Soil Water Dynamics under Various Agricultural Land Covers on Subsurface Drained Fields in North-central Iowa, USA[1]

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Abstract

In intensively drained fields soil water dynamics affects infiltration, subsurface drainage and nitrate-nitrogen (NO_3-N) loss through the drainage system. Modification of land cover systems such as cover cropping is being studied in Iowa due to their potential benefits in increasing soil water depletion in the spring period. The objective of this study was to evaluate the impacts of modified land covers on soil water dynamics. In each individual year, modified land covers including winter rye-corn (rC), winter rye-soybean (rS), kura clover as a living mulch for corn (kC), and perennial forage (PF), as well as conventional corn (C) and soybean (S), were grown in subsurface drained plots in north-central Iowa. Results showed that subsurface drainage was not reduced under modified land covers but slightly higher than conventional corn and soybean. Soil water storage (SWS) was significantly reduced by kC and PF treatments when compared to the cropping system with corn or soybean only ($p<0.05$). Treatments of rC and rS typically maintained higher SWS than C and S, respectively, during the three years of this study. In the spring during a ten- to fifteen-day period when the rainfall was minimal, SWS in plots with rye, kura clover, and forage grass decreased at a significantly higher rate than the C and S plots which were bare. Estimated evapotranspiration (ET) during this period was significantly higher in rS, kC, and PF treatments than C and S. The results of this study suggested that higher ET and drainage for modified land covers will increase water infiltration thus reduce surface runoff. The significant higher ET in kC and PF indicated that the stream flow may be reduced by converting conventional corn-soybean rotation into kura clover-corn dual cropping system or perennial grass. Because subsurface drainage reduction was not seen in this study, impact of modified land covers on NO_3-N loss needs further investigation.

Keywords: soil water dynamics, rye cover crop, kura clover, perennial forage

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1. Introduction

Nutrient loss through subsurface drainage systems in the Midwest of the United States has been an increasing concern as a result of hypoxia in the Gulf of Mexico. Approximately 70 percent of subsurface drainage flow and nitrate-nitrogen (NO_3-N) loss has been shown to occur in the upper Midwest U.S. in spring when the main crops have not established (Helmers et al., 2005; Randall and Vetsch, 2005). Introducing agricultural land covers that can grow in the spring is a promising approach to increase evapotranspiration thereby decreasing subsurface drainage and/or surface runoff in the Midwest region of the United States. Studies have shown that annual cover crop, perennial living mulch and perennial forage grassland have the potential to reduce drainage and NO_3-N leaching in the Midwest (Baker and Melvin, 1994; Kassavalou and Walters, 1999; Zemenchik et al, 2000; Eleki, 2003; Affeldt, et al. 2004; Strock et al., 2004; Kaspar et al., 2007; Heggenstaller et al., 2008).

Adding winter cover crop into conventional corn-soybean cropping system could exert beneficial and/or detrimental impacts on soil water storage. Soil water can be recharged by infiltration and be depleted by crop water consumption. Unger and Vigil (1998) found that runoff can be reduced by increasing infiltration and rainfall interception due to the existence of the cover crop; soil water storage can be affected by increasing the infiltration rate and water consumption by transpiration, and by a modification of soil matrix porosity structure. Moschler et al. (1967) demonstrated elevated soil water content with winter rye cover crop in soil layers from 0 to 60 cm. In British Columbia, Canada, Odhiambo and Bomke (2007) compared gravimetric soil water content in winter cover crops to that in bare plots in the early spring and found that soil water content in a rye treatment was significantly higher for top soil (0-20 cm) possibly due to reduced soil evaporation and increased infiltration. Because evapotranspiration of rye cover crop may offset the increased infiltration, soil water storage had a similar pattern in a rye cover field compared to a no rye cover field (Islam et al., 2006). Alternately, transpirational water consumption by rye cover crop may reduce the soil water storage so much it could lead to water stress for the following main crop. Munawar et al. (1990) compared the soil water content between early killed (3 weeks before corn planting) and later killed (on the corn planting day) winter rye cover crop and documented that soil water content in late killed plots was significantly lower than that in early killed plots.

Other than annual winter cover crop, kura clover as a living mulch for corn has potential benefits to water quality management and biomass production. However, the effect of kura clover as a living mulch for corn on soil water content was not consistent in related studies. Gravimetric soil water content in corn grown with kura clover showed no difference from a treatment of solely kura clover, which could be attributed to excessive rainfall water supply (Zemenchik et al., 2000). However, in other studies, available soil water could be the most limiting factor for the main crop growth in the north central United States (Eberlein et al., 1992) and in the U.S. Coastal Plain when the precipitation was below the long-term average (Ewing et al., 1991). Kurtz et al. (1952) and Pendleton et al. (1957) observed grain yield loss of corn which was grown with an interseeded legume due to soil water deficit conditions.

Besides introducing cover crops and living mulches into conventional corn and soybean system, replacing the row crops with perennial forage, pasture, or native prairie is another option for water and water quality management. Schilling (2005) reported that with a 13-52% increase of row crop land use in Iowa’s agricultural watersheds, the baseflow in rivers increased by 7-31%. The increased baseflow for row crop land use suggested that corn and soybean consumed less water than native prairie, thus lead to more surface runoff and/or soil drainage. Studies also showed that deep-rooted savanna, woodland and prairie extracted more water from the deeper soil profile than the annual corn crop in this region (Proffitt et al., 1985; Asbjornsen et al., 2007). Other than higher ET, less drainage or runoff in the prairie could also be attributed to larger rainfall interception than row crops (Brye et al., 2000).

In Iowa, studies have suggested that changes in land uses and vegetative cover affected water uptake patterns which may ultimately impact the hydrologic balance on a large scale (Asbjornsen et al., 2007). However, there is little information addressing the soil water impacts of introducing modified land covers into a conventional corn-soybean rotation system. With the increased concern about biomass production, nutrient loss reduction, and soil erosion control, the use of winter cover crops, living mulches, and perennial forage have the potential to alter the conventional mono-cropping system in Iowa and the larger Corn Belt (Sulc and Tracy, 2007; McDonald et al., 2008). As a result, there is a need to investigate the impacts of these modified land cover systems on soil water dynamics. The objective of this study was to investigate the impact of modified land covers, including a winter cover crop with corn and soybean, corn growing with kura clover as a living mulch, and perennial forage, on soil water storage and soil drainage when compared to the conventional corn-soybean rotation.

2. Materials and Methods

2.1 Site description

The Agricultural Drainage Water Quality - Research and Demonstration Site (ADWQ-RDS), located in Pocahontas County in north-central Iowa, is a subsurface drained site composed of seventy-six plots administrated by the Iowa Department of Agriculture and Land Stewardship and Iowa State University. Predominant soils are Nicollet (fine-loamy, mixed, superactive, mesic Aquic Hapludoll), Webster (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls), Canisteo (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls) and Okoboji (Fine, smectitic, mesic Cumulic Vertic Endoaquolls). Each plot is 38 m in length and 15.2 m in width with an average slope of 0.5% to 1.5%. The plots were established after the installation of corrugated plastic drain tiles through the center and along both boundaries parallel to the long dimension (7.6 m spacing) at a depth of 1.06 m. All subsurface drainage lines extend to separate drainage sumps where water flow from the center lines is measured and pumped into a nearby wetland. Detailed design has been described by Helmers et al. (2005), Singh et al. (2006) and Lawlor et al. (2008). Annual subsurface drainage volume was broken into spring drainage (March-June, when the spring land covers was expected to be effective) and summer-fall drainage (July-November).

An automatic meteorological station at the site monitored rainfall, air temperature, soil temperature at 10 cm depth, solar radiation, wind speed and direction, and humidity at a 5-minute interval. Daily reference evapotranspiration (ET_0) was computed using Penman-Monteith equation following FAO56 (Allen et al., 1998) to represent the integrated weather conditions. The long-term (1971-2000) average precipitation and temperature were obtained from the National Climate Data Center for the two weather stations located in Humboldt (Station No. 125) and Pocahontas (Station No. 070), IA, which are 20 km east and 19 km west from the experimental site, respectively.

The field experiment was established in a completely randomized block design. Plots were blocked by their long-term (15 years) drainage characteristics. This resulted in four blocks, high (H), medium high (MH), medium low (ML) and low (L) flow blocks. One plot in each block was randomly assigned to each of the six land cover treatments (6 treatments×4 blocks) in this study. In each individual year, land cover treatments were: corn (C), soybean (S), winter rye cover crop prior to corn (rC), winter rye prior to soybean (rS), corn with established kura clover as a living mulch (kC), and perennial forage (PF). The plots for C and the plots for S were rotated every other year as were the rC and rS plots. However, the plots for the other two cropping treatments, kC and PF, were unchanged during the whole experimental period of the study. The PF plots were mowed once or twice a year but were not grazed by animals. This experiment was initiated in October 2004 but data in this paper covers the period from 2006 through 2008. Due to previous treatment history, 2005 was considered a transition year.

2.2 Agronomic management

Agronomic field activities were completed in a timely manner prior to and during the crop season beginning in October 2004 with plot tillage and rye seeding. For the C and S plots, corn residue was chopped and chisel plowed in the fall followed by disking and field cultivation in the spring, and soybean residue was not disked until spring and was field cultivated prior to corn planting. For the plots with rye (rC and rS), tillage operations were conducted in the fall prior to rye planting. Corn residue in rC treatment was chopped, disked twice and smoothed with a field cultivator, and soybean residue was disked once and field cultivated. 'Rhymin' rye (*Secale cereale*) was drill seeded at a rate of 100 kg ha^{-1} in 19 cm rows with a skip row every 76 cm for subsequent corn or soybean planting, with 12 rows for each pass. Tillage for seedbed preparation for kura clover and forage was completed in the spring just prior to planting on April 18, 2005. 'Endura' kura clover (*Trifolium ambiguum*) was hand seeded at a rate of 13 kg ha^{-1}, the perennial forage plots were hand seeded with 'Duration' red (*Trifolium retense*), and 'Pinnacle' ladino (*Trifolium repens*) clovers with 'Extend' orchardgrass (*Dactylis glomerata*) at 9, 0.6, and 4.5 kg ha^{-1}, respectively.

In the spring glyphosate was applied at a rate of 239 mL ha^{-1} in rC and rS plots to terminate rye growth. Glyphosate resistant corn (Zea maize) and soybean (Glycine max) were used and planting dates were dictated by field conditions. Seeding rates were 77,000 seeds ha^{-1} for corn and 439,750 seeds ha^{-1} for soybean. Corn planting in the kura clover plots started in 2007, giving a 2-year (2005 and 2006) period for kura clover establishment according to recommended management. After corn planting, the entire kura clover plots were suppressed by glyphosate in 2007 and the plots were band sprayed in 2008. Commercial-grade 28% aqueous ammonia-nitrogen (N) was applied at 140 kg N ha^{-1} in the spring closely following corn emergence to plots with corn (C, rC, and kC), within the recommended rates of 112 to 168 kg N ha^{-1} (Blackmer et al., 1997). N fertilizer was applied mid-row to corn with a conventional knife applicator. For weed control in all corn and soybean plots, glyphosate was subsequently applied two more times during the growing season, as dictated by weed pressure. Similar operations were followed in all years and agronomic timing details are included in Table 1.

2.3 Biomass and yield sampling

To determine the biomass accumulation in spring, above ground rye shoots were sampled right before the growth termination with glyphosate, and kura clover and forage shoots was sampled between June 4 and June 8 in the three years. Rye was sampled along a 30-cm long section at four randomly selected locations; kura clover and forage were sampled using a 30×30 cm^2 area randomly selected at three locations in each plot. Samples were dried at 60 ºC for a week for dry biomass determination. Twelve rows of corn and soybean out of 20 rows in each plot were harvested by a 3-row combine to get the grain yield. Grain was weighed and sampled to determine grain water content for each pass.

2.4 Soil water content measurement

Three of the four blocks, with exception of the high drainage block, were selected for the soil water content measurement. A PR2 Profile probe and a Theta probe (Delta-T Services, UK) were used to measure the soil permittivity, and the permittivity was subsequently converted to volumetric soil water content using calibrated equations. The measurement was not conducted in the winter because the soil was frozen and the probes are not capable of monitoring soil permittivity in frozen soils. In each plot, soil permittivity was measured at two locations, one each in the southeast and northwest section of the plot. A fiberglass access tube was installed in fall 2005 at each location to facilitate soil permittivity measurement in the soil profile. The permittivity of the top soil (0-5 cm) was measured five times around each access tube with the Theta probe to provide adequate replication. The permittivity of the soil profile at 0-10, 10-20, 20-30, 30-40, 50-60 and 90-100 cm depths were measured by the PR2 Profile probe by inserting it into the fiberglass access tubes. The PR2 probe was calibrated and validated by in-situ soil sampling in three consecutive years (Qi and Helmers, 2010). Permittivity measured by PR2 probe was converted to volumetric water content by these calibrated equations. The permittivity output of the Theta probe was converted into volumetric water content by the equation calibrated by Kaleita et al. (2005) using field data collected in Des Moines Lobe soils.

The Theta probe and PR2 profile probe measurements were taken on a weekly basis from late March or early April through October in 2006-2008. The measurement date was dictated by the weather to avoid sampling on raining days. The soil water content at 0-10, 10-20, 20-30, 30-40, and 50-60 cm were assumed to be representative of water content of soil layers at 5-10, 10-20, 20-30, 30-45, 45-60 cm, respectively, and the soil water content in the top 0-5 cm layer was averaged over the 5 measurements from the Theta probe permittivity readings. The soil water content data were multiplied by the representative depth intervals to compute the soil water storage (SWS) for each depth, and then summed to obtain the SWS for 0-60 cm soil layer.

Because the soil water content at 100 cm would be largely influenced by the high water table, SWS was only calculated in the soil layers from 0 through 60 cm below the ground surface.

2.5 Evaportranspiration (ET) estimation

The water budget equation for the subsurface drained field was written in the form where ET is equal to precipitation minus the soil water storage change, subsurface drainage, runoff, and deep seepage:

$$ET = P - (SWS_e - SWS_b) - D - RO - SP$$

where ET is the evapotranspiration (mm), P is the precipitation (mm), SWS_b is the SWS at the beginning (mm), SWS_e is the SWS at the end (mm), D is the subsurface drainage through tile lines (mm), RO is the surface runoff (mm), and SP is the deep seepage into groundwater (mm). Because RO and SP are not measured, ET can be calculated when runoff and deep seepage are negligible, such as under a situation that there is no intensive rainfall and the groundwater maintains a high water table. From the early- through mid-spring, which is the main drainage season in Iowa, the water table of this site usually maintains at a high level.

2.6 Statistical method

The experiment followed a completely randomized block design with 3 replications. Data were analyzed for each individual year separately. The 3-year data was also combined to test the significance of difference between treatments across years. In this study, differences in soil water storage (SWS) among treatments were analyzed via the PROC MIXED procedure (Littell et al., 1999) using the monitoring date as a repeated measure. Autoregressive order 1 was selected as the covariance structure in MIXED repeated procedure because the correlation of SWS was larger between short sampling time intervals as compared to long intervals. Drainage block nested in the land cover treatments was considered a random effect in the statistical analysis.

Similar statistical methods using PROC MIXED model with repeated measure in SAS has been applied to analyze the differences between temporally repeatedly measured soil water storage, crop production, and NO_3-N loss in drainage systems (Lyon et al., 1998; Aparicio et al., 2008).

3. Results and Discussion

3.1 Weather conditions

Monthly precipitation and temperature for the study period are presented in Table 2. The annual precipitation for 2006, 2007, and 2008 were 626, 1050, and 926 mm, respectively, with 550, 935 and 827 mm in the drainage season from March to November in 2006, 2007, and 2008. The long-term average annual precipitation (1971-2000) for the ADWQ-RDS site is 821 mm, of which 753 mm occurred during the drainage season from March through November. In general, temperature in 2006 was warmer than the long-term average, but in 2008 the averaged daily temperatures on a monthly basis from January through October were consistently lower than the long-term average by 1.0 to 3.8 °C. Cold weather was observed in early April, 2007 with the lowest temperature was -10.0 °C on April 7 when rye shoots were damaged by the cold temperatures.

Because during the main growth period of a rye cover crop in Iowa from March through May, soil water is normally abundant for rye growth, other weather factors which determine the biomass accumulation rate are temperature, solar radiation, wind speed, and humidity. Therefore, reference evapotranspiration (ET_0) could be an integrated indicator of weather conditions for cover crop growth. In general, weather in the spring was the most favorable for crop growth in 2006 (Figure 1). Total ET_0 during March through May was 647 mm for 2006, 18% and 69% higher than that for 2007 and 2008, respectively. Monthly ET_0 in 2008 was generally lower than in 2006 and 2007, particularly from January through May. This was likely due to relatively cool temperature, high humidity and low solar radiation in 2008.

3.2 Biomass and Grain Yield

The above ground dry biomass that land covers produced in the spring was 1.04, 3.82, and 3.06 Mg ha^{-1} when averaged across three years for rye, kura clover and perennial forage, respectively. Kura clover and forage biomass were significantly greater than rye biomass ($p<0.05$). The biomass of rye in rS treatment was 1.67 Mg ha^{-1}, significantly higher than that of rye in rC treatment where a biomass yield of 0.46 Mg ha^{-1} was observed ($p<0.05$); moreover, rye biomass in both rS and rC plot was significantly lower when compared with the forage and kura plots ($p<0.05$). Winter rye cover crop growing in the rS treatment was chemically desiccated in middle to late May and the rye in the rC treatment was killed in late April. When averaged across 3 years, within the 20 days after the rye followed by corn was killed, rye followed by soybean accumulated 72% of the biomass. Biomass of each spring land cover for 2006 was significantly higher than those for other years ($p<0.05$). The rainfall and temperature conditions during early spring of 2006 were favorable for establishing spring land covers. The calculated reference ET_0 in 2006 was the highest in April and May for the three years. Due to the short term extreme low temperature in April 2007 and long period of cold weather in 2008, the growth of land covers in spring was affected to different extents.

While corn and soybean in the plots with rye as a winter cover (rC and rS) did not show grain yield disadvantage compared with the conventional corn and soybean plots (C and S), corn that grew with kura clover as living mulch (kC) had significantly lower biomass accumulation and grain production ($p<0.05$, Figure 2). On average, the corn yield was 8.7 and 8.3 Mg ha^{-1} for C and rC treatment, but was 2.5 Mg ha^{-1} for the kC treatment. Water, nutrient, and sunlight competition could be responsible for the poor corn establishment and low grain production in the kC plots.

3.3. Subsurface Drainage

Subsurface tile drainage typically initiated in late March, and continued to late fall depending on the rainfall pattern. The volume of subsurface drainage varied due to precipitation, and showed large variability between plots. The average annual drainage from all treatments was 354 mm which related to 41% of average annual rainfall. The percentage of drainage occurring from March to June was about 64% of the annual total, slightly lower than the 15-year observation of 70% in this region (Helmers et al., 2005). This is due to the wet weather in late summer and fall in 2007.

Statistical tests showed that the modified land cover treatments including rC, rS, kC, and PF did not significantly influence annual or seasonal drainage flow volume (Table 3). When averaged over the 3 years, the annual drainage in the modified land cover treatment (rC, rS, kC, and PF) was even slightly higher than conventional C and S treatments. During March-June, the three year average drainage of modified land cover treatments was also slightly higher than the C and S treatments with an exception that the spring drainage for rS was about 13% lower than that for S treatment (198 vs. 227 mm). The general slightly higher drainage, yet not significant, suggest that the modified land covers may slightly increase infiltration and reduce runoff. Although the differences may exceed 20% in drainage volume between modified land covers and conventional corn and soybean treatments, they were not significant as a result of statistical analysis due to the high temporal and spatial variability. The annual discharge for the 24 plots ranged from 30 mm in 2006 to 1053 mm in 2008. Within one year, for example, in 2008, the average annual drainage of rC was 516 mm while the drainage in C was 387 mm, however, the standard deviation of the annual drainage were 189 mm and 128 mm for rC and C, respectively, which were more than 30% of the average. In spite of the high field variability, the effect of block on drainage was evident, with the 3-year average drainage volume from H block (455 mm) significantly higher than from L block (256 mm) ($p<0.05$).

3.4 Soil Water Dynamics

3.4.1 General pattern of SWS

A total of 29 Weekly SWS values were obtained in 2006, 35 in 2007, and 31 in 2008. During periods with substantial precipitation, such as in early spring of 2008 and early fall of 2007, average SWS in the 0 to 60 cm depth soil profile for each treatment was essentially the same across various land cover treatments. Soil water storage was generally higher in early spring and late autumn but lower in the summer for all the treatments. Average SWS in April and October over the three years was 203 and 200 mm, respectively, while the average SWS in July was 179 mm. The lowest SWS (114 mm) was observed across all the treatments on July 17, 2007, which indicated a soil water content of 0.19 $cm^3\ cm^{-3}$, close to the average wilting point ($\theta_{1500kPa}$) of 0.21 $cm^3\ cm^{-3}$ measured in the lab for soils from 0-60 cm deep (Qi, 2009). The highest SWS (220 mm) occurred on June 9, 2008, corresponding to a soil water content value of 0.37 $cm^3\ cm^{-3}$. This highest soil water content was near to the lab measured field capacity (θ_{330kPa}) of 0.38 $cm^3\ cm^{-3}$ for soils from 0-60 cm deep.

The average weekly soil water content varied among years due to the differences in precipitation and other weather conditions. The average weekly SWS for all the treatments was 185 mm for 2006, 196 mm for 2007, and 202 mm for 2008, significantly different from each other ($p<0.05$) (Table 4). Despite the fact that the amount of precipitation in 2007 was the highest among the three years, the weekly average SWS was significantly lower than in 2008 because the rainfall was more evenly distributed and the reference ET_0 was lower in 2008 (Figure 1). For each treatment, average soil water storage in a year was significantly different from other years ($p<0.05$) except for the rC and PF treatment where SWS in 2007 was not statistically different from SWS in 2008.

Land cover treatment significantly affected the repeatedly measured SWS both annually and seasonally ($p<0.05$, Table 4). For the 3-year annual average SWS, PF showed the lowest average weekly SWS (181 mm) of all the land cover treatments, significantly lower than C, rC, S, rS, and kC treatments ($p<0.05$). In the kC treatment, mean SWS was significantly lower than rC and rS treatments ($p<0.05$). In the treatments with corn and soybean, the mean weekly SWS in rC was significantly higher than C treatment ($p<0.05$). However, SWS in rS showed no significant difference from S treatment when averaged over 3 years. The SWS differences were more evident in the year of 2006 and the summer of 2007 when rainfall was below average. The differences in SWS among treatments seem more distinct during the season from May through July. Statistical analysis showed similar pattern for the seasonal average to the annual average, except that SWS in kC from May through July was found to be significantly lower than all corn-soybean with and without rye treatments, when averaged over 3-years.

3.4.2 Soil water dynamics in winter cover crop treatments

In Iowa, the growth of winter rye was not appreciable in the winter season from late-December to late-March. As a result, the effect of rye on hydrological components related to winter weather is not a primary concern in Iowa. For example, based on field observation, rye may not be able to trap appreciable snow, or affect the process of soil freezing and thaw because it was very sparse and less than 5 cm tall until after the snow melted. To investigate the causes of increased SWS in treatments with rye as a winter cover crop in Iowa, attention should be paid to the impact of rye on water infiltration, soil evaporation, and rye root water uptake. Winter rye cover crop has been shown to increase infiltration by adsorbing raindrop energy, hence preventing soil surface sealing, and increasing soil macroporosity (Dabney, 1998). In the discussion above, slightly higher drainage discharge (not significant) was observed from modified land covers. Cover crops have also been shown to reduce soil surface evaporation by blocking the wind and shading the surface, but conversely, SWS may be reduced by the transpiration of rye.

Temporal patterns of SWS and the comparison between rC and C, and rS and S are illustrated in Figure 3 and 4, respectively. Increase of SWS by rye as a winter cover crop was consistently observed for both rC and rS treatments. The increased SWS in rC and rS plots may be attributed to rye root growth in the soil and the coverage of rye residue on the ground. Rye root may increase soil porosity thus increase the infiltration and rye residue may reduce the soil evaporation between corn or soybean rows. The average weekly SWS in rC over the three years was significantly higher than C treatment ($p<0.05$), but SWS in rS showed no significant difference from the S treatment (Table 4). The lack of difference in average weekly SWS between rS and S is likely due to high transpiration of rye in rS treatment in the spring (Figure 4).

The findings on drainage and soil water storage in this field plot study were in contrast to the field non-weighing lysimeter study in Iowa (Qi and Helmers, 2010) during the same years from 2006 to 2008. In the lysimter study, drainage and SWS was lower for the rye lysimeters than bare lysimeters. The differences in agronomic management between plot and lysimeter studies are: corn and soybean were planted after rye in the plot study while not in the lysimeters; rye was removed from the lysimters after harvest while its residue stayed in the plots after spray; tillage was reduced in plots with rye compared with C and S while both bare and rye lysimeters received the same tillage. The non-weighing lysimeter was placed in a different micrometeorological situation from field plots. There was a 20-cm high standing board around each lysimeter, which may have blocked the wind and protected the rye in the winter and spring. Therefore, the higher SWS and drainage in rC and rS may be attributed to the surface rye residue cover, reduced tillage, and the different micrometeorological conditions.

Impact of rye on SWS was evident for rS treatment during a certain period in each year. Rye in rS plots was terminated on May 16 in 2006, May 23 in 2007, and May 26 in 2008. This study showed that rye accumulated 72% of the total biomass in rS treatment in the 20 days before termination. About 10 to 15 days before rye in the rS plots was sprayed, when the rainfall and drainage was minimal, SWS decreased drastically relative to the S treatment ($p<0.05$, Table 5). For example, during the 15-day period from May 1 through May 16 in 2006, the decrease of soil water storage (ΔSWS) was 12 mm for rS, significantly higher than that for S plots, which lost 5 mm ($p<0.05$). Statistical analysis demonstrated that this type of difference was also significant for a 13-day period for 2007, and a 10-day interval in 2008 prior to rye growth termination of rS plots ($p<0.05$).

The ET was calculated because runoff and deep seepage could be negligible due to high water table and minimal rainfall for this period (Table 5). The computed ET for the rye in rS, when averaged over 3 years, was 1.9 mm d^{-1} in this plot study, slightly lower than the 2.4 mm d^{-1} in the lysimeter study (Qi and Helmers, 2010). The calculated average evaporation in C and S, during this period when the plots bared, was 0.6 mm d^{-1}, also lower than the average evaporation in lysimeters. Note that rye in this plot study was terminated 5-14 days earlier than rye in the lysimeters. The Lower ET in the plot study may be also attributed to the lower rye biomass accumulation than in the lysimeter study. The average total biomass harvested in the rS treatment was 1.67 Mg ha^{-1}, while the biomass yield in the lysimeter study was as high as 2.70 Mg ha^{-1}.

Winter rye cover crop effected SWS even after the growth termination. In corn and soybean plots with rye growing in the spring, SWS was almost always higher than in plot with just corn or soybean. Because the rye shoot was chemically burned down but was not removed, there is the potential that it still mitigated raindrop impact energy and blocked the wind, thereby potentially increasing infiltration and reducing soil surface evaporation. While the burned rye stand usually collapsed in late summer, there still appeared to be an influence of the rye on the SWS into late fall. In the fall of each of the three years, greater SWS in rye treatments compared to treatments without rye was more apparent for the rC plots than for the rS plots (Figure 3 and 4). The soil surface of rC plots was well protected by rye in the spring and by corn canopy in the summer and fall; but in rS plots, due to late and smaller soybean canopy, the rye residue weathered at a higher rate. In the fall, the soil surface of soybean plots with or without rye in the spring was visually smooth and covered with surface soil crust, while the soil surface of corn plots was rougher and softer. The rough and soft ground surface in corn plots could be attributed to two reasons, one was that the soil was disturbed by fertilizer applicator knives in May, the other was that corn canopy protected the soil surface from being compacted by raindrops. Moreover, more extensive corn canopy may make rye residue more effective for corn plots for soybean plots, because the rye residue would stay longer on the soil surface due to the protection of corn canopy. It should also be noted that while the soil water content in plots with rye was increased the overall trafficability did not seem to be affected.

3.4.3 Soil water dynamics under living mulch

In general, the kC treatment showed significantly lower annual and seasonal SWS than corn and soybean treatment with and without rye ($p<0.05$, Table 3). The SWS in kC during the spring had large fluctuations when compared to the C treatment (Figure 5). The kC treatment showed higher SWS values after a period of intensive rainfall, such as late April in 2007 and early June in 2008. This may be attributed to the increased porosity by the root development, which is similar to rye plots. During the summer, SWS was usually lower in the kC treatment than C. However, in the early fall, the soil water depleted by kC was recharged to the same level. This indicated that the infiltration in kC was higher than in C treatment.

Comparison of SWS change and ET estimation during late spring periods is listed in Table 5. The magnitude of SWS decrease in kC treatment was found to be significantly higher than C treatment. There was no treatment × year effect which indicated that the treatment effect was consistent in each individual year. During the periods listed in Table 5, the transpirational water use of kura clover was higher in 2007 and 2008, though the reference ET_0 was lower in these two years than in 2006. This is because in 2006 the kura clover had not full established, leaving a lot bare spots in the plots. The 3-year average daily ET of kura clover was 2.6 mm d^{-1}, higher than the rS treatment (1.9 mm d^{-1}). When compared to the C treatment, ET kura clover during in May was about 2 mm d^{-1} higher.

Low SWS in the kC treatment may have negatively impacted corn growth. Overall corn above ground biomass and corn grain yield in kC was reduced when compared to treatment C. Nutrients, light and water are three major resources for which corn would compete with kura clover in the summer growing season. Soils were sampled in kC and C treatments in 2008 and the difference of soil residual NO_3-N between kC and C treatments was negligible before the corn planting and after corn harvesting (data not presented). During early stages of corn development, its establishment could be delayed by light interception of kura clover. Overall, the limited growth and corn grain yield loss can most likely be attributed to water competition, particularly in the vegetative stages from emergence to silking. In other words, the available soil water stored in the soil profile could not support the simultaneous growth of corn and kura clover, especially in year with a dry summer such as 2007.

Figure 6 demonstrates the temporal pattern of soil water content in 5-15 cm soil layer in kC and C treatments during the corn growing season of the three study years. Soil water content pattern at 5-15 cm soil layer showed similar pattern with the SWS trend of the 0-60 cm soil profile. After kura clover was suppressed by herbicide, the transpirational water use was largely reduced and SWC was maintained at a high level, but this only lasted for about two weeks. In these two weeks, kura clover acted as a blanket cover of the soil surface and may have reduced soil evaporation. For example, when kura clover was suppressed on May 26, 2008, kC plots recovered to a high SWS similar to C plots in the following two weeks, but showed a rapid drop of SWS during the following period of kura clover recovery. In 2006, corn was not planted in the kC treatment for which SWC was generally lower than the C treatment in the late spring but similar in August through September. This suggests that the amount of water depletion by kura clover was higher than corn from May to July and similar to corn in August to September. If corn could not successfully establish its canopy to suppress the growth of kura clover, the growth of corn would be retarded by soil water stress. It is demonstrated in 2007 that corn established a poor canopy and experienced a long period of water stress until early August when two significant rain events occurred on August 1 (31 mm) and August 4 (66 mm). However, these rain events were too late because corn had already silked. The corn yield in kC was higher in 2008 than in 2007 possibly due to the 102 mm rainfall that occurred in July 2008. The corn grain yield of the kC treatment compared with the C treatment was 1.03 Mg ha^{-1} versus 7.35 Mg ha^{-1} for 2007, and 4.07 Mg ha^{-1} versus 9.62 Mg ha^{-1} for 2008. As noted above, the rainfall in June and July of 2007 was well below average. Besides for effective kura clover suppression, the rainfall amount in June and July is suspected to be critical to corn growth and production. Under effective kura clover suppression management and limited competition, corn yields in the kC treatment have been shown to reach the same level as C treatment in Wisconsin (Zemenchik et al., 2000)

3.4.4 SWS under perennial forage

The SWS in PF treatment was significantly lower than any other treatments when statistical analysis for SWS was conducted over 3-years and over each individual year ($p<0.05$, Table 4). The PF treatment showed the lowest average weekly SWS (181 mm) among all the land cover treatments ($p<0.05$). The pattern of SWS in PF treatment was similar to kC in early and middle spring and late summer when the main rainfall events occurred (Figure 7). Lower SWS in PF treatment started in late spring and this difference continued unless the study site received high rainfall amounts. The largest difference of SWS between kC and PF (38.5 mm) was observed on July 17, 2007. Compared with conventional corn plots (C), the maximum SWS difference between PF and C was 40.2 mm in 2006, 51.0 mm in 2007, and 60.9 mm in 2008.

The computed ET of PF treatment in May was significantly higher than C treatment in 2006 and 2007 ($p<0.05$), with a 3-year average of 2.7 versus 0.5 mm d^{-1} during the time listed in Table 5. If we assume the computed ET can represent the actual ET in the whole month of May, the estimated monthly ET for PF and C were 84 and 16 mm, respectively. The 3-year observed average in May under PF plots compared with C treatment was 57 versus 49 mm for drainage, and 20 mm loss versus 1 mm increase for SWS change. Based on the water balance equation, the estimated infiltration in May were 121 and 66 mm for PF and C, respectively. However, the estimated infiltration for PF exceeded the average rainfall in May (89 mm). It may suggest that in the pasture plots water may move from shallow groundwater table to soil layers of 0-60 cm due to high plant water consumption. Therefore, converting corn-soybean rotation into perennial forage grassland could significantly reduce the surface runoff during and after a summer storm, which may subsequently reduce the stream flow volume in the summer.

4. Conclusion

Soil water storage in 0 to 60 cm soil profiles and subsurface drainage were monitored during the growing season of three years from 2006 through 2008 under various land covers in Iowa. Applied land covers in each year were corn, rye-corn, soybean, rye-soybean, kura clover as a living mulch for corn, and perennial forage. In this study, drainage was not significantly reduced under spring land covers but however slightly higher than conventional corn-soybean plots. It suggested that the modified land cover systems may increase water infiltration. Though varied from year to year, soil water storage was significantly reduced by the corn with kura clover and forage treatments when compared with corn and soybean plots. Annual soil water storage in the rye-corn plots was higher than the corn plots.

In the spring of each year, during a ten- to fifteen-day period when the rainfall was minimal, soil water storage in plots with every spring land cover species, rye, kura clover, and forage grass, decreased at a significantly higher rate than the corn or soybean plots without any winter cover. In general, soil water stored in the top 60 cm of the soil profile under kura clover-corn treatment was significantly less than that under rye-corn and rye-soybean treatments across the three years of the study. Low soil water content in the kura clover-corn plots likely contributed to low corn biomass and yield. The soil water storage under perennial forage was significantly lower than other treatments in each individual year. The estimated ET of the spring land covers in rye-soybean, corn with kura clover, and perennial forage was significantly higher than conventional corn and soybean plots. The significant high ET, combing with the slightly high drainage, suggest that infiltration was increased thus runoff was decreased in those three modified land cover treatments. Due to the short growing time of rye in the rye-corn system, ET was not different from no rye treatments during this period. However, the significant high soil water storage in rye-corn than corn suggests that rye root facilitated water infiltration.

This study also showed that in 3 years the winter rye cover crop did reduce soil water storage during the growing season, which is a practical concern to producers. However, the cover crop growth during the early spring period has potential to increase transpirational water use which could have a positive effect on increasing infiltration thus reducing surface runoff in the spring. Kura clover growing with corn as a living mulch needs further study to establish a feasible agronomic management to avoid corn yield loss. Significant higher soil water depletion in kura clover-corn and perennial forage treatments suggests that the infiltration would be increased significantly, thus the stream flow may be reduced by converting conventional corn-soybean rotation into kura clover-corn dual cropping system or perennial grass. Because subsurface drainage reduction under modified land cover was not seen in this study, the impact of agricultural land covers on NO_3-N loss through tile drainage system needs further investigation.

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Tables

Table 1. Agronomic management in the three years of study.

Management	2005 [a]	2006	2007	2008
Termination of rye followed by corn		24-Apr	30-Apr	6-May
Corn planting [b]		4-May	14-May	15-May
Soybean planting		10-May	17-May	23-May
Termination of rye followed by soybean		16-May	23-May	26-May
Suppression of kura clover for corn establishment [c]		-	29-May	26-May
Fertilization to corn		18-May	5-Jun	20-Jun
Soybean harvest		3-Oct	15-Oct	11-Oct
Corn harvesting		7-Oct	22-Oct	20-Oct
Rye seeding	11-Oct	12-Oct	25-Oct	21-Oct

[a] Management prior to rye seeding in 2005 were not listed

[b] Corn was not planted in kC treatment in 2006.

[c] Kura clover was not suppressed in 2006.

Table 2. Rainfall and temperature at the study site.

Month	Precipitation (mm)				Temperature (˚C)			
	long-term [a]	2006	2007	2008	long-term	2006	2007	2008
January	23	22	45	27	-9.3	-1.7	-7.9	-10.3
February	19	19	42	25	-5.7	-5.7	-11.1	-9.5
March	55	92	69	45	1.0	1.3	3.8	-1.1
April	81	93	106	90	8.6	11.7	7.4	6.5
May	99	22	90	156	15.6	15.8	18.1	14.1
June	116	47	44	161	21.0	21	21.5	20.3
July	110	10	41	102	22.8	23.2	22.2	22.7
August	111	113	367	81	21.3	21	22.2	18.1
September	78	107	97	65	16.7	14.5	17.9	16.4
October	57	19	119	84	9.8	7.7	12.5	9.8
November	46	46	1	42	0.9	2.1	1.4	1.3
December	27	35	27	48	-6.6	-1.6	-8	-9.5
Total	821	626	1050	926	8.0	9.1	8.3	6.6

[a] long-term norms were averages of weather data over 1971-2000 for Pocahontas (Station No. 125) and Humboldt (Station No. 070), IA, 19 km west and east from the research site. Obtained from National Climatic Data Center, NOAA.

Table 3. Annual and seasonal subsurface drainage in 2006-2008.

Treatment	2006			2007			2008			Average		
	Annual	Mar-Jun	Jul-Nov	Annual	Mar-Jun	Jul-Nov	Annual	Mar-Jun	Jul-Nov	Annual	Mar-Jun	Jul-Nov
C	119 a	110 a	8 a	488 a	172 a	316 a	387 a	332 a	55 a	331 a	205 a	126 a
rC	98 a	78 a	19 a	545 a	186 a	359 a	516 a	492 a	24 a	386 a	252 a	134 a
S	124 a	111 a	12 a	383 a	141 a	243 a	492 a	430 a	63 a	333 a	227 a	106 a
rS	116 a	106 a	9 a	577 a	142 a	435 a	352 a	336 a	16 a	348 a	198 a	153 a
kC	91 a	87 a	4 a	538 a	173 a	365 a	470 a	433 a	37 a	366 a	231 a	135 a
PF	108 a	105 a	3 a	437 a	154 a	282 a	534 a	465 a	69 a	360 a	241 a	118 a

Table 4. Average weekly soil water storage for each land cover treatment.

Treat-ment	3-year average		2006		2007		2008	
	Annual	May-Jul	Annual	May-Jul	Annual	May-Jul	Annual	May-Jul
fC	196 bc	194 a	187 b	183 ab	198 ab	191 a	202 a	206 a
rC	202 a	199 a	197 a	194 a	203 ab	195 a	206 a	208 a
fS	196 bc	193 a	190 ab	187 a	196 b	190 a	202 a	204 a
rS	200 ab	198 a	193 ab	189 a	201 ab	196 a	206 a	209 a
kC	193 c	184 b	176 c	164 bc	195 b	182 ab	206 a	203 a
PF	181 d	170 c	166 d	155 c	185 c	168 b	188 b	187 b
average	195	190	185	178	196	187	202	203

Mean within years and on average (i.e., within column) followed by the same letter are not significantly different at $p=0.05$.
Annual average soil water storage is significantly different among years: 2008>2007>2006 at $p<0.05$.

Table 5. Soil water dynamics in spring (prior to rye growth termination) in all land cover treatments (unit mm).

Year	Hydrologic components	Modified land covers				Conventional land covers		Differences									
		rC	rS	kC	PF	fC	fS	rC-fC		rS-fS		kC-fC		PF-fC		PF-kC	
2006						Beginning: May 1, End: May 16 (Rainfall 11 mm)											
	SWS_b	209	205	201	202	195	196										
	SWS_e	205	193	177	173	193	191										
	ΔSWS	-4	-12	-23	-29	-2	-5	-2	ns	-8	**	-21	***	-27	***	-6	**
	Drainage	10	8	8	8	11	9	-1	ns	-1	ns	-3	ns	-3	ns	0	ns
	Total ET	5	16	27	32	2	6	2	ns	10	ns	25	**	30	**	5	ns
	Daily ET	0.3	1.1	1.8	2.2	0.2	0.4	0	ns	-0.6	ns	1.6	**	2.0	**	0.4	ns
2007						Beginning: May 8, End: May 21 (Rainfall 6 mm)											
	SWS_b	213.1	212	211	215	208	206										
	SWS_e	205.6	187	168	171	197	195										
	ΔSWS	-8	-25	-43	-44	-11	-11	3	ns	-13	**	-32	***	-34	***	-1	ns
	Drainage	11.9	8	7	13	12	9	0	ns	-1	ns	-5	ns	1	ns	6	*
	Total ET	1	23	42	38	5	8	-3	ns	15	***	37	***	33	***	-4	ns
	Daily ET	0.1	1.8	3.2	2.9	0.4	0.6	0	ns	-1.1	***	2.9	***	2.5	***	-0.3	ns
2008						Beginning: May 12, End: May 22 (Rainfall 1 mm)											
	SWS_b	217	222	217	218	215	213										
	SWS_e	200	194	185	175	201	199										
	ΔSWS	-17	-28	-33	-43	-13	-14	-3	ns	-14	**	-20	*	-30	**	-10	ns
	Drainage	7	0	5	14	3	6	4	ns	-6	ns	2	ns	11	ns	9	ns
	Total ET	11	29	29	30	11	9	0	ns	20	**	18	ns	19	ns	1	ns
	Daily ET	1.1	2.9	2.9	3.0	1.1	0.9	0	ns	-2.0	**	1.8	ns	1.9	ns	0.1	ns
Average	**Daily ΔSWS**	**-0.8**	**-1.8**	**-2.7**	**-3.2**	**-0.8**	**-0.9**	**0**	**ns**	**-0.9**	*******	**-1.9**	*******	**-2.4**	*******	**-0.5**	**ns**
	Daily Drainage	**0.8**	**0.4**	**0.5**	**1.0**	**0.6**	**0.7**	**0.2**	**ns**	**-0.3**	**ns**	**-0.1**	**ns**	**0.4**	**ns**	**0.5**	**ns**
	Daily ET	**0.5**	**1.9**	**2.6**	**2.7**	**0.5**	**0.6**	**0**	**ns**	**1.3**	*******	**2.1**	*******	**2.2**	*******	**0.1**	**ns**

SWS_b: soil water storage at the beginning date; SWS_e: soil water storage at the end date; $\Delta SWS = SWS_e - SWS_b$. *, **, and ***: means within year are significantly different from 0 at p=0.1, 0.05, and 0.001, respectively. ns: means are not significantly different from 0 at p=0.1.

Figures

Figure 1. Monthly reference ET_0 in the three years of study.

Figure 2. Corn and soybean grain yield averaged over the three years of study. In the kC treatment, corn was planted in 2007 and 2008 not in 2006 (Error bar is ±1 standard deviation).

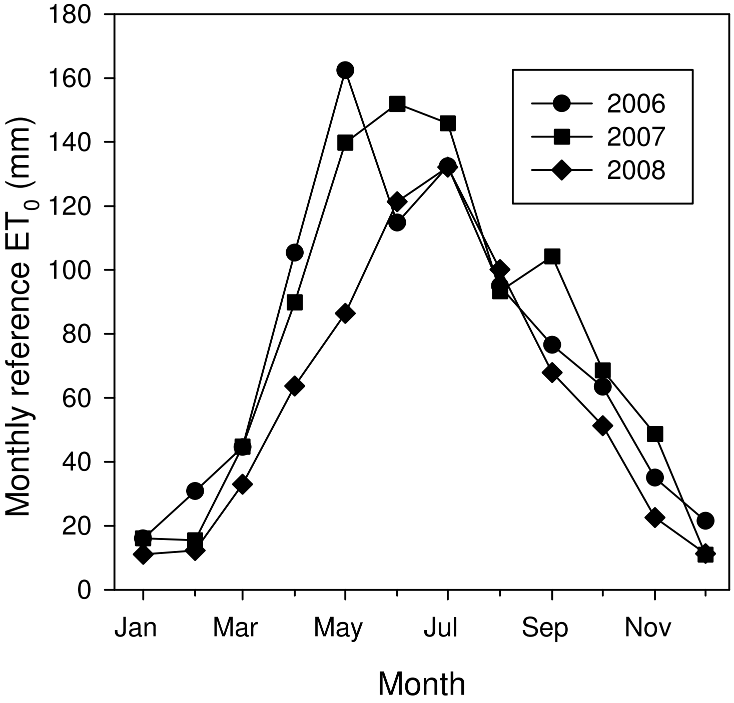
Figure 3. Comparison of SWS in conventional corn (C) versus rye-corn (rC) in (a) 2006, (b) 2007, and (c) 2008.

Figure 4. Comparison of SWS in conventional soybean (S) versus rye-soybean (rS) in the three years from (a) 2006, (b) 2007, and (c) 2008.

Figure 5. Comparison of SWS in conventional corn (C) versus kura clover as a living mulch for corn (kC) in (a) 2006, (b) 2007, and (c) 2008.

Figure 6. Soil water content at 5-15 cm of kura clover as a living mulch for corn (kC) and conventional corn (C) treatments in (a) 2006, (b) 2007, and (c) 2008.

Figure 7. Comparison of SWS in kura clover as a living mulch for corn (kC) versus perennial forage (PF) in (a) 2006, (b) 2007, and (c) 2008.



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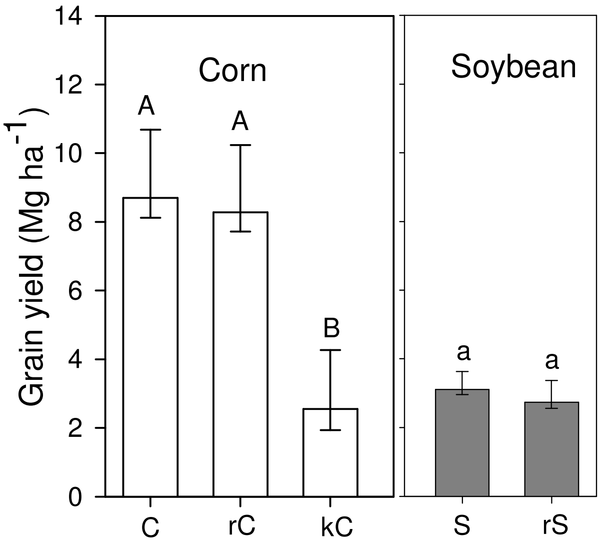

Figure 2. Corn and soybean grain yield averaged over the three years of study. Mean followed by the same letter are not significantly different at p=0.05. In the kC treatment, corn was planted in 2007 and 2008 not in 2006 (Error bar is ±1 standard deviation).

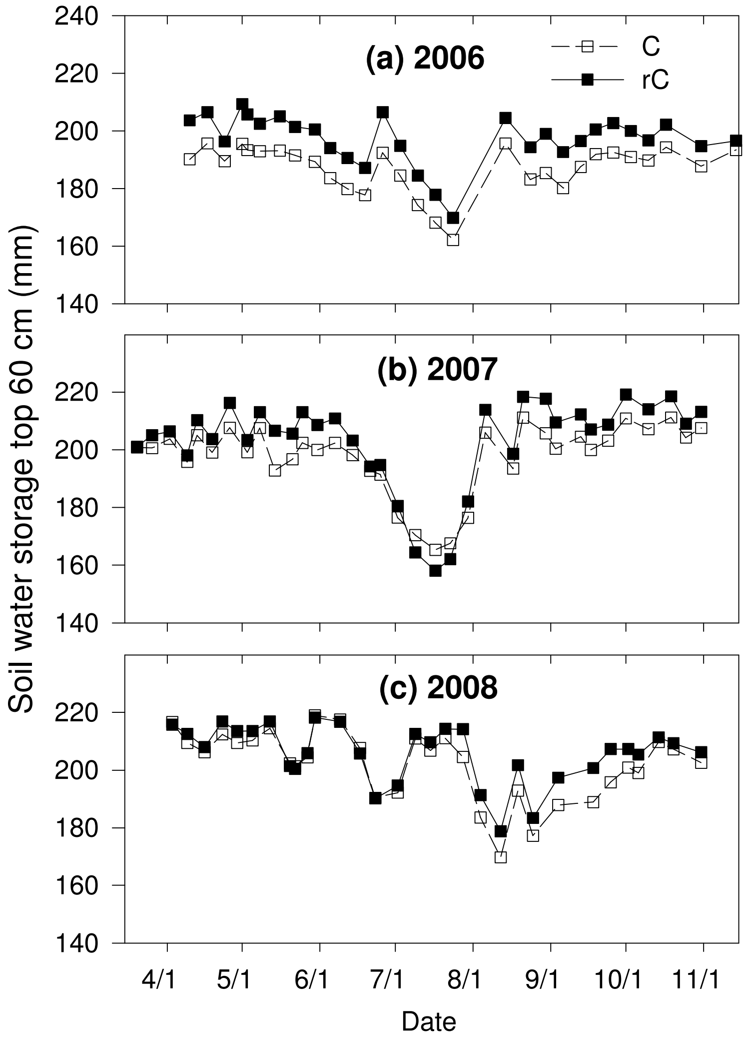

Figure 3. Comparison of SWS in conventional corn (C) versus rye-corn (rC) in (a) 2006, (b) 2007, and (c) 2008.

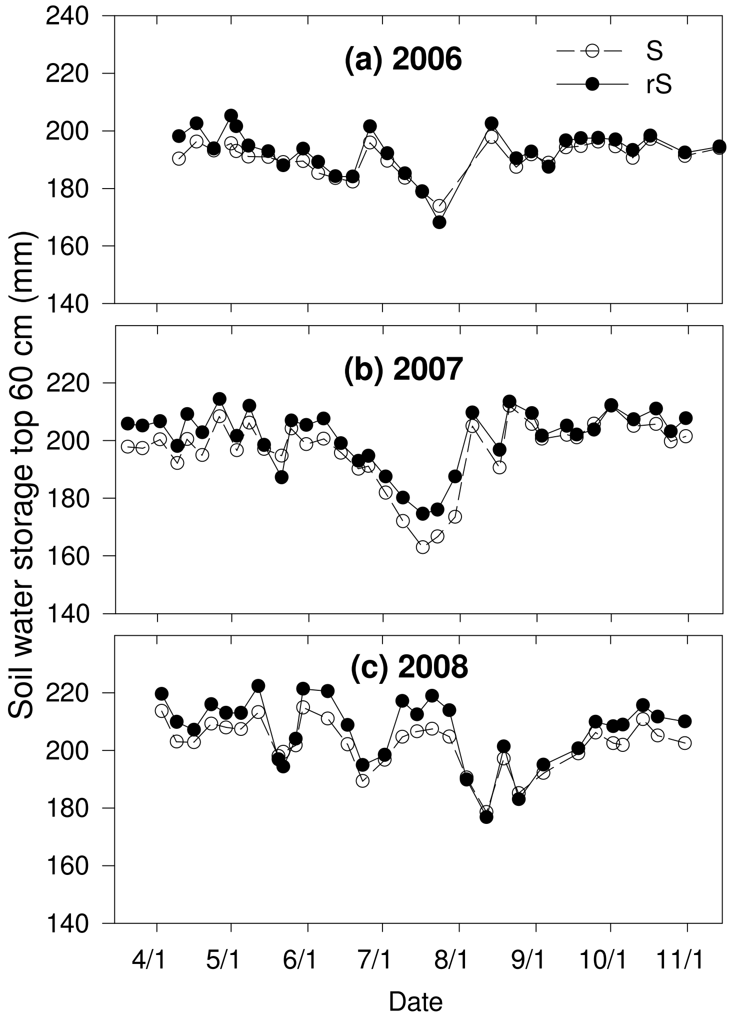

Figure 4. Comparison of SWS in conventional soybean (S) versus rye-soybean (rS) in the three years from (a) 2006, (b) 2007, and (c) 2008.

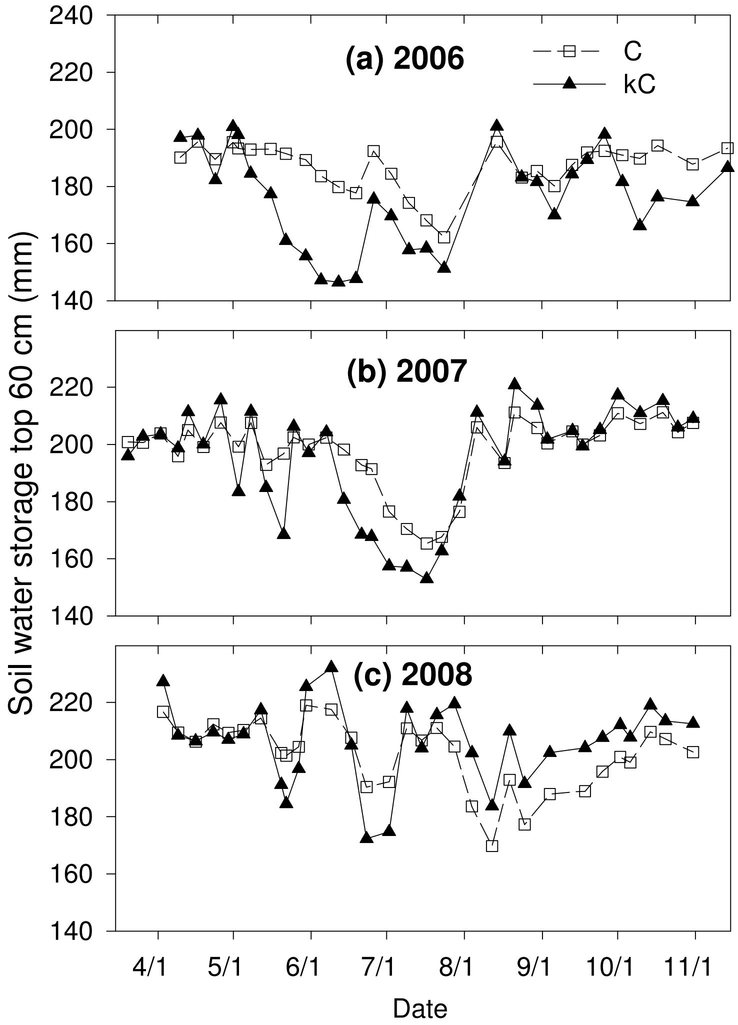

Figure 5. Comparison of SWS in conventional corn (C) versus kura clover as a living mulch for corn (kC) in (a) 2006, (b) 2007, and (c) 2008.

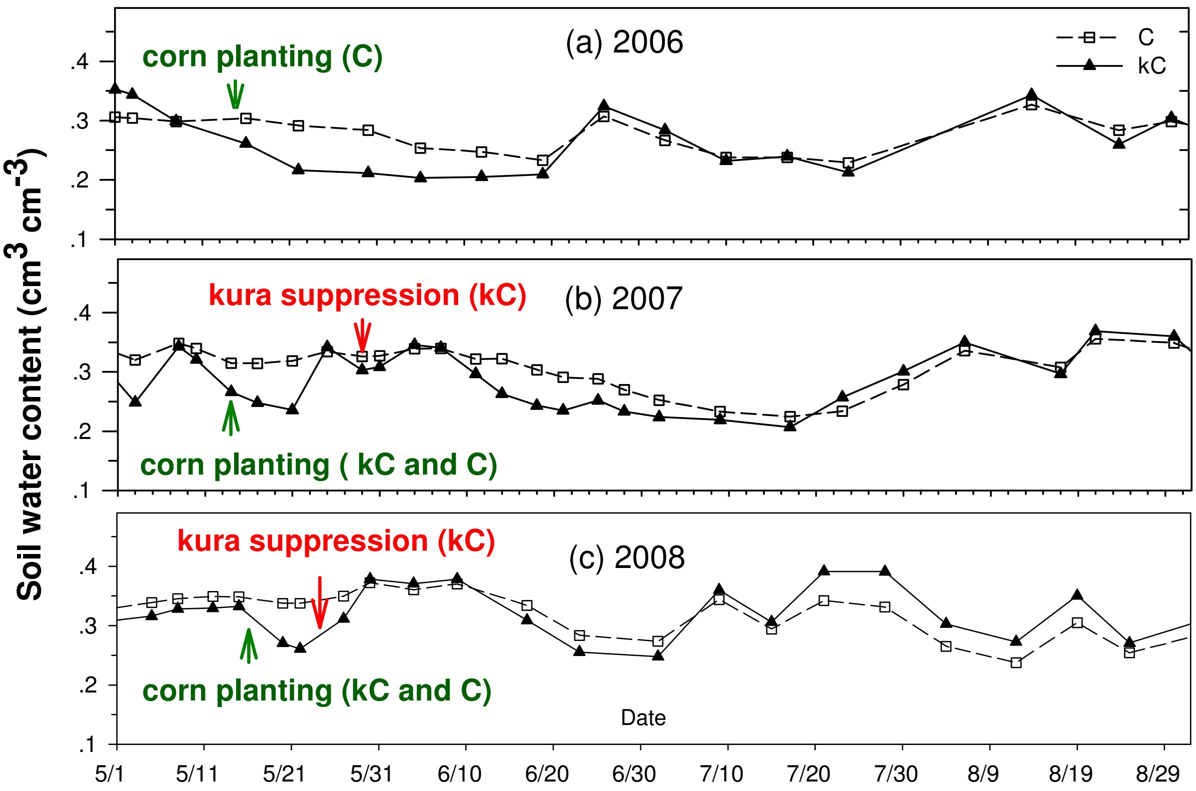

Figure 6. Soil water content at 5-15 cm of kura clover as a living mulch for corn (kC) and conventional corn (C) treatments in (a) 2006, (b) 2007, and (c) 2008. Corn was not planted in kC plots in 2006.

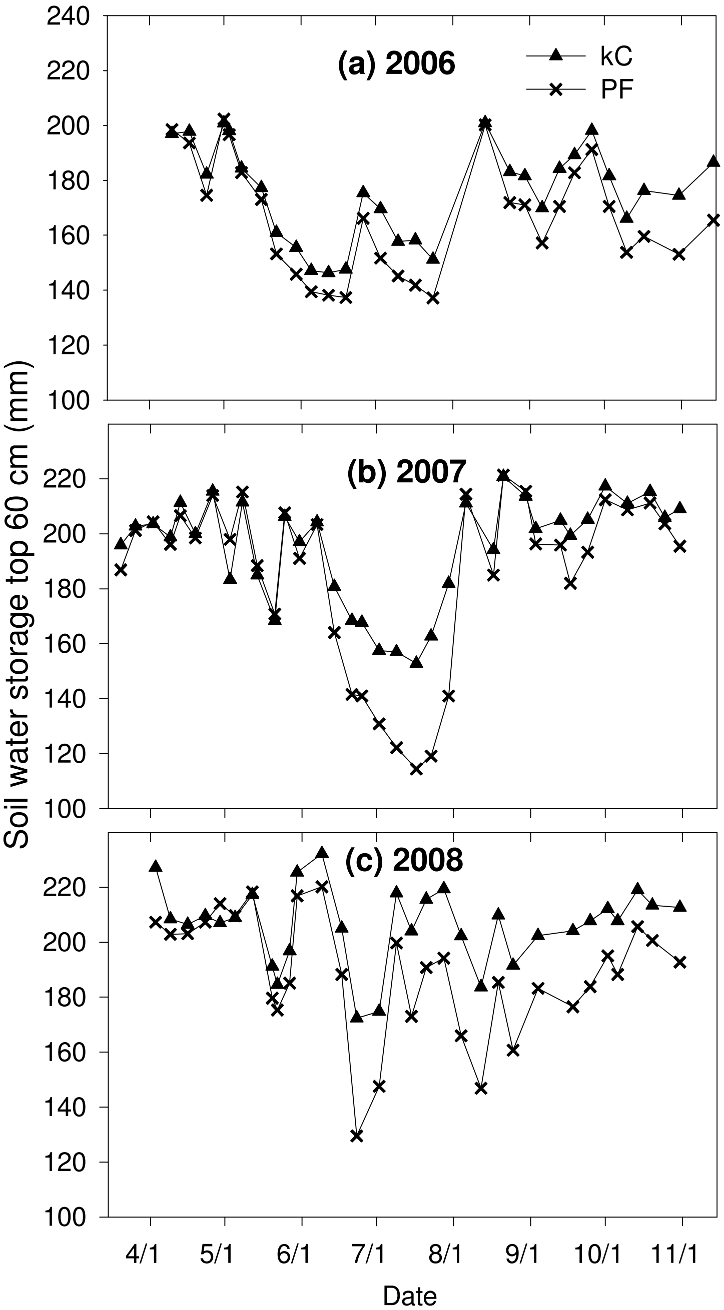

Figure 7. Comparison of SWS in kura clover as a living mulch for corn (kC) versus perennial forage (PF) in (a) 2006, (b) 2007, and (c) 2008.