Corn Production with Kura Clover as a Living Mulch

Robert A. Zemenchik, Kenneth A. Albrecht,* Chris M. Boerboom, and Joseph G. Lauer

ABSTRACT

Cropping systems that improve soil conservation are needed for mixed grain and forage enterprises in the upper Midwest. Our objective was to determine whether established kura clover (*Trifolium ambiguum* M. Bieb.) stands could serve as a living mulch for no-till corn (*Zea mays* L.) production, followed by a return to clover without replanting. Treatments included corn sown into established kura clover that was: (1) killed and sidedressed with N, (2) killed, (3) band-killed, leaving 15 cm of untreated kura clover between rows, (4) suppressed and sidedressed with N, and (5) suppressed and (6) untreated kura clover without corn. Corn whole-plant yield in 1996 ranged from 14.0 to 15.7 Mg ha^{-1} and was greatest in Treatments 2 and 4 and least in Treatment 5. Corn whole-plant yield in 1997 ranged from 9.5 to16.9 Mg ha^{-1} and was greatest in Treatments 1 and 2 and least in Treatment 5. Grain yields in 1996 were not different among treatments, while in 1997 yields ranged from 7.2 to 11.1 Mg ha^{-1} and were greatest in Treatments 1 and 2 and least in Treatment 5. Clover yield in 1997 following 1996 corn production was greatest in the untreated control, but there was no clover yield difference in 1998 following either 1996 or 1997 corn production. Kura clover can be managed as a living mulch in corn with little or no corn whole-plant or grain yield reduction and clover will recover to full production within 12 mo without replanting.

Alfalfa–corn rotations occupy approximately 2.4 million ha of Wisconsin cropland (Wisconsin Dep. of Agriculture, Trade, and Consumer Protection, 1997). Conservation tillage systems (i.e., where residue provides at least 30% ground cover) in these rotations lower the risk for soil erosion, particularly during crop establishment (Wollenhaupt et al., 1995); yet, as recently as 1995, only 14.5% of Wisconsin's 1.6 million ha of forages were established using such systems (Conservation Technology Information Center, 1995). Tillage incorporates beneficial crop residue and exposes soil aggregates to direct impact from rainfall. Crop residue and living plants reduce soil erosion in the rotation by intercepting rainfall and limiting sediment detachment, surface sealing, and sediment transport in runoff (Gallagher et al., 1996; Wollenhaupt et al., 1995; Zemenchik et al., 1996). Zemenchik et al. (1997) illustrated that once alfalfa is established, the risk for soil erosion is much less than at any other time in the rotation. Extending the soil-conserving characteristics of established perennial forages throughout a rotation with corn would greatly improve soil conservation.

Living mulches are plants intercropped with a cash crop that can decrease erosion (Wall et al., 1991), suppress weeds (Enache and Ilnicki, 1990), reduce insect pests (Litsinger and Moody, 1976), and in the case of legumes, supply N (Scott et al., 1987). Many studies in the North Central USA on legume interseeding in established corn stands report grain yield losses that are attributed to moisture stress (Kurtz et al., 1952; Pendleton et al., 1957), N deficiency (Scott et al., 1987; Triplett, 1962), and reduced corn populations associated with wider row spacing (Schaller and Larson, 1955; Stringfield and Thatcher, 1951). Living mulch systems have also been evaluated where existing forage is managed with herbicides to allow corn production. Corn yields in such systems were equal to or greater than those in conventional corn production, but these systems were evaluated in the northeastern states, where seasonal precipitation is higher than in the Midwest (Enache and Ilnicki, 1990; Mayer and Hartwig, 1986). Similar results in the North Central states have not been achieved consistently, primarily because of the continued problem of competition for water, and to a lesser extent, light and nutrients (Eberlein et al., 1992; Echtenkamp and Moomaw, 1989).

Kura clover is a long-lived, perennial, rhizomatous legume (Bryant, 1974; Speer and Allinson, 1985; Taylor and Smith, 1998) that tolerates frequent defoliation in monoculture (Peterson et al., 1994) or in binary mixture with grass (Kim, 1996) and is suitable for hay or pasture production in this region (Sheaffer et al., 1992). Kura clover is adapted to long, cold winters (Sheaffer and Marten; 1991) and has already persisted for 9 yr in binary mixture with Kentucky bluegrass (*Poa pratensis* L.), smooth bromegrass (*Bromus inermis* Leyss.), or orchardgrass (*Dactylis glomerata* L.) when defoliated from three to five times annually to either a 4- or 10-cm cutting height (Zemenchik, 1998).

Characteristics of kura clover should allow it to be used successfully as a living mulch in corn. Subjecting kura clover to herbicide suppression before corn planting will allow a substantial portion of roots, rhizomes, petioles, and leaflets to be mineralized and provide inorganic N for corn. Kura clover does not produce abundant dry matter during dry periods of the growing season (K.A. Albrecht, unpublished data, 1999) and should therefore compete less than other perennial legumes with corn for limited resources, especially water. Its persistence may allow use of herbicides for vegetative control during the corn year so that interspecific competition will be limited. Kura clover left in the field after an autumn corn-silage harvest may provide substantial winter and spring ground cover to protect the soil. In addition, kura clover could provide protein to supplement corn stover when grazed following grain harvest. Viable meristematic tissue remaining on the rhizomes

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Abbreviations: ADF, acid-detergent fiber; CP, crude protein; GDU, growing degree units; GLM, general linear model; NDF, neutral-detergent fiber.

may allow recovery of kura clover to full production following corn harvest.

This experiment was conducted to determine whether established stands of kura clover that are suppressed or band-killed with herbicides can allow for a year of no-till corn production, followed by a return to kura clover production without replanting.

MATERIALS AND METHODS

This experiment was conducted at the University of Wisconsin Lancaster Agricultural Research Station (42°50′ N, 90°47′ W; elev. 325 m) on Rozetta silt loam soil (gently sloping, fine-silty, mixed, superactive, mesic, Typic Hapludalf). The site was occupied by a monoculture stand of 'Rhizo' kura clover that was established in the spring of 1994 by direct-seeding at 15.7 kg ha^{-1}. Kura seed was inoculated with a commercially available three-strain mixture of *Rhizobium* spp. (Liphatech, Milwaukee, WI) specific to kura clover. Annual grass and broadleaf weeds were controlled during kura clover establishment by using EPTC (*S*-ethyl dipropylcarbamothioate) applied preplant incorporated at 2.14 kg a.i. ha^{-1}. Grass weeds were controlled in established kura clover in 1994 and 1995 by using sethoxydim (2-[1(ethoxyimino)butyl]-5-[2-ethylthio)-propyl]-3-hydroxy-2-cyclohexen-1-one) at 0.27 kg a.i. ha^{-1} along with a nonionic surfactant mixed at 2.5 mL L^{-1}. Kura clover was harvested for hay once in 1994 and twice in 1995. Soil P, K, and pH levels were maintained as for alfalfa based on soil test recommendations (Kelling et al., 1991).

Kura clover was 6 to 8 cm tall and covered approximately 75% of the soil surface at corn planting and when initial herbicide treatments were imposed. Field corn hybrid 'DeKalb 493' was planted no-till on 14 May 1996; field corn hybrid 'Northrup King N4242-Bt' was planted no-till on 30 Apr. 1997. An air-delivery no-till planter (Model 6104, White Manufacturing, Coldwater, OH) was used to plant corn in both years on a 76-cm row spacing at 79 000 seeds ha^{-1}. The planter was equipped with a notched coulter positioned directly in front of the seed disc openers, and unit-mounted, notched-disc row cleaners (Martin and Co., Elkton, KY). Macronutrients in the starter fertilizer were applied with the planter and placed 5 cm to the side and 2 cm below the seed at a rate of 9.9, 17.4, and 17.4 kg ha^{-1} of N, P, and K, respectively. Corn seed insecticide treatment in both years consisted of carboxin (5,6-dihydro-2-methyl-*N*-phenyl-1,4-oxathiin-3-carboxamide), diazinon (*O*,*O*-diethyl *O*-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate), and lindane (γ-1,2,3,4,5,6-hexachloro-cyclohexane).

The experiment was arranged in a randomized complete block design with four replications in 1996 and was repeated on an adjacent set of plots in 1997. Plot dimensions in 1996 were 3.6 by 9.1 m (four corn rows) and in 1997 were 5.5 by 9.1 m (six corn rows). Treatments included corn planted into an established kura clover stand that was: (1) killed with glyphosate [*N*-(phosphonomethyl)glycine] at 3.4 kg a.e. ha^{-1} and sidedressed with 45 kg N ha^{-1}; (2) the same as (1), but without N; (3) band-killed with glyphosate applied at 4.0 kg a.e. ha^{-1} in 61-cm strips centered on the corn row, leaving 15 cm of untreated kura clover between rows; (4) suppressed with glyphosate at 1.7 kg a.e. ha^{-1} and sidedressed with 45 kg N ha^{-1}; and (5) the same as (4), but without N. We also included a control treatment of kura clover without corn in each replicate with dimensions of 7.3 by 9.1 m.

Metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] was applied preemergence to all treatments at 2.2 kg a.i. ha^{-1} to control annual grass weeds. Similarly, herbicides were applied postemergence to control broadleaf weeds and provide additional suppression or control of kura clover. In Treatments 1 and 2, dicamba (3,6-dichloro-*o*-anisic acid) was broadcast-applied at 0.6 kg a.e. ha^{-1}; in Treatment 3, dicamba was band-applied in the same manner as glyphosate at 0.7 kg a.e. ha^{-1}; and in Treatments 4 and 5, bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) was broadcast-applied at 0.4 kg a.i. ha^{-1}.

Gravimetric soil moisture and soil nitrate concentration were measured in samples taken every 2 wk from the time of corn planting until corn grain harvest. Soil sampling near corn rows early in the growing season was not done so as to prevent collection of starter fertilizer. Soil sampling was not conducted between the center pair of corn rows of each plot in order to reduce foot traffic that might damage kura clover plants and affect experimental results. Soil samples in the band-killed treatment were not taken from within the 15 cm of untreated kura clover. Gravimetric soil moisture in each plot at each date was determined by collecting four otherwise random soil samples with a 1.3-cm (inner diam.) soil probe from depths of 0 to 22.5 cm and from 22.5 to 45 cm, which corresponded approximately to the A and Bt_1 horizons of this soil. Samples of field-moist soil in all treatments were composited for each sampling depth, and a subsample of approximately 0.2 kg was oven-dried at 105°C for 24 h to calculate gravimetric moisture content. The remainder of the sampled soil from both depths was combined, and approximately 0.2 kg was retained in a cooled container. This soil was subsequently analyzed in the laboratory using a 2 mol L^{-1} KCl extraction followed by colorimetric procedures for nitrate-N concentration (Keeney and Nelson, 1982) using injection flow analysis (Lachat Instruments).

Whole-plant corn at approximately 40% milk line (typical maturity stage for silage) was hand-harvested on 10 Sept. 1996 and 15 Sept. 1997. Corn was harvested in both years at a 15-cm cutting height from the center 7.6 m of an appropriately bordered 9.1-m-long row randomly chosen from within each plot. Harvested corn was then mechanically chopped to a 1-cm particle size using commercially available equipment. From this chopped material, four to six subsamples totaling approximately 1.5 kg wet weight were collected by hand and oven-dried at 60°C for 4 d to determine yield on a dry-weight basis. This material was ground with a Thomas-Wiley mill (A.H. Thomas Co., Philadelphia, PA) to pass a 4.0-mm screen, reduced in volume by 75% using a sample splitter, then reground to pass a 1.0-mm screen for subsequent laboratory analysis.

Corn grain was harvested on 17 Oct. 1996 and 10 Oct. 1997. Corn grain yield was determined by hand-collecting corn ears at physiological maturity from the center 7.6 m of another appropriately bordered row and then passing the ears through a stationary small-plot corn sheller. Corn grain yields were adjusted to a moisture concentration of 155 g kg^{-1}. Corn populations at grain harvest were determined by counting and recording the number of plants harvested within each plot.

Aboveground kura clover biomass was measured in Treatments 1 through 5 at corn tasseling and at corn physiological maturity in order to obtain an estimate of competition. Living vegetation was hand-harvested from two 0.3- by 0.76-m quadrats in each plot. This vegetation was oven-dried at 60°C for 4 d to determine yield on a dry-weight basis.

Kura clover yields in living mulch treatments and in the untreated kura clover treatment were determined for 2 yr following 1996 corn production and for 1 yr following 1997 corn production. Forage yield was measured by harvesting 0.6-m-wide by 9.1-m-long strips to a height of 10 cm with a rotary mower equipped with a collection cage. Strips in living

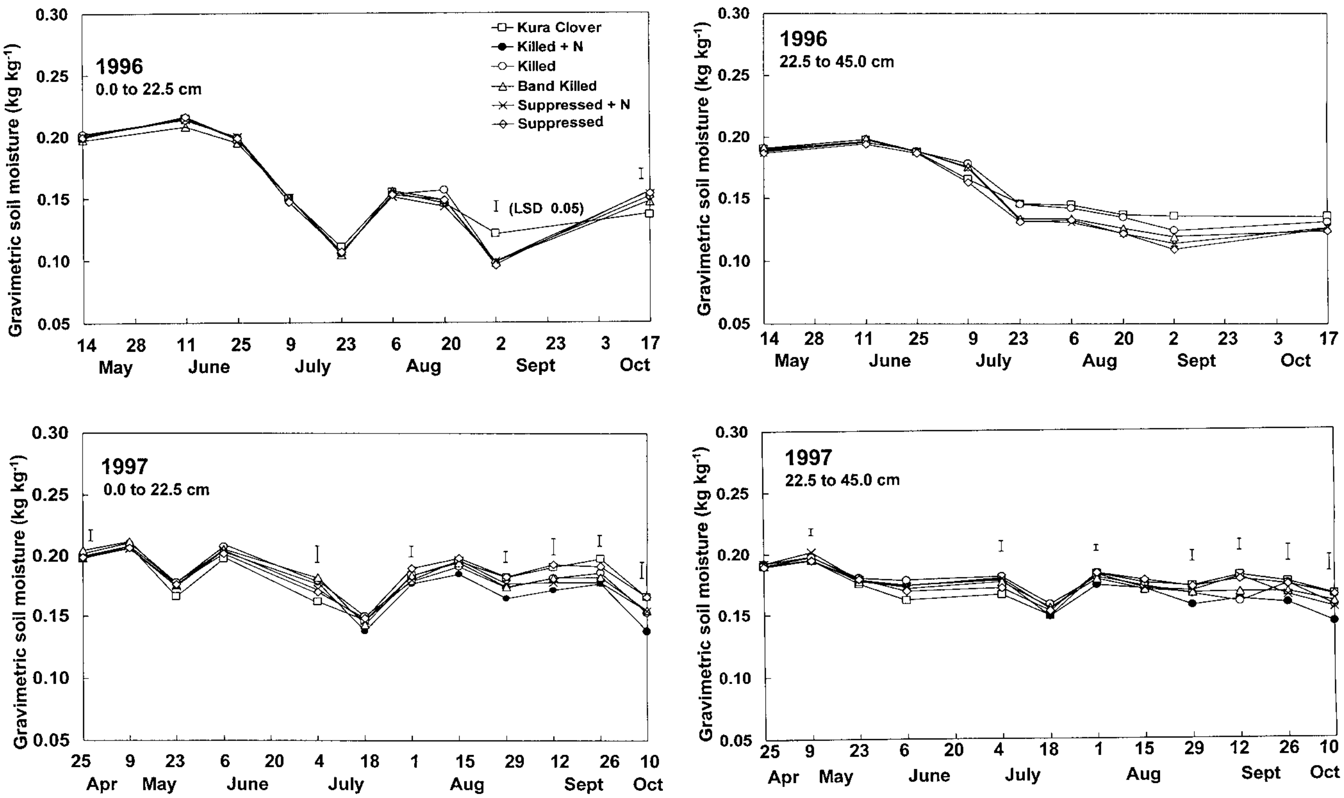

Fig. 1. Gravimetric soil moisture content from 0.0 to 0.25 cm and from 22.5 to 45 cm in Rozetta silt loam soil in all treatments during the 1996 and 1997 growing seasons near Lancaster, WI.

mulch treatments were located between the center pair of corn rows within each plot and were harvested on 10 June, 15 July, and 30 August. Width of the harvest area was increased to 0.76 m in the band-killed treatment to account for nonuniform kura clover regrowth between corn rows. The untreated kura clover was harvested on 3 June, 15 July, and 30 August. A 0.5-kg subsample of material from each plot at each harvest was collected and oven-dried at 60°C for 4 d to determine forage yield on a dry-weight basis. Two individuals independently made visual estimates of the weed proportion of standing forage in each plot just before harvest, and an average value was computed.

Ground samples of whole-plant corn and kura clover regrowth following the year of corn production were analyzed in the laboratory to obtain estimates of forage quality. Neutral-detergent fiber (NDF) and acid-detergent fiber (ADF) concentrations were determined by the method of Robertson and Van Soest (1981), with modifications. Modifications included a reduction in sample size to 0.5 g and treating the samples with 0.1 mL of α-amylase (no. A1064; Sigma Chemical, St. Louis) during refluxing in neutral-detergent solution and again during sample filtration (Hintz et al., 1996). Kjeldahl N was determined using the semimicro-Kjeldahl procedure of Bremner and Breitenbeck (1983), with the salicylic acid modification of Bremner (1965) for the recovery of nitrate. Kjeldahl N was multiplied by 6.25 to estimate crude protein (CP) concentration. Season means were computed and weighted to reflect the contribution of each harvest to annual plot yields.

Analysis of variance procedures using the GLM procedure of SAS (SAS Inst., 1990) at $P = 0.05$ were used to test the effects of year, treatment, and treatment × year interactions for all measurements except gravimetric soil moisture and soil nitrate concentration. These repeated soil measures were modeled using the PROC MIXED statement of SAS (SAS Inst., 1990) with the ar(1) variance structure. Corn population was also tested as a covariate in the corn whole-plant and grain yield models. Separation of treatment means was performed in all models using Fisher's protected *F*-test ($P = 0.05$).

RESULTS AND DISCUSSION

Corn Whole-Plant and Grain Yield

A treatment × year interaction in the corn whole-plant and grain yield models required that 1996 and 1997 be analyzed separately. Growing conditions in early 1996 were more conducive to corn growth than in early 1997 for all living-mulch treatments. These conditions include effective kura clover suppression, rapid onset of warm weather immediately after planting, adequate rainfall (Fig. 1), and abundant soil N (Fig. 2) from the time of planting until tasseling.

Corn whole-plant yield in 1996 ranged from 14.0 to 15.7 Mg ha^{-1} and was not different between treatments where kura clover was killed and where it was suppressed and the corn was fertilized with N (Table 1). Grain yield in 1996 ranged from 8.6 to 10.4 Mg ha^{-1} and was not different among treatments. It is significant to note that grain yield in the suppressed + N treatment was 10.3 Mg ha^{-1}, while in the killed treatment it was 10.4 Mg ha^{-1}. Meanwhile, corn whole-plant yield in 1996 in the suppressed + N treatment was 15.7 Mg ha^{-1}, while in the killed treatment it was 15.5 Mg ha^{-1}.

In contrast to 1996, corn whole-plant yield in 1997 ranged from 9.5 to 16.9 Mg ha^{-1} and was greatest in treatments where kura clover was killed and least where

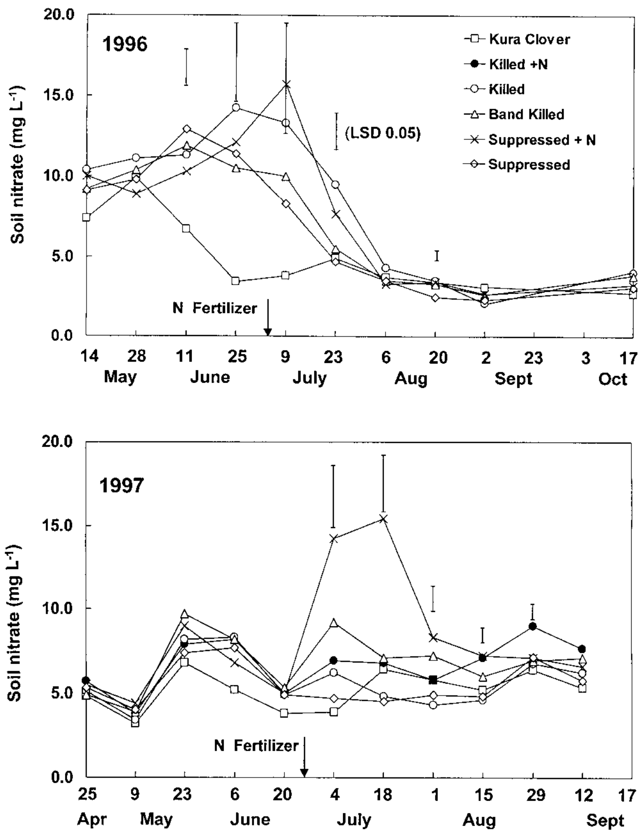

Fig. 2. Soil nitrate concentration from 0.0 to 45 cm in Rozetta silt loam soil in all treatments during the 1996 and 1997 growing seasons near Lancaster, WI.

it was only suppressed and given no N. Corn whole-plant yields in the band-killed, suppressed + N, and suppressed living mulch treatments in 1997 were 20, 17, and 41% less than the killed treatment, and 24, 20, and 44% less than the killed + N treatment, respectively. Corn grain yield in 1997 ranged from 7.2 to 11.1 Mg ha^{-1} and was greatest in both treatments where kura clover was killed, and least where it was suppressed and given no N. Corn grain yields in band-killed, suppressed + N, and suppressed living mulch treatments in 1997 were 15, 30, and 34% less than the killed treatment, and 16, 32, and 35% less than the killed + N treatment, respectively.

Unexpected cool temperatures impeded early corn growth in spring 1997. Cool conditions enabled kura clover, a C_3 species, to recover from suppression and obtain an early competitive advantage over corn, a C_4 species. Minimum daily temperatures measured during the first 18 d after corn planting averaged 10°C in 1996, compared with 3°C in 1997. In 1996, 119 growing degree units (GDU, base 10°C) had accumulated 15 d after planting, and 231 GDU had accumulated 30 d after planting. In 1997, only 41 GDU had accumulated 15 d after planting, with 107 GDU 30 d after planting. These conditions in early 1997 caused kura clover to impede corn seedling development, as corn plants in killed treatments were noticeably larger than in living mulch treatments. This was especially true for suppressed treatments where kura clover vegetation was in close proximity to corn rows. Physiological development of corn plants in the suppressed treatments appeared to be behind corn plants in the band-killed system throughout the growing season. Grain moisture content at harvest in 1997 was approximately 50 g kg^{-1} greater in the suppressed and suppressed + N treatments (data not shown), and some of the grain kernels near the base of corn ears in these two treatments had not reached black-layer. Grain moisture and maturity differences among treatments were not observed in 1996.

Reduced corn populations in living mulch treatments also contributed to lower corn yields with the living mulch treatments in 1997, but not in 1996. Corn population in 1997 was a significant covariate in the grain yield model, even after accounting for variance due to treatment within that year (Table 1). Without additional kura clover suppression in unusually cool springs, corn planting dates in living mulch systems may need to be delayed in this region. Similar problems were encountered by Fisher and Burrill (1993), who recommended season-long suppression through multiple herbicide or mechanical treatments in a white clover (*Trifolium repens* L.) sweet corn living mulch system.

Corn grain yield in the band-killed treatment was not significantly different from that of the killed treatment in either year. However, the trend was for the band-killed treatments to yield 14% less grain in either year. More consistent year-to-year grain yields occurred in the band-killed treatment than in the broadcast-suppressed treatments. Corn seedling vigor from emergence to the three-leaf growth stage appeared greater in the band-killed treatment. Based on field observations, we believe that not having competitive kura clover plants in close proximity to the corn in the band-killed treatments may have allowed for less competition

Table 1. Yield of whole corn-plant, corn grain, and corn populations in kura clover–corn living mulch systems near Lancaster, WI.

Kura treatment	Whole plant dry matter 1996	Whole plant dry matter 1997	Corn grain† 1996	Corn grain† 1997	Population density 1996	Population density 1997
	Mg ha^{-1}				plants ha^{-1}	
Killed + N	–	16.9a	–	11.1a	–	74 100ab
Killed	15.5ab‡	16.2a	10.4	10.9ab	61 500	70 000a
Band-killed	14.3bc	12.9b	9.0	9.3bc	58 000	65 200bc
Suppressed + N	15.7a	13.5b	10.3	7.6cd	60 800	54 800c
Suppressed	14.0c	9.5c	8.6	7.2d	60 000	53 100c
CV, %	6	8	12	13	8	13

† Corn grain yields are adjusted to a moisture content of 155 g kg^{-1}.
‡ Within columns, means followed by the same letter are not significantly different at $P = 0.05$ according to Fisher's protected LSD.

Table 2. Kura clover biomass at corn tasseling and at corn physiological maturity in living mulch systems near Lancaster, WI.

Kura treatment	Tasseling		Physiological maturity	
	1996	1997	1996	1997
	Mg ha^{-1}			
Killed + N	–	0.15b	–	0.20c
Killed	0.10b†	0.13b	0.05c	0.29bc
Band-killed	0.55a	1.08a	0.11bc	0.46ab
Suppressed + N	0.65a	0.94a	0.16ab	0.62a
Suppressed	0.73a	1.04a	0.18a	0.60a
CV, %	30	25	36	27

† Within columns, means followed by the same letter are not significantly different at $P = 0.05$ according to Fisher's protected LSD.

Table 3. Corn whole-plant N concentration and total corn N yield in a kura clover–corn living mulch system near Lancaster, WI.

Kura treatment	N concentration		N yield	
	1996	1997	1996	1997
Killed + N	–	11.6	–	196a
Killed	11.0†	11.6	170a	185a
Band-killed	10.0ab	12.0	142ab	155b
Suppressed + N	10.7a	11.5	167a	155b
Suppressed	9.0b	11.8	127b	113c
CV, %	8	5	12	6

† Within columns, means followed by the same letter are not significantly different at $P = 0.05$ according to Fisher's protected LSD.

through shading. This was particularly important in the spring of 1997, when conditions were cool and unfavorable for early corn growth. Corn whole-plant and grain yields in the band-killed treatment might be improved by sidedressing N, but that approach was not included in this study.

Corn Yield and Soil Nitrate-Nitrogen

Kura clover growth that occurred after 30 August the year before both corn plantings resulted in approximately 1.0 Mg ha^{-1} of total biomass and represented 40 kg N ha^{-1} when killed by frost (data not shown). It is not known how much of this N contributed to the soil nitrate pool present when corn was planted the following spring. Warmer spring air temperatures and a later planting date in 1996 resulted in greater net soil nitrate-N concentration (hereafter, soil N) at corn planting than in 1997. Soil N (Oberle and Keeney, 1990a; Oberle and Keeney, 1990b) and synchrony of corn N demand and N mineralization from soil organic N and legume tissues (Smith et al., 1992; Stute and Posner, 1995) greatly affect corn development and harvest yield. Soil N in all treatments in 1996 was approximately 10 mg kg^{-1} at corn planting (Fig. 1) and remained relatively constant until silking, when 70 to 75% of seasonal N is accumulated in corn (Richie et al., 1993). Optimal late-spring soil N required for maximum corn yield following either corn or soybean in Iowa was 23 to 26 mg kg^{-1} in the surface 30-cm layer of soil, and 16 to 19 mg kg^{-1} in the surface 60-cm layer of soil (Binford et al., 1992). However, research at Lancaster in a typical year showed that soil N in late spring in first-year corn following alfalfa averaged only 15 mg kg^{-1} in the top 45 cm layer of soil, and that there was no significant response in corn yield to sidedressed N (Bundy and Andraski, 1993).

Soil N was generally lower from planting until silking in 1997 than in 1996, and may be related to cooler temperatures and greater kura clover regrowth in the summer of 1997 (Fig. 2). Kura clover vegetation at tasseling in living mulch treatments in 1997 ranged from 0.94 to 1.08 Mg ha^{-1}, compared with in 1996, when it ranged from 0.55 to 0.73 Mg ha^{-1} (Table 2). As a result, we speculate that kura clover may have removed more soil inorganic N in 1997 than in 1996. Starter fertilizer probably compensated somewhat for adversely low soil N, especially in early 1997.

Soil N was not different among living mulch treatments at any time during 1996. However, soil N among living mulch treatments in 1997 was greatest in the suppressed + N treatment from the time of sidedressing to early grain-fill (Fig. 2). Soil N in both years was increased to approximately 15 mg kg^{-1} in the suppressed treatment immediately after fertilizer N was applied. Sidedressed N increased whole-plant corn yield of the broadcast suppressed + N treatment compared with the suppressed treatment by 12% in 1996 and by 42% in 1997, suggesting that N was limiting corn growth.

Utilization of soil N by corn was extensive in both years. Total N yield of whole-plant corn in the killed treatment in 1996 was 170 kg ha^{-1}, which was 20% greater than the band-killed treatment and 34% greater than the suppressed treatment (Table 3). Total N yield of whole-plant corn in the 1997 killed treatment was 185 kg ha^{-1}, which was 21% greater than the band-killed treatment and 66% greater than the suppressed treatment. There was no difference in corn whole-plant or grain yield between the killed and killed + N treatments in 1997. This suggests that kura clover in this rotation contributed enough N to the pool of soil N to satisfy all of the N requirements for first-year corn production in this environment. Similar results for alfalfa were also found for this soil type (Bundy and Andraski, 1993).

Minor delays in mineralization of legume N appear largely surmountable by corn if not accompanied by excessive competition from the associated living mulch. Stute and Posner (1995) reported that the effects of year on release of legume N was not significant when accumulated growing degree units were close to the 30-yr mean in Wisconsin. They also showed that very little legume N is released beyond 10 wk after corn planting.

Kura clover provides N during the vegetative and early reproductive growth phases of the corn plants. Decaying roots, rhizomes, nodules and top growth shortly after spraying are sources of N. In both years, most of the kura clover foliage developed early in the growing season in the living mulch treatments rapidly senesced and decomposed after suppression. There was little, if any, green kura clover foliage beneath the dense corn canopy until mid-August.

Soil Moisture

Soil moisture was not different among corn treatments at either the 0- to 22.5-cm or 22.5- to 45-cm sampling depth in either year (Fig. 1). This suggests that

Table 4. Kura clover yield in 1997 and 1998 following 1996 corn production, and kura clover yield in 1998 following 1997 corn production, from living mulch treatments near Lancaster, WI.

Kura treatment	Corn year	Forage year	Cut 1	Cut 2	Cut 3	Total
			Mg ha^{-1}			
Untreated kura	1996	1997	3.6a†	2.3	1.8	7.7
Band-killed	1996	1997	1.9b	2.2	2.3	6.4
Suppressed + N	1996	1997	1.7b	2.4	2.4	6.5
Suppressed	1996	1997	2.0b	2.1	2.1	6.2
Untreated kura	1996	1998	5.0	2.6	2.2	9.8
Band-killed	1996	1998	4.9	3.1	2.7	10.7
Suppressed + N	1996	1998	5.2	2.9	2.1	10.2
Suppressed	1996	1998	4.9	2.7	2.1	9.7
Untreated kura	1997	1998	4.8a	2.7	2.1b	9.6ab
Band-killed	1997	1998	3.8b	2.6	2.4ab	8.8b
Suppressed + N	1997	1998	4.7a	2.8	2.7a	10.2a
Suppressed	1997	1998	4.7a	2.8	2.2b	9.7a

† Within columns and corn-year/forage-year combinations, means followed by the same letter are not significantly different at $P = 0.05$ according to Fisher's protected LSD.

Table 5. Estimated percent weed content in 1997 and 1998 following 1996 corn production, and estimated percentage weed content in 1998 following 1997 corn production, from living mulch treatments near Lancaster, WI.

Kura treatment	Corn year	Forage year	Cut 1	Cut 2	Cut 3	Total
			% of total dry matter			
Untreated kura	1996	1997	24a†	4b	5c	13b‡
Band-killed	1996	1997	9b	25a	30a	22a
Suppressed + N	1996	1997	3c	12b	24ab	14b
Suppressed	1996	1997	4c	10b	17b	10b
Untreated kura	1996	1998	4a	31b	11b	13b
Band-killed	1996	1998	15a	46a	41a	31a
Suppressed + N	1996	1998	4b	32b	21b	15b
Suppressed	1996	1998	4b	33b	25b	17b
Untreated kura	1997	1998	4bc	10	6b	5b
Band-killed	1997	1998	5c	17	16a	12a
Suppressed + N	1997	1998	1a	11	11ab	6b
Suppressed	1997	1998	2ab	11	12ab	7b

† Within columns and corn-year/forage-year combinations, means followed by the same letter are not significantly different at $P = 0.05$ according to Fisher's protected LSD.
‡ Totals for each year are yield-weighted for each cutting.

additional moisture stress due to the remaining clover did not affect corn yield results as was reported for alfalfa living mulches with field corn (Eberlein et al., 1992) and white clover with sweet corn (Vrabel, 1983). Soil moisture at the greater sampling depth varied less between sampling times in all treatments, and was generally greater during very dry periods such as July 1996 and August of both years. For example, precipitation in July and August 1996 was 47 and 52% of normal, respectively. This resulted in gravimetric soil moisture as low as 0.10 kg kg^{-1} in the upper 22 cm of the soil profile (Fig. 2), which is near the permanent wilting point for this soil type (Schulte and Walsh, 1994). We speculate that corn plants continued to grow by accessing deeper moisture in the soil profile when little or none was available near the surface. No leaf rolling or wilting was seen in any of the treatments during the study. Greater kura clover biomass at tasseling in the 1997 living mulch treatments may have been a function not only of cooler spring temperatures, but also of the greater soil moisture present that year (Fig. 1).

Kura Clover Mulch and Recovery

Kura clover recovery from herbicide suppression and shading recommenced as corn plants matured during the ear-fill period and light availability improved. Increased late-season kura clover growth was observed during the corn ear-fill period. Significant fall growth was also possible because of reduced demand for soil moisture by the corn, as well as the ability of kura clover to fix N after corn had exhausted much of the soil N. At corn physiological maturity, kura clover biomass accumulation in living mulch treatments ranged from 20 to 58% less than that measured at tasseling (Table 2). Despite available resources, kura clover has a similar growth habit to other clovers in that much of its dry matter is produced earlier in the year (Zemenchik, 1998). Rhizome growth observed late in the season allowed kura clover to spread into the open areas of the band-killed treatment.

Corn requires less soil nutrients (Richie et al., 1993) and light as it matures, late in the growing season. Without kura clover, nutrients and light penetrating through the maturing corn canopy might have remained underutilized or fostered weed growth. Kura clover and corn in the living mulch systems were more compatible after tasseling because the species differed greatly in stature and corn had sequestered much of the resources necessary to complete its life cycle. This ecological differentiation is the necessary condition for coexistence according to the competitive exclusion principle (Hardin, 1960), and was made possible by effective early-season treatment of kura clover in favor of corn.

Kura clover in all treatments continued to grow after silage or grain was harvested until hard frosts occurred in late autumn. Late summer and autumn kura clover growth in the living mulch treatments provided a potential high-protein forage source to supplement rations of cattle grazing corn stover. Additionally, excellent winter ground cover was available and was estimated to cover at least 60% of the soil surface. This cover lasted until spring, when decomposition coincided with newly emerged growth.

Kura clover forage production in 1997 following 1996 corn production ranged from 6.2 to 7.7 Mg ha^{-1} for three harvests and was greatest in the untreated kura clover in the first harvest (Table 4). Yields were not different among treatments in the second or third harvests of that year. Dandelion (*Taraxacum officinale* Weber ex F.H. Wigg. group) was the predominant weed in the first harvest of untreated kura clover (Table 5). Kura clover yield was not different between the untreated and the broadcast treatments in 1998 following 1997 or 1996 corn production (Table 4). However, kura clover yield in 1998 following the 1997 band-killed treatment was significantly less than kura clover in all other treatments except the untreated control. Kura clover rhizome expansion into the band-killed areas was incomplete, and some bare soil surface areas were observed during the first harvest.

Annual weeds such as yellow foxtail [*Setaria glauca* (L.) P. Beauv.] in the second and third harvests of the band-killed and suppressed + N living mulch treatments

Table 6. Mean laboratory estimates of forage quality of kura clover in 1997 and 1998 following 1996 corn production, and in 1998 following 1997 corn production, from living mulch treatments near Lancaster, WI.

Kura treatment	Corn year	Forage year	Constituent
			g kg^{-1}
ADF			
Untreated kura	1996	1997	202b†‡
Band-killed	1996	1997	223a
Suppressed + N	1996	1997	215ab
Suppressed	1996	1997	208b
Untreated kura	1996	1998	253
Band-killed	1996	1998	252
Suppressed + N	1996	1998	240
Suppressed	1996	1998	244
Untreated kura	1997	1998	235
Band-killed	1997	1998	244
Suppressed + N	1997	1998	239
Suppressed	1997	1998	239
NDF			
Untreated kura	1996	1997	303c
Band-killed	1996	1997	364a
Suppressed + N	1996	1997	338ab
Suppressed	1996	1997	329bc
Untreated kura	1996	1998	324b
Band-killed	1996	1998	364a
Suppressed + N	1996	1998	329b
Suppressed	1996	1998	340ab
Untreated kura	1997	1998	318b
Band-killed	1997	1998	342a
Suppressed + N	1997	1998	331ab
Suppressed	1997	1998	320b
CP			
Untreated kura	1996	1997	222
Band-killed	1996	1997	196
Suppressed + N	1996	1997	215
Suppressed	1996	1997	216
Untreated kura	1996	1998	227a
Band-killed	1996	1998	202b
Suppressed + N	1996	1998	218ab
Suppressed	1996	1998	217ab
Untreated kura	1997	1998	238a
Band-killed	1997	1998	220b
Suppressed + N	1997	1998	232a
Suppressed	1997	1998	235a

† Within corn-year/forage-year combinations, means followed by the same letter are not significantly different at $P = 0.05$ according to Fisher's protected LSD.
‡ Means for acid-detergent fiber (ADF), neutral-detergent fiber (NDF), and crude protein (CP) concentrations correspond to annual yield-weighted averages in a three-harvest system.

contributed to sward yields in 1997 following 1996 corn production (Table 5), and also increased fiber concentrations (Table 6). Forage ADF concentrations in 1997 were not different among treatments within harvests, but for the entire year the concentration was greatest in the band-killed treatment (Table 6). Meanwhile, second-harvest NDF concentrations were least in the untreated kura clover and greatest in the band-killed and suppressed + N treatment for the entire year. A similar result occurred in the band-killed treatment in 1998 following 1997 corn production, where NDF concentrations were again increased by annual grass weeds.

No herbicide or cultural controls were attempted after the living mulch treatments since we wanted to assess differences in weed pressure and recovering kura clover growth among treatments. Even though differences in forage quality measures caused by weeds were exhibited among treatments in 1997 and 1998, all values would be considered excellent for lactating dairy cattle (*Bos taurus*). More importantly, weeds competed with foliage from expanding kura clover rhizomes and may have impeded rapid, complete stand recovery. Annual weeds were a problem in the living mulch treatments when more than 80% of the kura clover biomass was controlled to facilitate corn production. Weeds comprised as much as 13% of the estimated biomass in the untreated kura clover in 1997 and 1998, suggesting that weed invasion might be problematic for monoculture kura clover even without undergoing a year as a living mulch.

CONCLUSIONS

The data show that with adequate suppression, kura clover can be managed as a living mulch in corn with little or no corn whole-plant or grain yield reduction and will recover to full production within 12 mo without replanting. Close monitoring and careful control of kura clover competition is required to maintain high corn yields in this system. There is a greater risk for corn yield loss associated with very early planting dates, because established kura clover is less inhibited by cool weather than newly planted corn and could obtain a competitive advantage. In particularly cool springs, subsequent suppression of kura clover may be needed in order to prevent delayed corn seedling development that may arise if legume growth proliferates. Band-kill strategies were less risky and more consistent than broadcast suppressed strategies in terms of corn population and yield, but more research is needed to determine optimum planting dates and whether a significant corn yield response to sidedressed N would occur.

Although there are still many management questions to be investigated, we believe that a kura clover–living mulch system could be largely N self-sufficient, leave less opportunity for weed invasion, result in year-round ground cover, require less tillage, and reduce soil erosion. The system may be applicable anywhere alfalfa–corn rotations are now used and where slope and soil erosion is a problem.

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