Water balance and nitrate leaching under corn in kura clover living mulch

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In the midwestern United States, corn production is a dominant land use. In 2008, approximately 37 million acres of corn were planted in Illinois, Iowa, Minnesota, and Wisconsin, accounting for 46% of all cropland in those states. Corn yields in the region are high and increasing due to good soils and climate, improved hybrids, and expert management. These yields also support large industries such as livestock production and, increasingly, ethanol production. Corn-based cropping systems make this one of the most verdant agricultural regions in the world, for a few months each year.

For the remainder of the year, however, fields are dormant, solar radiation is not captured for photosynthesis, soil organic carbon is lost to respiration, the soil surface is relatively unprotected, and nutrient-rich soil water is prone to leach out of the root zone. These problems are exacerbated when corn is harvested for silage or if stover is harvested for biofuel production or livestock feed. The resulting negative off-site impacts on groundwater, surface water, and atmospheric greenhouse gas concentrations are major environmental concerns. The agricultural systems of the region, to meet global resource needs and to be sustainable, must undergo a process of biological intensification.

Biological intensification is the process of intentionally increasing the number of complementary species in an agricultural system. It is pursued to: (i) increase agricultural productivity per unit of land area, (ii) conserve and improve the soil, and (iii) create positive off-site impacts on water quality and greenhouse gas concentrations.

Living mulches may provide one path to effective biological intensification of agriculture. A living mulch is a cover crop grown with a main crop and maintained as a living ground cover throughout the growing season. Living mulches can reduce soil erosion and pesticide transport, improve soil quality, and promote biological control ▶

▶ **Corn grown in kura clover living mulch.**

of weeds and insect pests. Leguminous living mulches can also supply a portion of the N needs of a cereal crop through biological N fixation. Studies further suggest that living mulches can reduce nitrate leaching significantly under cereal crops, but no data are available to quantify the effects of leguminous living mulches on nitrate leaching.

Kura clover is a perennial, rhizomatous legume that is well suited as a living mulch for corn production in the midwestern United States. Some studies in the region have found that kura clover can provide year-round soil protection with little or no reduction in corn yield. Kura clover is also compatible with other annual grass species for forage production. Binary mixtures of kura clover with winter wheat and winter rye, for example, have produced similar yields to monocultures of the grasses while producing forage of higher nutritive value.

One of the primary challenges with living mulch cropping systems is competition for water between the main crop and the living mulch. Research in Illinois and Minnesota has documented yield reductions from living mulches of 20 to 29%, on average, for nonirrigated corn, with smaller or no yield reductions for irrigated corn. Despite these indications of water limitations, little is known about soil water balance under living mulches.

The general objective of a recent study in the *Agronomy Journal* was to learn whether corn grown in kura clover living mulch is a viable option for biological intensification of agriculture in the midwestern United States. The specific objective of this research was to determine the impact of a kura clover living mulch on the water balance and nitrate leaching under corn near Arlington, WI.

Field conditions

Field studies were conducted from April 2006 through November 2008 at a research station near Arlington, WI. Kura clover (experimental line KTA202) was established in the plot area in spring 2004 and mechanically harvested three times per season in the two years before this experiment was initiated. The experiment was a randomized complete block design with four replications. The control was corn following a perennial legume (i.e., kura clover) and is comparable to corn following alfalfa, a common cropping system supporting dairy and beef production in the midwestern United States. The control was managed for no-till corn production with a nonlimiting N supply. Living mulch treatments were corn grown in herbicide-suppressed (glyphosate and dicamba) kura clover with five fertilizer N rates ranging from 0 to 80 lb/ac. The 0 and 80 lb/ac N rates were selected for soil water and N measurements because resources were limited, and these rates were likely to produce the lowest and highest levels, respectively, of N leaching under the living mulch in this study.

The experiment was marked by above-average precipitation in general. In fact, the period from December 2007 through May 2008 was the second wettest on record for the upper Mississippi River basin. However, April through July was dry in 2007 with cumulative precipitation 28% below the 30-year average. Also, July through September was dry in 2008 with cumulative precipitation 30% below average.

Corn yields

Whole-plant corn (as for silage) was hand-harvested at about 50% kernel milk-line, typically in mid-September. Grain yields were determined by hand harvest in October each year. Corn grain yield was adjusted to 15.5% moisture content. After grain harvest, all remaining corn was cut at about a 6-inch stubble height, and the cut plants were removed from the field, simulating silage harvest or stover harvest.

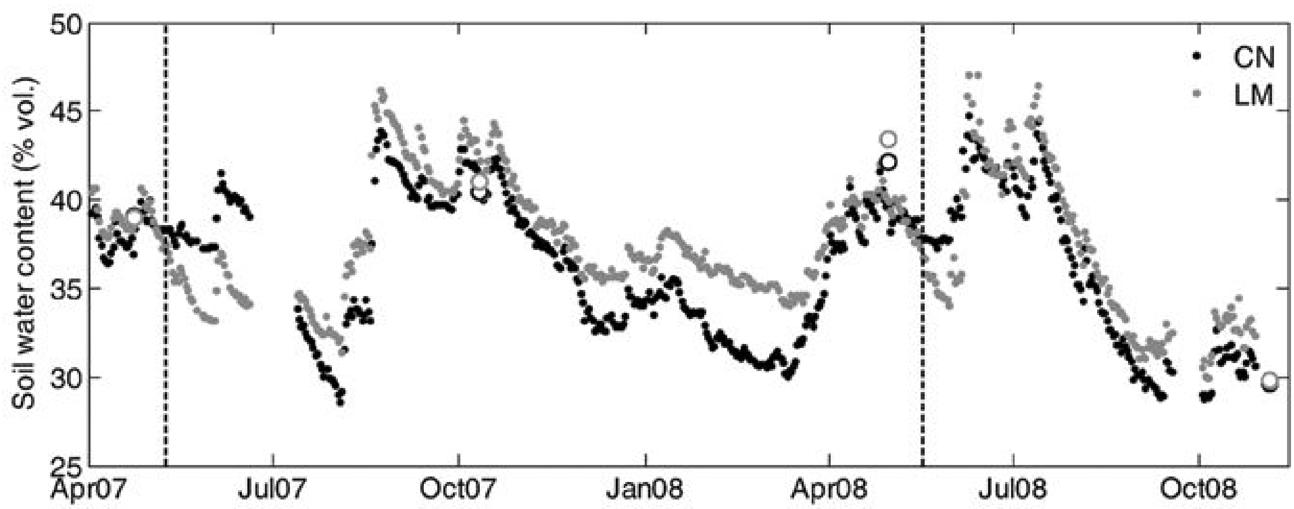


Fig. 1. Average time domain reflectometry (TDR) measured liquid soil water content to 3-ft depth under control (CN) and living mulch (LM). Open circles represent direct measurements of soil water content from soil sampling. Dashed vertical lines at May 9, 2007 and May 17, 2008 mark the beginning of spring soil water depletion by the living mulch.

The control produced high yields of both whole-plant dry matter (8.0 to 9.8 tons/ac) and grain (6.2 to 6.8 tons/ac). Yields were generally lower in the living mulch treatments than in the control. Specifically, for the living mulch receiving 80 lb/ac N annually, yields were reduced 14% on average relative to the control. Whole-plant and grain yields in this treatment were lowest in 2007; water stress resulting from the April through July dry period is a likely explanation. For the living mulch with no added N, the average yield reduction relative to the control was 30%.

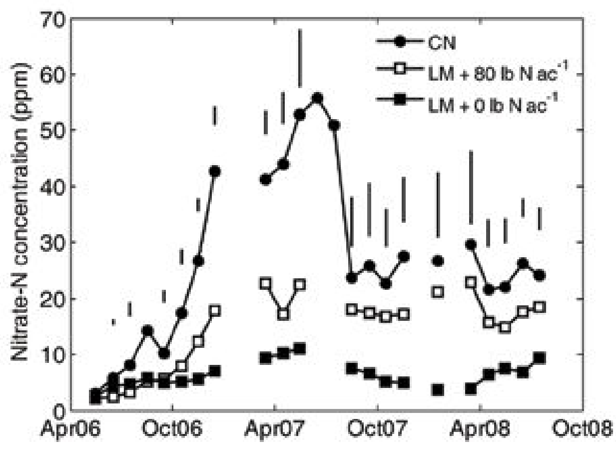
Soil water content

Soil water storage to 3 ft in depth was monitored daily by time domain reflectometry (TDR) sensors in one replication of the control and the living mulch receiving 80 lb/ac N. The TDR waveforms were then processed and used to estimate soil water content during the course of the experiment (Fig. 1). In addition, one tensiometer was installed in each plot to 3 ft in depth to provide supplemental data about soil moisture status. Tensiometer readings were recorded every two weeks when the soil was not frozen.

Averaged across all three years, the soil water content to 3 ft in depth was 40% by volume at the beginning of the growing season for both the control and the living mulch. Thus, both the control and the living mulch treatments entered the growing seasons at "field capacity" with no soil water deficit carried over from the prior year.

In 2007, greater early growing season transpiration led to lower soil water contents in the living mulch relative to the control beginning on May 9 (Fig. 1). The largest measured deficit was 2 inches on June 19. In May 2008, the living mulch also depleted soil water content beginning about May 17, reaching a maximum soil water deficit of 1.5 inches less than the control on May 30. Unlike in 2007, however, these effects were soon negated by heavy rain in June. Overall, the TDR and tensiometer data suggest that the living mulch increases the probability of corn experiencing water stress, especially when the late spring is drier than average. The magnitude of the increased risk remains to be quantified and will likely be site specific.

Later in the growing season, at the time of maximum soil water depletion, soil water content was lower under the control. This was evident in both 2007 (1.4-inch difference on August 3) and 2008 (1.1-inch difference on September 12). At these times, the corn canopies were dense, and transpiration by the corn likely accounted for most of the water depletion. Thus, the researchers hypothesized that the living mulch reduced or delayed the development of the corn root system to some extent, thereby reducing the corn's ability to deplete soil water stores. Reduced belowground corn biomass would be consistent with the ▶



▶ **Fig. 2. Monthly mean nitrate-N concentration in soil solution samples at 3-ft depth for the control (CN) and two living mulch (LM) treatments. Vertical bars above the data series indicate the least significant difference ($p = 0.10$). Absence of vertical bars indicates no significant differences occurred.**

reduced corn yields under the living mulch treatments, assuming similar root/shoot ratios for corn in each treatment.

Nitrate leaching

The nitrate-N concentration in the soil solution at 3 ft in depth was monitored using ceramic suction cup samplers (Model 1920F1, Soilmoisture Equipment Corp.) in all replications of the control and the living mulch with 0 and 80 lb/ac N. Soil water samples were collected every two weeks when the soil was not frozen and the soil water content was sufficient to permit water collection. Nitrate-N concentrations in the samples were measured by flow injection analysis (Model QC8500, Lachat Instruments) using the colorimetric Cd reduction method.

At 3 ft in depth, nitrate-N concentrations in the soil solution were significantly reduced in both living mulch treatments relative to the control (Fig. 2). Mean monthly nitrate-N concentration in the control increased steadily from background concentrations at the beginning of the experiment to a peak of 56 ppm in June 2007. This trend was likely the result of mineralization of the killed kura clover combined with the addition of N fertilizer. The effects of mineralization would likely be less in rotations that do not include a killed perennial legume.

Following the peak in June 2007, nitrate-N beneath the control at 3 ft in depth declined sharply and stabilized between 22 and 30 ppm, a comparable range to that observed in previous studies with continuous corn. In April through July 2008, long after the effects of mineralization had dissipated, nitrate-N concentrations under the control were still significantly higher than under the living mulch with 80 lb/ac N. For most of the experiment, nitrate concentrations under the control exceeded 10 ppm, the maximum contaminant level (MCL) for drinking water set by the USEPA.

The living mulch with no added N maintained nitrate concentrations below 10 ppm for most of the experiment (Fig. 2). These data show that corn may be grown for three consecutive years in kura clover living mulch with no added N while maintaining low nitrate levels in water draining beneath the root zone.

The living mulch with 80 lb/ac N exhibited nitrate-N concentrations intermediate to the control and the living mulch with no added N. Nitrate-N concentrations in the soil solution at 3 ft in depth increased through the first year of the experiment before stabilizing around 20 ppm (Fig. 2); thus this level of N addition is too large to meet the MCL target at this site. Prior studies have found 40 lb/ac N to be adequate for the living mulch system. Whether or not the MCL target is achieved for corn in kura clover living mulch receiving 40 lb/ac N is a question for future research.

Below 3 ft in depth over the course of the experiment, the total nitrate-N leaching under the living mulch with no added N was reduced 74% relative to the control, and the total nitrate-N leaching under the living mulch with 80 lb/ac N was reduced 31% relative to the control. Since drainage amounts were similar across treatments, these large reductions are due primarily to lower nitrate-N concentrations beneath the living mulch. The observed leaching total for the control corresponds to an annual nitrate-N leaching loss of 54 lb/ac N. This is similar to the results of other studies in this region, which have found annual nitrate-N leaching under no-till continuous corn ranging from 37 to 50 lb/ac.

Conclusions

The impacts of kura clover on the soil water balance under corn were generally small, but temporary soil water depletion occurred under the living mulch during the spring and contributed to subsequent water stress in the corn. The living mulch treatments resulted in important water quality benefits, reducing nitrate-N leaching 31 to 74% relative to the control. The living mulch also provided valuable soil cover in this corn production system where both the grain and stover were harvested. Thus, the living mulch system has potential to improve the sustainability of whole-plant corn harvest, whether for livestock feed or for bioenergy. Corn yields were reduced in the living mulch systems, and thus only two of the three objectives of biological intensification (i.e., conserve and improve the soil and create positive off-site impacts on water quality and greenhouse gas concentrations) were achieved.

Harvesting or grazing the kura clover or accounting for the value of the biological N fixation might improve the agricultural and economic productivity. Future work should consider these possibilities. More research is also needed on other aspects of the kura clover living mulch system including soil carbon effects, greenhouse gas emissions, and suitable crop rotations. In this living mulch experiment, biological intensification produced important environmental benefits, but the potential economic losses due to yield reductions cannot be ignored. ■

Adapted from the July–August 2010 Agronomy Journal *article "Water Balance and Nitrate Leaching under Corn in Kura Clover Living Mulch," by Tyson E. Ochsner, Kenneth A. Albrecht, Todd W. Schumacher, John M. Baker, and Robert J. Berkevich (Agron. J. 102:1169–1178)*

September–October 2010 Self-Study Quiz

Water balance and nitrate leaching under corn in kura clover living mulch (no. SS 04078)

This quiz is worth 1 CEU in Soil & Water Management. A score of 70% or higher will earn CEU credit. The International CCA program has approved self-study CEUs for 20 of the 40 CEUs required in the two-year cycle. An electronic version of this test is also available at www.certifiedcropadviser.org. Click on "Self-Study Quizzes to Earn CEUs."

Directions

1. **After carefully reading the article, answer each question by clearly marking an "X" in the box next to the best answer.**
2. **Complete the self-study quiz registration form and evaluation form on the back of this page.**
3. **Clip out this page, place in envelope with a $20 check made payable to the American Society of Agronomy (or provide your credit card information on the form), and mail to: ASA c/o CCA Self-Study Quiz, 5585 Guilford Road, Madison, WI 53711. Or you can complete the quiz online (www.certifiedcropadviser.org) and save $5.**

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1. Intentionally increasing the number of complementary species in an agricultural system is referred to as
- ❑ a. agricultural diversification.
- ❑ b. biological intensification.
- ❑ c. agricultural intensification.
- ❑ d. crop system diversification.

2. Living mulches are
- ❑ a. cover crops planted in the fall after harvest.
- ❑ b. organic residues grown with a main crop.
- ❑ c. cover crops grown with a main crop.
- ❑ d. perennial crops grown in place of the main crop.

3. One of the primary challenges with living mulch cropping systems is
- ❑ a. competition for water between the main crop and the living mulch.
- ❑ b. allelopathic effects between the main crop and the living mulch.
- ❑ c. emergence of the main crop.
- ❑ d. increased weed and insect pressure.

4. The time domain reflectometry and tensiometer data in this study suggest that the living mulch increases the probability of corn experiencing water stress, especially
- ❑ a. when the living mulch is maintained throughout the growing season.
- ❑ b. with a leguminous perennial living mulch such as kura clover.
- ❑ c. when temperatures are warmer than average.
- ❑ d. when the late spring is drier than average.

5. In this study, the researchers hypothesized that the living mulch reduced or delayed
- ❑ a. development of the corn root system.
- ❑ b. emergence of the corn.
- ❑ c. anthesis of the corn.
- ❑ d. transpiration in the corn.

6. In this study, the living mulch with 80 lb/ac N exhibited nitrate N concentrations
- ❑ a. that were below the maximum contaminant level for drinking water set by the USEPA.
- ❑ b. comparable to those of living mulch with no added N.
- ❑ c. comparable to those of the control.
- ❑ d. that were greater than maximum contaminant level for drinking water set by the USEPA.

7. In this study, temporary soil water depletion occurred
- ❑ a. under kura clover during the summer.
- ❑ b. under the continuous corn treatment.
- ❑ c. under the living mulch during the spring.
- ❑ d. in the second year of the experiment.

Quiz continues next page

8. The living mulch treatments reduced nitrate-N leaching
- ❑ a. compared with the perennial cover crop treatments.
- ❑ b. compared with the control only when N was not added.
- ❑ c. 22 to 43% relative to the control.
- ❑ d. 31 to 74% relative to the control.

9. Which of the following is NOT one of the three objectives of biological intensification listed in this article?
- ❑ a. Conserve and improve the soil.
- ❑ b. Reduce labor and fuel costs.
- ❑ c. Increase agricultural productivity per unit of land area.
- ❑ d. Create positive off-site impacts on water quality.

10. In the living mulch systems, corn yields
- ❑ a. were reduced 14 to 30%.
- ❑ b. were similar to corn without living mulch.
- ❑ c. decreased with increased mulch.
- ❑ d. were reduced 5 to 10%.

SELF-STUDY QUIZ REGISTRATION FORM

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❑ $20 check payable to the American Society of Agronomy enclosed. ❑ Please charge my credit card (see below)

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This quiz issued September 2010 expires July 2013

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Rating Scale: 1 = Poor 5 = Excellent

Information presented will be useful in my daily crop-advising activities: 1 2 3 4 5

Information was organized and logical: 1 2 3 4 5

Graphics/tables (if applicable) were appropriate and enhanced my learning: 1 2 3 4 5

I was stimulated to think how to use and apply the information presented: 1 2 3 4 5

This article addressed the stated competency area and performance objective(s): 1 2 3 4 5

Briefly explain any "1" ratings: ______________________________

Topics you would like to see addressed in future self-study materials: ______________________________