensilage des céréales cultivées seules variait de 5,18 à 7,02 Mg par hectare, contre 4,57 à 5,21 Mg par hectare pour le paillis vivant et 3,95 à 6,00 Mg par hectare pour le paillis mort. Le trèfle du Caucase rehausse la valeur nutritive de l'ensilage. Compte tenu de ces résultats, on pourrait utiliser le trèfle du Caucase comme paillis mort pour la production de céréales d'ensilage en Alberta.

Mots clés: Paillis vivant, trèfle du Caucase, destruction des mauvaises herbes, incidence de la maladie, composition des espèces, qualité du fourrage

Barley (*Hordeum vulgare* L.) is the second most important cereal crop in Alberta, Canada, sown on approximately 1.66 to 1.98 million ha (Statistics Canada 2006). In 2010, 154 000 ha of barley were harvested as silage in Alberta (Su 2010). Triticale (×*Triticosecale wittmack*) is also commonly grown for silage in Alberta. Silage production can be input intensive, and often requires 10 to 20 kg nitrogen (N) ha^{-1} more than grain crops (Baron et al. 2000). With costs of production increasing and profits declining, livestock producers growing energy intensive annual crops for feed are exploring cropping techniques that can reduce input use. One such technique being considered is intercropping.

Abbreviations: **ADF**, acid detergent fibre; **B**, barley; **B-B**, barley monoculture; **CP**, crude protein; **DM**, dry matter; **ERS**, Edmonton Research Station; **LAC**, Lacombe Research Centre; **LM**, living mulch; **LM+B-B**, living mulch+barley-barley; **LM+T-B**, living mulch+triticale-barley rotation; **NDF**, neutral detergent fibre; **RFV**, relative feed value; **SLM**, suppressed living mulch; **SLM+B-B**, suppressed living mulch+barley-barley rotation; **SLM+T-B**, suppressed living mulch+triticale-barley rotation; **T**, triticale

Intercropping can provide numerous benefits to producers, such as enhanced yields, yield stability, and improved resource use (Lynam et al. 1986). Intercrop components can also suppress weeds, reduce disease levels (Trenbath 1993), and improve soil tilth (Anil et al. 1998). In Atlantic Canada, barley is often cropped with a legume, such as red clover (*Trifolium pratense* L.), for grain or forage production (Kunelius et al. 1992). In New Brunswick, when barley was underseeded with red, Persian (*Trifolium resupinatum* L.), or alsike (*Trifolium hybridum* L.) clovers, barley grain yields were not significantly different from those from conventionally fertilized barley monocultures (Rees et al. 1999). Soil organic matter has the potential to increase due to the presence of the clovers (Rees et al. 1999). In Alberta, barley and triticale intercropped with berseem clover (*Trifolium alexandrium* L.) produced high forage yields (Ross et al. 2004a).

One form of intercropping, called a living mulch (LM), involves maintaining a legume cover crop into which an annual crop is seeded (Hartwig and Ammon 2002). Legume LMs can supply the annual crop with nitrogen, reduce soil erosion, decrease surface water runoff and improve soil structure and health (Hartwig and Ammon 2002). They also help reduce weed pressure and disease severity (Leary and DeFrank 2000). Living mulches of white clover (*Trifolium repens* L.) and birdsfoot trefoil (*Lotus corniculatus* L.) significantly decreased weed biomass in winter wheat (Hiltbrunner et al. 2007a). The biomass of monocotyledonous weeds was 42 kg ha^{-1} in a white clover LM treatment compared with 742 kg ha^{-1} in a non-LM treatment (Hiltbrunner et al. 2007b). White clover also decreased the dispersal of *Septoria tritici* Roberge in Desmaz. pycnidiospores when sown with wheat (Bannon and Cooke 1998). Based on these studies, legume LMs have the potential to provide numerous benefits to producers in the Canadian prairies.

Kura clover (*Trifolium ambiguum* M. Bieb.) is a long-lived, rhizomatous perennial legume, originating in the Caucasus region of Russia (Speer and Allison 1985). It is well adapted to a wide range of climatic conditions and tolerates poorly drained, acidic, and infertile soils. Kura clover is extremely winter hardy and drought tolerant (Speer and Allison 1985). This clover is used in pastures, for hay, and silage, and has similar nutritional qualities to white clover (Taylor and Smith 1998). Drawbacks of this species include slow establishment (Taylor and Smith 1998), low herbage production during the year of establishment, and slow nodulation (Speer and Allison 1985).

Kura clover has been evaluated as a LM for corn (*Zea mays* L.) (Zemenchik et al. 2000; Affeldt et al. 2004) and soybean [*Glycine max* (L.) Merr.] production (Pedersen et al. 2009; Singer and Moore 2010). Zemenchik et al. (2000) seeded corn into established plots of kura clover that were either suppressed or killed with herbicides at varying rates. They found no significant difference in corn yield between the suppressed LM plots and the killed LM plots (Zemenchik et al. 2000). Winter wheat has also been sown into a kura clover LM and harvested for silage (Contreras-Govea et al. 2006). Dry matter yield of the winter wheat-kura mixture was less than that of sole winter wheat, but double that of sole kura clover.

Little information is available on kura clover LM for cereal silage production in Canada. To date, most of the studies have been conducted with corn or soybean-kura clover LM systems in the United States. The objective of this experiment was to assess the compatibility of a kura clover LM with barley or triticale for silage production in the Parkland region of central Alberta. More specifically, if the presence of an unsuppressed or suppressed kura clover LM: (i) decreased weed density and biomass, (ii) reduced barley leaf disease levels, (iii) decreased silage yield, and (iv) increased forage quality.

MATERIALS AND METHODS

Site Characteristics

Field experiments were conducted in 2006 and 2007 at two sites representing the Parkland region of central Alberta, Canada. The first site, located at the University of Alberta Research Station (ERS) in Edmonton, AB (lat. 53°34′N, long. 113°31′W), was on a Malmo silty clay loam soil, classified as an orthic Black Chernozem (Typic Cryoboroll). The second site was at the Agriculture and Agri-Food Canada Research Centre (LAC) in Lacombe, AB (lat. 52°27′N, long. 133°44′W), on a thin orthic Black Chernozem (frigid Typic Haplustoll) with a clay loam texture. Rainfall and temperature data were collected from on site weather stations at both locations. Experiments were established on fallow soil at ERS and on canola stubble at LAC.

The seasonal mean temperature from 2006 May 01 to Sep 30 at ERS was 15.7°C, slightly warmer than the 30-yr average of 14.5°C. At LAC, the season mean temperature in 2006 was 14.1°C, also warmer than the 30-yr average of 12.9°C. In 2007, seasonal mean temperatures were again slightly warmer than the 30-yr averages, 15.9°C at ERS and 13.4°C at LAC. At ERS, rainfall for May 01 to Sep. 30 was less than the 30-yr average (326.3 mm) in both 2006 (170.4 mm) and 2007 (195.8 mm). Rainfall for May 01 to Sep. 30 at LAC was more than the 30-yr average (320.7 mm) in both 2006 (406.4 mm) and 2007 (447.4 mm). Overall, the study was conducted under slightly warmer and drier conditions than the 30-yr average at ERS, and under slightly warmer and wetter conditions than the 30-yr average at LAC.

Experimental Design and Plot Management

The experiment was a split-plot arrangement of a randomized complete block design with four replications per site. Sub-plot dimensions were 2.76 by 6 m at ERS and 3.66 by 7.62 m at LAC. Soil nitrogen level was the main plot treatment and rotation was the sub-plot treatment. The soil at ERS had inherently high nitrogen levels, resulting in the low soil N treatment being 90 kg N ha^{-1}. As a result, the medium (150 kg N ha^{-1}) and high (225 kg N ha^{-1}) treatments were scaled up to create three distinct soil N treatments. In 2006, these target rates were achieved or exceeded at both sites, except for one subplot rotation treatment at ERS and in the low soil N treatment at LAC. In 2007, due to equipment restrictions, these target soil N rates were not met for the low soil N treatment at ERS or for any of the soil N treatments at LAC. However, there were three distinct low, medium, and high soil N treatments at each site. The low, medium, and high soil N treatments at LAC were as follows: 11–23 kg N ha^{-1}, 93–114 kg N ha^{-1}, and 176–190 kg N ha^{-1}, depending on subplot rotation. The six subplot rotation treatments, as well as the seeding sequence, are outlined in Table 1.

Cossack kura clover plots were established in June 2005 (Tables 1 and 2) at ERS with a four-row disc drill, and at LAC with a Conservpak® air seeder (Conserva Pak Seeding Systems, Indian Head, SK). Kura clover was seeded at a rate of 12 kg ha^{-1}, a depth of 1.5 to 2 cm, and with a row spacing of 30 cm at ERS and 23 cm at LAC. Kura clover seed was inoculated with a commercially available mixture of *Rhizobium leguminosarum* biovar *trifolii* strain prior to sowing. Seebe barley and AC Morgan oats (*Avena sativa* L.) were seeded at a rate of 300 seeds m^{-2} and with a row spacing of 23 cm into designated plots in order to establish the two cereal monoculture rotations (Table 1). Soil phosphorus (P), potassium (K), and sulphur (S) levels were maintained based on soil test recommendations (Norwest Labs, Edmonton, AB). Edmonton Research Station plots were hand-weeded. In September 2005, both sites were mowed with a sickle mower and the plant material raked off the plots.

Plot over-sprays of a mixture of 0.02 kg a.i. ha^{-1} imazethapyr [2-(4.5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl)-5-ethyl-3 pyridine carboxylic acid] and 0.19 kg a.i. ha^{-1} sethoxydim [2 (1-{ethoxyimino} butyl)-5-(2-{ethylthio} propyl)-3-hydroxy-2-cyclohexen-1-one] for weed control occurred twice in May 2006 at LAC. In 2006 and 2007, glyphosate [*N*-(phosphonomethyl)glycine] at 0.41 kg a.i. ha^{-1} was applied to the suppressed living mulch (SLM) and the cereal monoculture (B-B and T-B) rotations 2 wk before seeding (Table 2).

Cereals were seeded in 2006 and 2007 (Table 2) according to the previously described rotation sub-plot treatments at a depth of 2.5 to 4 cm, a seeding rate of 300 seeds m^{-2}, and a row spacing of 23 cm. Fertilizer (P, K, and S) was applied according to soil test recommendations for barley and triticale (Norwest Labs, Edmonton, AB). Nitrogen fertilizer (46-0-0) was applied to achieve the soil nitrogen levels previously listed and then broadcast and incorporated during seeding at ERS, or side-banded during seeding at LAC. A six-row, zero-till disc drill was used at ERS, and a Conservpak® air seeder at LAC. Cereals were seeded perpendicular to the kura clover rows at ERS and seeded between the kura clover rows at LAC.

Early-season weed density was measured at the four-leaf cereal stage. A 1-m^2 quadrat was placed in two locations per plot. The weed species and number of seedlings per quadrat were recorded. Barley leaf disease levels were measured twice during the growing season; at the five-leaf cereal stage and at silage harvest. At the five-leaf cereal stage, 50 second true leaves were examined from plants at two sites per barley-containing plot, and the number with a lesion was recorded. Prior to harvest, the percent barley leaf-area infected was measured. Twenty flag leaves and twenty penultimate leaves were randomly removed from each barley plot 8 d before harvest at ERS, and 15 d before harvest at LAC. The percent leaf-area infected of those leaves was visually estimated. Samples of the leaves' lesions were cultured in order to identify the diseases present.

Plots were harvested at the soft-dough cereal stage (stage 85) (Zadoks et al. 1974) (Table 3). Prior to machine harvest, species composition was determined using a 0.5-m^2 quadrat placed over three cereal rows per plot and kura in the intervening spaces. Plants were clipped by hand and separated into cereal, clover, and weeds. Percent composition was determined from the dry weight of each. Silage yield was taken at ERS from a sample 0.6 by 5.4 m collected with a Swift Current flail mower (Swift Current, SK). A 0.3 m swath was first removed from the front and back of each plot to avoid

Table 1. Subplot rotation treatment plant species seeding sequence at Edmonton and Lacombe, AB, Canada

Subplot rotation treatment	2005	2006	2007
Barley-barley (B-B)	Barley[z]	Barley	Barley
Triticale-barley (T-B)	Oat[y]	Triticale[x]	Barley
Living mulch + barley-barley (LM + B-B)	Kura clover[w]	Barley	Barley
Living mulch + triticale-barley (LM + T-B)	Kura clover	Triticale	Barley
Suppressed living mulch + barley-barley (SLM + B-B)	Kura clover	Barley	Barley
Suppressed living mulch + triticale-barley (SLM + T-B)	Kura clover	Triticale	Barley

[z]Seebe was the variety of barley seeded.
[y]AC Morgan was the variety of oats seeded.
[x]Pronghorn was the variety of triticale seeded.
[w]Cossack was the variety of kura clover seeded.

Table 2. Seeding date, herbicide suppression application date, and harvest date for plots at Edmonton and Lacombe, AB, Canada

Location	Seeding date	Herbicide suppression application date[z]	Harvest date
		2005	
Edmonton	Jun. 21	–[y]	Sep. 21
Lacombe	Jun. 16	–	Sep. 08
		2006	
Edmonton	May 23	May 05	Aug. 08 and 21[x]
Lacombe	May 29	May 11	Aug. 15 and 29
		2007	
Edmonton	May 24	May 08	Aug. 08
Lacombe	May 31	May 10	Aug. 15

[z]Herbicide suppression applied to cereal monoculture and suppressed living mulch rotation treatments.
[y]No herbicide suppression was applied during the establishment year of the living mulch and suppressed living mulch rotation treatments.
[x]First harvest date in 2006 was for the barley plots and the second harvest date was for the triticale plots.

edge effects. The remaining unharvested biomass was mowed and raked off the plots. A Swift Current plot forage harvester (Swift Current, SK) was used at LAC to collect material from the whole plot. Both the machine and hand harvested materials were placed in a forced air dryer for 48 h at 48°C, and weighed. Samples from the LAC 2006 and 2007 silage material were ground with a Wiley mill to 1 mm and then analyzed for forage quality. Nitrogen was determined using a LECO N-analyzer (Model CN-2000, Leco Corp., St Joesph, MI) and multiplied by 6.25 for crude protein (CP). The acid detergent fibre (ADF) and neutral detergent fibre (NDF) analyses were conducted using batch procedures outlined by ANKOM Technology Corporation (Fairport, NY) for an ANKOM200 Fibre Analyzer (Komarek 1993; Komarek et al. 1994). Relative feed value (RFV) was calculated from ADF and NDF concentrations using the equations presented in Jeranyama and Garcia (2004).

Six weeks after silage harvest, kura clover regrowth was measured. This length of time was chosen as it would cover the period in the fall in which plant growth was still possible prior to fall frost. A 1-m^2 quadrat was placed in the centre of each LM and SLM plot. Kura clover biomass within that quadrat was hand-clipped to a height of 2.5 cm. The harvested regrowth material was then placed in a forced air dryer for 48 h at 48°C and weighed. Kura regrowth samples from LAC 2006 and 2007 were ground with a Wiley mill to 1 mm and then analyzed for forage quality. Nitrogen was determined using a LECO N-analyzer (Model CN-2000, Leco Corp., St Joesph, MI) and multiplied by 6.25 for CP.

Statistical Analysis

An analysis of variance was performed using the PROC MIXED procedure of SAS (Littell et al. 2006) at $P<0.05$. Years were analyzed separately due to significant year-by-rotation interactions. Nitrogen level, rotation, and their interaction were considered fixed effects in the split plot analysis. Replicates (blocks) and replicate interactions were considered as random effects in the model. Site was considered as a random effect in the model as we wished to make inferences for the Parkland region of central Alberta. Significant nitrogen level effect

Table 3. Early-season weed density and weed biomass at crop maturity (on a dry matter basis) averaged across all soil nitrogen level treatments, grown in 2006 and 2007, at Edmonton and Lacombe, AB, Canada

Subplot rotation treatment	Weed density 2006	Weed density 2007	Weed biomass 2006	Weed biomass 2007
	(plants m^{-2})		($Mg\ ha^{-1}$)	
Barley-barley (B-B)	50	125	0.45	2.62
Triticale-barley (T-B)	65	160	1.16	3.37
Living mulch + barley-barley (LM + B-B)	65	24	0.47	0.27
Living mulch + triticale-barley (LM + T-B)	63	43	0.35	0.09
Suppressed living mulch + barley-barley (SLM + B-B)	59	77	0.21	0.07
Suppressed living mulch + triticale-barley (SLM + T-B)	60	87	0.16	0.53
ANOVA				
Nitrogen F-test (df = 2)	NS	NS	NS	NS
SE[z] nitrogen	8.58	15.56	0.18	0.35
Rotation F-test (df = 5)	NS	***	**	***
SE rotation	12.14	15.60	0.25	0.50
N × R (df = 17)	NS	NS	NS	NS
Contrasts				
B-B vs. T-B	NS	*	**	NS
B-B vs. LM + B-B and SLM + B-B	NS	***	NS	***
LM + B-B vs. SLM + B-B	NS	***	NS	NS
T-B vs. LM + T-B and SLM + T-B	NS	***	***	***
LM + T-B vs. SLM + T-B	NS	**	NS	NS

[z]Standard error of the difference of two least-squares means.
*, **, *** Significant at $P<0.05$, $P<0.01$, and $P<0.001$ probability levels, respectively; NS, not significantly different at $P<0.05$.

means were separated with orthogonal polynomial contrasts, using coefficients derived in the IML procedure of SAS. Significant rotation effect means were separated using single degree of freedom contrasts. Normality through heterogeneity of variance was assessed for all data using Bartlett's test and a plot of the residuals (Littell et al. 2006). Percentage data was arcsin transformed for analysis and untransformed data is presented in the tables. A significance level of $P<0.05$ was used for the above statistical tests.

RESULTS AND DISCUSSION

Weed Pressure

Early Season Weed Density

The major weed species observed included: stinkweed (*Thlaspi arvense* L.), henbit (*Lamium amplexicaule* L.), redroot pigweed (*Amaranthus retroflexus* L.), shepherd's purse (*Capsella bursa-pastoris* L.), and lamb's-quarters (*Chenopodium album* L.). Soil N had no significant effect on weed density. In 2006, there were no differences in early-season weed density at the four-leaf cereal stage among the rotation treatments (Table 3). Other studies also noted an absence of a weed-suppressing benefit when intercropping cereals and forage legumes (Pridham and Entz 2008). In 2007, the LM and SLM rotations had significantly fewer weeds present than the cereal monoculture rotations (B-B and T-B) (24 to 87 vs. 125 and 160 weed plants m^{-2}). Hiltbrunner et al. (2007a, b) also observed significant weed suppression due to the presence of white or subterranean clover (*Trifolium subterraneum* L.) LMs in a crop of winter wheat. The rate of development of soil cover is a significant factor in the ability of a clover LM to suppress weeds (den Hollander et al. 2007). The ability of kura clover to increase ground cover as it becomes established likely contributed to the decreased weed pressure observed in 2007 compared with 2006 in the LM and SLM rotations (data not presented here). Herbicide suppression in the SLM rotations reduced the competitiveness of kura clover and its ability to suppress weeds in our experiment. The SLM rotations had a higher number of weeds present (77 and 87 weed plants m^{-2}) compared to the LM rotations (24 and 43 weed plants m^{-2}). However, there were still fewer weeds present than in the cereal monoculture rotations, indicating that the weed suppressing benefit of the suppressed LM was still realized.

Weed Biomass at Crop Maturity

Weed biomass at crop maturity was measured to illustrate the season-long competitiveness of a kura clover LM with weeds (Table 3). In 2006, the LM and SLM triticale-barley rotations (LM + T-B and SLM + T-B) had significantly lower weed biomass at crop maturity than the triticale-barley cereal rotation (T-B). In 2007, all the rotations containing kura clover had significantly lower weed biomass present at crop maturity than the cereal monoculture rotations. This reduction in weed biomass due to the presence of legumes has been observed in other studies (Ilnicki and Enache 1992; Moynihan et al. 1996). In our study there were no significant differences in weed biomass between the LM and SLM rotations. This suggests that the kura clover was able to recover from the herbicide suppression and effectively compete with weeds as the growing season progressed.

Incidence of Barley Leaf Disease

Early Season Barley Leaf Disease Incidence

Early-season barley leaf disease incidence was evaluated in select rotations in 2006 and all rotations in 2007 at the five-leaf cereal stage (Table 4). While soil N had no effect on barley leaf disease incidence in 2006, disease incidence increased linearly as soil N increased in 2007. In both years, the presence of the kura clover in the LM and SLM rotations reduced the incidence of barley leaf disease lesions. The LM rotations also had a lower leaf disease incidence than the SLM rotations. This is likely the result of a combination of factors: fewer barley host plants were present in the LM rotations due to the negative impact on barley emergence, a more competitive environment for the barley seedlings (data not presented), and the increased interception of disease inoculum by the kura clover plants. The incidence of barley leaf disease in the barley monoculture (B-B) rotation was significantly greater than that of the triticale-barley (T-B) rotation in 2007. Krupinsky et al. (2004) also observed higher levels of leaf disease lesions in continuous barley compared with treatments where crop species were rotated annually.

The presence of the kura clover LM in this study had a similar beneficial effect on early-season disease incidence as that of crop rotation. The barley plants in the living mulch + barley-barley (LM + B-B) and suppressed living mulch + barley-barley (SLM + B-B) rotations had lower incidences of barley leaf disease lesions than barley plants grown in the barley monoculture (B-B) rotation in 2007. Intercropping increases crop diversity, helping manage crop diseases. The presence of the second crop could alter the microclimate of the canopy. This alteration to the environment may render it less conducive to disease development (Krupinsky et al. 2002). The second crop can also interfere with the dispersal of inoculum between its source and the host plants, as well as between host plants (Trenbath 1993). Ntahimpera et al. (1998) found that the presence of a sudangrass (*Sorghum* spp.) LM significantly interfered with the splash dispersal of anthracnose disease (*Colletotrichum acutatum*) conidia. In our study, the kura clover canopy may have acted as a barrier to the movement of disease inoculum between the barley residue on the soil surface and growing barley plants, and on the dispersal of inoculum between barley plants, thereby decreasing barley leaf disease development.

Table 4. Early-season barley leaf disease incidence, proportion of barley penultimate leaf-area infected, and proportion of barley flag leaf-area infected averaged across all rotation treatments or all soil nitrogen level treatments, grown in 2006 and 2007, at Edmonton and Lacombe, AB, Canada

Treatment	Early barley leaf disease incidence[z]		Proportion of penultimate leaf-area infected		Proportion of flag leaf-area infected	
	2006	2007	2006	2007	2006	2007
	(%)					
Main plot soil nitrogen level treatment						
Low soil nitrogen	43	46	6	5	3	2
Medium soil nitrogen	42	53	6	6	3	2
High soil nitrogen	42	53	5	4	2	2
Subplot rotation treatment						
Barley-barley (B-B)	86	74	10	9	4	4
Triticale-barley (T-B)	NA[y]	56	NA	8	NA	3
Living mulch + barley-barley (LM + B-B)	15	35	3	1	2	0
Living mulch + triticale-barley (LM + T-B)	NA	32	NA	1	NA	0
Suppressed living mulch + barley-barley (SLM + B-B)	26	60	4	5	2	2
Suppressed living mulch + triticale-barley (SLM + T-B)	NA	50	NA	4	NA	2
ANOVA						
Nitrogen F-test (df = 2)	NS	**	NS	NS	NS	NS
SE[x] nitrogen	0.04	0.03	0.02	0.02	0.01	0.02
Rotation F-test (df = 5)	***	***	***	***	***	***
SE rotation	0.04	0.05	0.01	0.01	0.01	0.01
N × R (df = 17)	NS	NS	NS	NS	NS	NS
Orthogonal polynomials						
N linear	NS	**	NS	NS	NS	NS
N quadratic	NS	NS	NS	NS	NS	NS
Contrasts						
B-B vs. T-B	NA	***	NA	NS	NA	NS
B-B vs. LM + B-B and SLM + B-B	***	***	***	***	***	***
LM + B-B vs. SLM + B-B	***	***	NS	**	NS	*
T-B vs. LM + T-B and SLM + T-B	NA	***	NA	***	NA	**
LM + T-B vs. SLM + T-B	NA	***	NA	**	NA	**

[z]Percentage of second true leaves with disease lesions present at the five-leaf cereal stage.
[y]Data not collected from the treatment.
[x]Standard error of the difference of two least-squares means.
*, **, *** Significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$ probability levels, respectively; NS, not significantly different at $P < 0.05$.

Proportion of Barley Leaf-Area Infected

Spot-form net blotch (*Drechsler teres* f. *maculata* Smedeg.) was the most commonly occurring leaf disease on the penultimate and flag leaves, while *Alternaria* spp. and *Cladosporium* spp. were also isolated from sampled material. Spot-form net blotch is a common disease of barley in Canada and one of the most economically important leaf diseases on the prairies (Tekauz 2003).

The proportions of barley penultimate and flag leaf areas infected were low (less than 10%) in both 2006 and 2007 (Table 4). In 2006, the proportion of the barley leaf area infected was significantly reduced in the rotations containing kura clover (LM and SLM) compared with the cereal monoculture rotations (B-B and T-B). There was no difference in the amount of leaf area infected between the LM + B-B and SLM + B-B rotations. In 2007, the rotations containing the kura clover LMs had smaller leaf areas infected than the cereal monoculture rotations. The addition of chemical suppression to the kura clover in the SLM rotations led to higher proportions of penultimate and flag leaf areas infected compared with their LM counterparts.

The flag leaf area infected was smaller than the penultimate leaf area infected in the kura clover living mulch rotations (LM and SLM). The kura clover canopy may have acted as a barrier to the movement of the disease inoculum vertically from infested residues at the soil surface or from infected barley leaves lower in the canopy. Bannon and Cooke (1998) also noted a reduction in the vertical movement of inoculum from the base of a wheat plant to its upper leaves in the presence of white clover.

Silage Dry Matter Yield

In both 2006 and 2007, a significant linear relationship between yield and soil N level was identified (Table 5). In 2006, silage dry matter (DM) yield ranged from 4.57 Mg ha^{-1} to 7.02 Mg ha^{-1}. The presence of the kura

Table 5. Silage yield (on a dry matter basis), proportion of cereal in the silage, and proportion of kura clover in the silage averaged across all rotation treatments or all soil nitrogen level treatments, grown in 2006 and 2007, at Edmonton and Lacombe, AB, Canada

Treatment	Silage yield		Cereal proportion of silage		Kura proportion of silage	
	2006	2007	2006	2007	2006	2007
	------------ ($Mg\ ha^{-1}$) -----------		---------- (%) ----------			
Main plot soil nitrogen level treatment						
Low soil nitrogen	5.16	4.20	55	28	41	59
Medium soil nitrogen	5.93	4.84	61	35	34	55
High soil nitrogen	6.12	5.41	59	40	35	49
Subplot rotation treatment						
Barley-barley (B-B)	6.58	5.18	96	74	0	0
Triticale-barley (T-B)	7.02	5.18	88	66	0	0
Living mulch + barley-barley (LM + B-B)	4.57	5.23	27	3	68	94
Living mulch + triticale-barley (LM + T-B)	5.12	5.21	32	10	65	89
Suppressed living mulch + barley-barley (SLM + B-B)	5.12	3.95	58	24	40	75
Suppressed living mulch + triticale-barley (SLM + T-B)	6.00	4.15	49	29	49	66
ANOVA						
Nitrogen F-test (df = 2)	*	**	NS	NS	NS	*
SE[z] nitrogen	0.34	0.27	0.04	0.07	0.04	0.05
Rotation F-test (df = 5)	***	***	***	***	***	***
SE rotation	0.40	0.38	0.06	0.06	0.06	0.07
N × R (df = 17)	NS	NS	NS	NS	NS	NS
Orthogonal polynomials						
N linear	*	**	NS	NS	NS	**
N quadratic	NS	NS	NS	NS	NS	NS
Contrasts						
B-B vs. T-B	NS	NS	NS	NS	NS	NS
B-B vs. LM + B-B and SLM + B-B	***	NS	***	***	***	***
LM + B-B vs. SLM + B-B	NS	**	***	***	***	***
T-B vs. LM + T-B and SLM + T-B	***	NS	***	***	***	***
LM + T-B vs. SLM + T-B	*	**	***	***	***	***

[z]Standard error of the difference of two least-squares means.
*, **, *** Significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$ probability levels, respectively.
NS, not significantly different at $P < 0.05$.

clover in the LM and SLM rotations decreased DM yield by 15 to 31% compared with the cereal monocultures (B-B and T-B). Other studies involving seeding cereals with legume LM also documented decreased yields (Erberlein et al. 1992; Contreras-Govea and Albrecht 2005; Carof et al. 2007). The addition of herbicide suppression in our study did result in a higher silage DM yield in one instance (SLM + T-B yield was greater than the LM + T-B yield).

In 2007, silage DM yield ranged from 3.95 to 5.23 Mg ha^{-1}. There was no significant difference in yield between the cereal monoculture rotations and the kura clover living mulch (LM and SLM) rotations. This was likely due to the reduced cereal emergence and establishment experienced that year as a result of lower rainfall at the time of seeding. However, there was a significant difference between the yields of the LM and SLM rotations. The yields of the LM rotations were 26 to 32% greater than the SLM rotations. The LM rotations were mainly kura clover due to poor barley emergence and vigorous growth of the kura clover in the absence of suppression.

Species Composition

In both 2006 and 2007, soil N had no significant effect on the proportion of cereal harvested (Table 5). The LM and SLM rotations had significantly less cereal than the B-B and T-B rotations. This could be one cause of the lower silage yields observed in the LM and SLM rotations. Contreras-Govea and Albrecht (2005) also found that kura clover significantly decreased the amount of cereal contributing to yield when the cereal was seeded into it. The two SLM rotations did have higher proportions of cereal contributing to silage DM yield (24 to 58%) than the LM rotations (3 to 32%).

In order to increase the effectiveness of suppression and the cereal component of the silage contributing to yield, an increased rate of glyphosate should be applied prior to seeding the cereals. According to Affeldt et al. (2004), glyphosate rates up to 1.66 kg a.i. ha^{-1}, greater than the rate applied in this experiment, were required to provide the level of kura control necessary to decrease competition for corn production. Pedersen et al. (2009) found that even with four applications of glyphosate to suppress a kura clover LM during the growing season, soybean grain and forage yield reductions still occurred.

Soil N had no significant effect on the proportion of kura clover at harvest in 2006. However, in 2007, the amount of kura clover harvested decreased linearly as soil N increased. This could be due to the cereal component of each treatment becoming more competitive as a result of the increase in nitrogen. In both 2006 and 2007, the LM rotations had significantly more kura clover present (65 to 94% kura clover) than the SLM rotations (40 to 75% kura clover). This difference can be attributed to the herbicide suppression applied to the SLM rotations before cereal seeding, indicating that the glyphosate did negatively affect kura clover growth to some extent.

Kura clover still represented 40 to 75% of silage DM yield even with herbicide suppression in the SLM rotations. The amount of kura contributing to the overall silage yield also increased significantly from 2006 to 2007 in both the LM and SLM rotations. Laberge et al. (2005) found that the proportion of kura clover increased from 18% of the yield in the first year to 45% in the second when grown with grasses in a pasture. Kura clover is able to spread via rhizomes (Sheaffer and Marten 1991) and once established, will soon out-compete companion plants (Laberge et al. 2005). The increase in kura clover growth in 2007 likely contributed to the reduction in the cereal component of the silage harvest (data not presented).

Forage Quality

Forage quality of silage harvested from all six rotation treatments at LAC was average to excellent (meets the nutritional needs of cows in mid-pregnancy and after-calving) (Table 6). In this study, CP concentrations of barley were slightly higher than, and CP concentrations of triticale on a par with, previously reported barley and triticale CP values (Baron et al. 2000). There was no difference in CP between the cereal monocultures and the LM and SLM rotations in 2006 (ranged from 98 to 132 g kg^{-1}). In 2007, CP concentrations were higher in the LM and SLM rotations than in the cereal monocultures (by 16 to 37 g kg^{-1}). Contreras-Govea and Albrecht (2005) also noted that mixtures of kura clover with oats, barley, and winter wheat had greater CP concentrations than the respective cereal monocultures.

Kura clover silage has previously had reported ADF values ranging from 170 to 252 g kg^{-1} and NDF values of 221 to 306 g kg^{-1} (Contreras-Govea et al. 2006). These values are lower than those documented in other trials for both barley and triticale silage (Baron et al. 2000). In this experiment, the ADF and NDF concentrations were lowest in the LM and SLM rotations (Table 6). Contreras-Govea et al. (2006) found

Table 6. Crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), and relative feed value (RFV) averaged across all soil nitrogen level treatments, grown in 2006 and 2007, at Lacombe, AB, Canada

	CP		ADF		NDF		RFV	
Subplot rotation treatment	2006	2007	2006	2007	2006	2007	2006	2007
	(g kg^{-1})						(%)	
Barley-barley (B-B)	117	115	270	325	533	600	119	99
Triticale-barley (T-B)	99	113	296	318	560	576	110	104
Living mulch + barley-barley (LM + B-B)	132	152	244	283	442	403	148	155
Living mulch + triticale-barley (LM + T-B)	110	150	281	278	500	400	125	158
Suppressed living mulch + barley-barley (SLM + B-B)	116	143	245	288	463	437	141	143
Suppressed living mulch + triticale-barley (SLM + T-B)	98	129	284	287	502	458	124	136
ANOVA								
Nitrogen F-test (df = 2)	NS	NS	NS	NS	NS	NS	NS	NS
SE^z nitrogen	8.56	8.55	5.32	8.29	10.70	18.70	3.56	6.54
Rotation F-test (df = 5)	**	***	***	**	***	***	***	***
SE rotation	7.84	8.94	7.53	11.73	15.13	23.68	5.04	9.24
N × R (df = 17)	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts								
B-B vs. T-B	*	NS	**	NS	NS	NS	NS	NS
B-B vs. LM + B-B and SLM + B-B	NS	***	***	**	***	***	***	***
LM + B-B vs. SLM + B-B	NS	NS	NS	NS	NS	NS	NS	NS
T-B vs. LM + T-B and SLM + T-B	NS	**	NS	**	***	***	**	***
LM + T-B vs. SLM + T-B	NS	*	NS	NS	NS	*	NS	*

^{z}Standard error of the difference of two least-squares means.
*, **, *** Significant at $P<0.05$, $P<0.01$, and $P<0.001$ probability levels, respectively.
NS, not significantly different at $P<0.05$.

that the addition of kura clover to winter wheat silage decreased the concentrations of ADF and NDF compared with winter wheat monocultures. The NDF concentrations of the harvested material from the LM and SLM rotations were lower in 2007 than in 2006. This was likely due to the increased percentage of kura clover in those treatments in 2007.

The RFVs for the LM and SLM rotations (125 to 158) were greater than for the B-B and T-B rotations (99 to 119) (Table 6). It is well documented that mixtures of kura clover and grasses or small grains have higher forage quality than grass or cereal monocultures (Sleugh et al. 2000; Ross 2004b). The increase in feed value with the addition of the kura clover could compensate for the lower yields observed in the LM rotations.

Kura Clover Regrowth and Crude Protein

Kura clover grew following the silage harvest in both 2006 and 2007, with yields ranging from 0.6 to 1.4 Mg ha^{-1} (Table 7). Walker (2002) observed regrowth yields from late season kura clover harvests of 0.50 to 3.00 Mg ha^{-1}. Other trials in the United States documented kura clover regrowth yields ranging from 1.00 to 3.50 Mg ha^{-1} (Seguin et al. 2000). There were no significant differences in regrowth between the LM + B-B and SLM + B-B rotations, or between the LM + T-B and SLM + T-B rotations in 2006. In 2007, however, the LM + T-B rotation had significantly more kura regrowth than the SLM + T-B rotation (1.0 Mg ha^{-1} versus 0.8 Mg ha^{-1}, respectively).

The concentration of CP in the kura regrowth material ranged from 171 to 221 g kg^{-1} in 2006, and from 246 to 252 g kg^{-1} in 2007 (Table 7). CP concentrations were not significantly different among the LM and SLM rotations in either year. The CP values obtained in our experiment generally agree with those found in the literature (Sheaffer and Marten 1991; Sleugh et al. 2000; Singer and Moore 2010). Based on previously documented ADF and NDF values for kura clover from Contreras-Govea et al. (2006), projected RFVs for this regrowth material would range from 210 to 293. Thus, the regrowth supplied by the kura clover LM has the potential to produce high quality feed for livestock.

CONCLUSION

The presence of a kura clover LM reduced cereal silage yield, but increased the nutrient value of the silage, while reducing weed pressure and disease incidence. The kura clover LM decreased weed density during the growing season and weed biomass at crop maturity. Chemical suppression of the kura clover reduced its ability to compete with weeds at the four-leaf cereal stage. However, this difference disappeared later in the growing season. The kura clover LM also reduced the development of barley leaf disease lesions at the five-leaf cereal stage, and the proportion of penultimate and flag leaves infected at harvest. Both the LM and SLM provided season-long disease control, a benefit similar to that provided by crop rotation.

The kura clover LM did not have a positive effect on silage yield. With or without chemical suppression, the rotations containing kura clover had lower silage yields than the cereal monoculture rotations. This was due to a lower cereal contribution to silage yield in the presence

Table 7. Kura clover fall regrowth yield (on a dry matter basis) averaged across all soil nitrogen level treatments grown in 2006 and 2007 at Edmonton and Lacombe, AB, Canada, and regrowth crude protein (CP) averaged across all soil nitrogen level treatments in 2006 and 2007 at Lacombe, AB, Canada

	Regrowth yield		Crude protein[z]	
Subplot rotation treatment	2006	2007	2006	2007
	---------- ($Mg\ ha^{-1}$)	----------	---------- ($g\ kg^{-1}$)	----------
Barley-barley (B-B)	–[y]	–	–	–
Triticale-barley (T-B)	–	–	–	–
Living mulch + barley-barley (LM + B-B)	1.4	1.0	183	250
Living mulch + triticale-barley (LM + T-B)	0.7	1.0	171	252
Suppressed living mulch + barley-barley (SLM + B-B)	1.2	0.9	192	247
Suppressed living mulch + triticale-barley (SLM + T-B)	0.6	0.8	221	246
ANOVA				
Nitrogen F-test (df = 2)	NS	NS	NS	NS
SE[x] nitrogen	0.06	0.12	33.09	12.19
Rotation F-test (df = 5)	***	*	NS	NS
SE rotation	0.06	0.07	38.21	9.73
N × R (df = 17)	NS	NS	NS	NS
Contrasts				
LM + B-B vs. SLM + B-B	NS	NS	NS	NS
LM + T-B vs. SLM + T-B	NS	*	NS	NS

[z]Crude protein concentration determined from regrowth material at Lacombe, AB only.
[y]Data not collected from the treatment.
[x]Standard error of the difference of two least-squares means.
*, **, *** Significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$ probability levels, respectively.
NS, not significantly different at $P < 0.05$.

of a highly competitive clover in the LM, and an inadequate level of herbicide suppression in the SLM plots. Silage quality increased with the addition of the kura clover LM. Crude protein concentration was higher, and fibre concentrations lower, in the LM and SLM rotations. The decrease in silage DM could be offset by the higher silage quality and by the addition of kura clover regrowth, which could be used as livestock feed.

Kura clover LMs could be utilized in Alberta to increase the sustainability of current cereal silage production systems. With the kura clover providing season-long weed control, herbicide applications could be reduced. Yield losses due to cereal leaf diseases could also be lowered. Our research suggests that a suitable target silage species composition would be approximately 50% cereal and 50% kura clover, as seen in the SLM + T-B rotation in 2006. With this species mix, yield reductions still occurred compared with the cereal monocultures, but the cereal-legume silage had a higher RFV than the cereal silage.

More effective methods of kura clover suppression should be investigated. Increasing the rate of glyphosate applied, or a combination of mechanical and chemical suppression may be more effective in suppressing kura clover to allow for increased cereal growth and higher silage DM yields. Alternatively, a selective in-crop herbicide phytotoxic to kura clover may provide an additional opportunity to suppress the clover. Further studies on the competition dynamics between the kura clover LM and cereal plants should be conducted in order to better understand the impact kura clover has on the growth and development of the cereal plants.

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