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Soil carbon and nitrogen dynamics under zone tillage of varying intensities in a kura clover living mulch system

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ABSTRACT

Zone tillage is a reduced-tillage approach that attempts to capture both the environmental advantages of year-round ground cover and the agronomic benefits of in-row tillage. This study was conducted to determine the effect of differing levels of zone tillage intensity on soil carbon and nitrogen cycling in a corn-kura clover cropping system (*Zea maize-Trifolium ambiguum*). Research took place in Rosemount, MN in 2015 and 2016 in an established kura clover stand. Soils and kura clover biomass were each sampled three times in crop rows per year in four treatments that varied by intensity: NT (spray-down no-till), ST (shank-till, traditional strip till unit), RZT (zone-till, PTO-driven rotary zone tiller), and DT (double-till, ST + RZT). Samples were analyzed for microbial biomass (MB), soil inorganic nitrogen, and permanganate oxidizable carbon (POXC). Additionally, potentially mineralizable nitrogen (PMN) was measured for 2016 post-spring tillage soils. Greater spring kura clover biomass in 2016 (2449 kg ha^{-1}) relative to 2015 (187 kg ha^{-1}) influenced overall differences in soil quality between years. The double-till (DT) treatment had greater post-till soil inorganic N than the no-till (NT) treatment in 2016, and by corn harvest, both zone-till (RZT) and double-till (DT) had higher soil inorganic N than NT, indicating that the addition of kura clover biomass contributed to in-row, plant-available nitrogen. Double-till was also more effective in reducing kura clover encroachment into crop rows than NT. No effect of tillage intensity on PMN, MB, or POXC was observed at any sampling time, although trends of decreasing POXC paired with increasing MB over the 2016 growing season suggest that the quantity of incorporated kura clover biomass may have governed belowground nutrient cycling and soil fertility.

1. Introduction

Zone tillage, a reduced tillage approach where only crop rows are tilled, has been proposed as a way to maintain ground cover while disturbing soil only where necessary to prepare seedbeds and incorporate nutrients (Brainard et al., 2013). Tillage has detrimental effects on soil structure (Kabiri et al., 2015), soil biological activity (Sapkota et al., 2012), and soil water capture and holding capacity (Haramoto and Brainard, 2012; Alliaume et al., 2014). However, zone tillage approaches can warm soil seedbeds in areas with cold and wet spring seasons (Licht and Al-Kaisi, 2005), clear crop rows of competing vegetation, and localize nutrient incorporation (Liebman and Davis, 2000).

Living mulches are maintained year-round or perennially, with the purposes of protection against erosion, soil-improvement, or nutrient enhancement. Their use necessitates either a band application of herbicide or some form of zone tillage for crop production, as the living vegetation must be removed from crop rows prior to sowing. Living mulches are generally biennial or perennial legumes such as clovers and alfalfa that can withstand frequent mowing as well as winter conditions. They have been examined for their potential to reduce between-row weeds (Enache and Ilnicki, 1990; Hiltbrunner et al., 2007; Gibson et al., 2011), reduce excess soil nitrogen (N; Brandsæter et al., 1998; Ochsner et al., 2010), and provide localized N to crop rows (Berkevich,

Abbreviations: BNF, biological nitrogen fixation; DT, double-till; KC, kura clover; MB, microbial biomass; NT, no-till; PMN, potentially mineralizable nitrogen; POXC, permanganate oxidizable carbon; PTO, power take-off; SOM, soil organic matter; ST, shank-till; TN, total nitrogen; TOC, total organic carbon; RZT, zone-till

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2008; Sawyer et al., 2010; Deguchi et al., 2007).

Kura clover (*Trifolium ambiguum*), a long-lived and rhizomatous perennial, has been studied for its use as an effective living mulch in the Upper Midwest. It is more winter hardy than many other perennials owing to its origin in the Caucasus region (Sheaffer and Marten, 1991; Zemenchik et al., 2000), and has been found to accumulate up to 276 kg N ha^{-1} via biological nitrogen fixation (BNF; Seguin et al., 2000). Kura clover can reduce soil and nutrient runoff by increasing water infiltration and protecting the soil surface (Siller et al., 2016), as well as reduce nitrate loading in water bodies through its extensive root system (Qi et al., 2011b).

Typical kura clover living mulch management includes suppression (spraying or tilling, or both), followed by crop planting, then kura clover recovery in the fall, post-harvest. A hardy stand will encroach into rows by the following spring. As a legume, kura clover can repeatedly supply fixed N to subsequent crops, provided enough biomass accumulates in the tillage zone between growing seasons (Zemenchik et al., 2000), and nitrogen fixation is effective. Perennial roots like those of kura clover have been found to enhance soil structure and contribute to soil microbial activity (Bissett et al., 2011; DuPont et al., 2010; Anderson and Coleman, 1985) via continuous root growth, sloughing, rhizodeposition, and turnover (Abdollahi et al., 2014). These N and soil organic matter (SOM) additions provide easily accessible, labile nutrient pools that may enhance soil nutrient cycling. Soil indicators of interest to measure contribution to such labile pools include soil microbial biomass (MB) and inorganic N, potentially mineralizable N (PMN), and permanganate oxidizable C (POXC), a methodologically defined SOM pool that determines the amount of soil C that is easily available to microbes for respiration (Weil et al., 2003), due to their sensitivity to soil disturbance and management (Culman et al., 2013, 2012; Larsen et al., 2014; Idowu et al., 2009). To date, most studies investigating living mulches in agronomic systems have examined the system capacity to increase yields or environmental services, rather than impact on soil nutrient cycling (Ochsner et al., 2010; Qi et al., 2011b; Sawyer et al., 2010).

One challenge to kura clover living mulch management in row crop systems includes reduced yields observed with conventional strip tillage equipment that utilizes a coulter-driven shank of relatively narrow width. Living mulch encroachment can cause subsequent competition with cash crops for water, sunlight, and nutrients (Grabber et al., 2014; Qi et al., 2011b; Sawyer et al., 2010). To this end, a novel zone tillage implement consisting of a PTO-driven rotary tiller to create a wider planting zone has been developed as an approach to reduce competition between the living mulch and the cash crop.

Our goal in this study was to compare the effect of tillage approaches that vary in intensity on soil carbon and nitrogen cycling in a corn (*Zea maize*)-kura clover cropping system. Specifically, our objectives were to examine the effect of tillage intensity on 1) soil N contributions, and 2) belowground nutrient cycling as mediated by microbial activity and easily accessible SOM pools.

2. Materials and methods

2.1. Study site

This experiment was conducted in Rosemount, MN (44°71′N, 93°7′W) at the University of Minnesota's Rosemount Research and Outreach Center in 2015 and 2016. Soil at the site is a Waukegan silt loam (fine-silty over skeletal mixed, super active, mesic Typic Hapludoll). Kura clover was planted in the field in 2006, and a corn/soy rotation had been planted into it since 2008, with the year immediately prior to the experiment in 2015 cropped to soybean. Due to kura clover slug damage after the 2015 corn harvest, the 2016 field plot was moved to an adjacent area, such that the year prior to the 2016 experiment was a rest year for the kura clover, during which the clover was managed as a hay crop with two cuttings and no clearing of crop rows via zone tillage. Thus, in 2015 the experiment followed eight years of row crop production, while in 2016, the experiment was planted into clover which did not have clover removed for rows in the previous year. Plot management history is provided in Table 1.

Table 1

. Schedule of field operations and sampling in 2015 and 2016, in Rosemount, MN. KC – kura clover.

Management and sampling details	2015	2016
Previous crop	soybean	KC forage
Spring field preparation	–	flail mowed
Pre-till KC sampling	30 Apr to 1 May	9 May
Pre-till soil sampling	30 Apr	11 May
NT spray	1 May	18 May
Tillage date	4 May	18 May
Fertilizer application	5 May	18 May
Corn planting	5 May	18 May
Sidedress fertilization	mid-June	mid-June
Post-till soil sampling	18 May	29 May
Mid-season KC sampling	21 Aug	26 July
Harvest KC sampling	–	4 Oct
Harvest soil sampling	9 Oct	4 Oct
Corn harvest	9 Oct	24 Oct

2.2. Experimental design

This study was designed as a randomized complete block, with four replications of four tillage treatments. Tillage treatments included NT (spray-down no-till), ST (shank-till, traditional strip till unit), RZT (zone-till, PTO-driven rotary zone tiller), and DT (double-till, ST + DT). No-till used 4 kg ae ha^{-1} glyphosate (*N*-(phosphonomethyl)glycine) applied in 30 cm wide bands to kill kura clover within the row before planting. A conventional strip tillage unit (1tRIPr, Orthman Mfg., Lexington NE) was implemented for ST, consisting of a shank with ground-driven coulters. The RZT implement was a PTO-driven 6-row rotary tiller (Northwest Tillers, Yakima WA), in which each set of rotary tines tilled a zone 30 cm wide and approximately 10 cm deep. Plot management details and dates are in Table 1. Plots had six rows, each 76 cm wide and 37 m long. All samples were collected from the two central rows. Plots were fertilized with 224 kg ha^{-1} of 18-46-0, 224 kg $ha^{-1}$of 0-0-60, and 84 kg ha^{-1} of 21-0-0-24 (N-P-K-S), resulting in 58 kg N ha^{-1}, 103 kg P_2O_5 ha^{-1}, 135 kg K_2O ha^{-1}, and 20 kg S ha^{-1} at planting in both years. Additionally, plots were side dressed with 41 kg N ha^{-1} in 2015 and 34 kg N ha^{-1} in 2016.

2.3. Kura clover and soil sampling

Kura clover biomass was collected immediately prior to spring tillage (pre-till) and in the middle of the growing season (mid-season) in both years, and at corn harvest in only 2016 (harvest; Table 1). In 2015, not enough biomass was present within rows at harvest to sample. It should be noted that kura clover biomass collections differed by 10 d between years, due to different timing of spring tillage events. Aboveground biomass was collected from in-row areas where crops were to be planted using a 0.1 m^2 quadrat. Biomass was then transferred to a 60 °C oven for at least 48 h before being ground to 1 mm and analyzed for C and N content on a combustion analyzer (Elementar VarioMAX CN analyzer, Elementar Americas).

Soils were also collected from within crop rows at three time points per year: pre-till, post-till, and at harvest (Table 1). A composite of ten samples from the top 15 cm were collected in a bucket, homogenized, and divided into two subsamples. One subsample was dried at 35 °C for at least 48 h before removing them, grinding and sieving to 2 mm, and setting aside for inorganic N extractions, POXC analysis, and C/N analysis (Elementar VarioMAX CN analyzer, Elementar Americas). The