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Residue biomass removal and potential impact on production and environmental quality

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Introduction

The implementation of conservation systems to sustain soil and improve environmental quality has to be considered in the current trend toward the increase of continuous corn acreage and future thinking of corn residue removal for cellulosic ethanol production. There is a high possibility that continuous corn production can increase the use of conventional tillage. The increase in conventional tillage coupled with high use of N fertilizer in continuous corn will present a significant soil and water quality challenge. This trend will present economic and environmental challenges that we need to consider as well. The use of corn stover for cellulosic ethanol production or any other purposes should be weighed against the potential impact on soil productivity, environmental consequences, and food availability. It is imperative that alternative perennial biomass sources for lingocellulosic ethanol production should be explored in combination with corn grain ethanol to strike a balance between environmental sustainability and economic viability.

Leaving crop residue on soil the surface will improve nutrients cycling and ultimately soil quality that increase and sustain soil productivity. Post-harvest residues are a critical source of soil organic matter, provide protection to the soil surface against water and wind erosion, and improvement of soil and water quality. On the contrary, alternative utilizations of corn residues for various purposes, such as, baling residue for animal use or for lignocellulosic ethonal production needs to be approached carefully, which potentially can have adverse effects on soil and water quality.

Sustainable stover removal rates depend on several factors, which include soil erodibility, surface slope, cultural practices, and climate conditions. Recent studies suggest that only 20% to 30% of the total stover production could be removed for biofuel, based on ground cover requirements to control soil erosion. It is not clear or well documented the methods or the guidelines for residue removal from any given field. It is also not clear whether current management practices for soil erosion control are appropriate for maintaining soil organic matter level and soil quality in general.

Residue removal impact on soil productivity and environmental quality is not a short-term outcome, particularly in the Midwest, where high organic matter, high soil productivity, and good agriculture production conditions minimize such effect in the short-term. However, it will have a devastating impact on soil sustainability and environmental quality in the long-term as documented by many studies in the Midwest and elsewhere. The continuous removal of corn residue coupled with intensive tillage is well documented in long-term studies, where soil quality, crop productivity, and air quality are compromised. In a long-term study established in 1888 and continuing to present in Missouri and Illinois with different crop rotations, manure, and tillage treatments, continuous corn production coupled with intensive tillage decreased soil organic matter by almost 64%. The loss of original soil organic matter due to tillage practices will exceed any potential additional of carbon from crop residue, because the majority (70-80%) of crop residue carbon when it decomposes will be lost as CO_2 to the atmosphere. Therefore, the loss of residues due to removal for any use can accelerate soil organic matter loss and nutrient source to the soil. It is also well documented that intensive tillage and mono-cropping systems such as continuous corn along with residue removal can have significant negative impact on degrading soil organic matter and increase CO_2 release and potential water quality problems. It was found in a long-term study that corn stover removal had reduced total source of carbon (SC) by 20% and corn derived soil organic carbon by 35% in 13 yr period.

Possible short term impacts of corn stover removal may include an increase in N, P, and K, Ca, and Mg nutrients application to replace these nutrients due to residue removal and potential deficiencies in soil nutrients pool in the long term. In one study, it was estimated that these macro-nutrients replacement cost due to residue removal was approximately $10/ton of harvested residue. These nutrients will be permanently lost from the soil system nutrients pool due to lack of replenishment from crop residue and they have to be added to keep soil productivity. In addition to the potential of productivity and soil quality losses, there is high potential for accelerating soil erosion due to lack of vegetative cover for significant length of time during any year. There are over 20 million acres in the state in row crop production. These acres normally have no crop growing on them from November to late March. During these five months soils are at the most vulnerable conditions, where high potential of surface runoff is very likely to take place. The soil loss from 20 million acres of cropland can be on average 4.7 tons/acre. The economic loss due to the loss of soil and organic matter as a source of most of the nutrients needed for corn or soybean productions coupled with off-site losses can be in the billions of dollars. The approximate cost of on-site (productivity loss) per ton of soil loss estimated to be $8/ton of soil and offsite cost was estimated to be $13/ton of soil. Crop residue along with conservation practices can lessen the impact of our demanding row cropping system to at least keeping the soil in its present conditions.

Study description

In agricultural systems, like any other ecosystem, the alteration of one part of the system may have large effects on the system as a whole. Under current agricultural practices, corn stover remains on the field after harvest and is reincorporated into the soil with conventional tillage accelerating decomposition, or is left on the surface with no-till where decomposition is slower. Some studies have suggested that in order to meet the demands of the bioethanol industry, farmers will need to increasingly adapt to no-till practices in order to offset soil C losses from corn stover removal. It has also been suggested that additional N fertilization will be needed to increases root biomass to further aid in soil C sequestration as a consequence of corn stover removal.

Therefore, the objectives of this study is to establish coordinated field and laboratory studies to determine the short-term and long-term impacts of varying corn stover removal and N fertilization rate and tillage systems on soil, air, and water resources. The project has four anticipated outcomes which include; (1) reliable estimates of C and nutrients removed and returned to the soil, (2) soil C and N sequestration potential, (3) amount of greenhouse gases being emitted, and (4) impacts on soil physical properties.

Study was established in fall of 2008 on a Nicollet-Webster (poor drainage) soil association at Iowa State University Agronomy Research Farm and Marshall (well drained) soil association at Armstrong Research and Demonstration Farm southwest of Atlantic, IA. There were three treatments; the main treatment was tillage practice (no-till and chisel plow), which was split into three different corn stover removal rates (0, 50, and 100%) which was then further split into six N fertilization rate treatments varying from 0 to 250 lb N/acre in spring of 2009.

Soil measurements are being conducted every August which include soil C, N, P, K, and bulk density. Additionally, soil temperature is being monitored on an hourly basis as well as weekly soil moisture. After every harvest, crop measurements include harvested corn for grain yield, and N, P, and K uptake. In addition, CO_2 and N_2O are measured on weekly basis. Other soil properties such as infiltration rate, soil compaction, aggregate stability, soil moisture, and soil temperature will be collected. Also, crop measurements including above ground and below ground biomass will be collected.

Results and discussions

Corn yield response to residue removal

Corn yield response due to residue removal by N rate is summarized in Figure 1. In 2009, there was generally no significant effect of residue removal on corn yields. The only exception is when no N was applied, removing residue increased corn yields. Both the poorly and well-drained sites had unusually cold and wet spring prior to June. In 2010, there was a significant residue removal effect on corn yields as affected by different N rates and tillage. Corn yields were much lower in 2010 due to a cold and wet spring similar to 2009 yields. In the well-drained soil, corn yields were higher when 50 and 100% of the corn residue was removed across all N rates. In the poorly drained soil, corn yields were also higher when 50 and 100% of residue was removed at N rates ranging from 50 to 200 lbs N ac-1. Corn yields were also affected by tillage (Figure 2). The lowest corn yields occurred when no residue was removed and under no-till. Hence, the highest corn yield occurred when 50 and 100 % of corn residue was removed under chisel plow. Increases in corn yield due to residue removal may be attributed to higher soil temperatures increasing potential organic mineralization resulting in greater biomass and grain production.

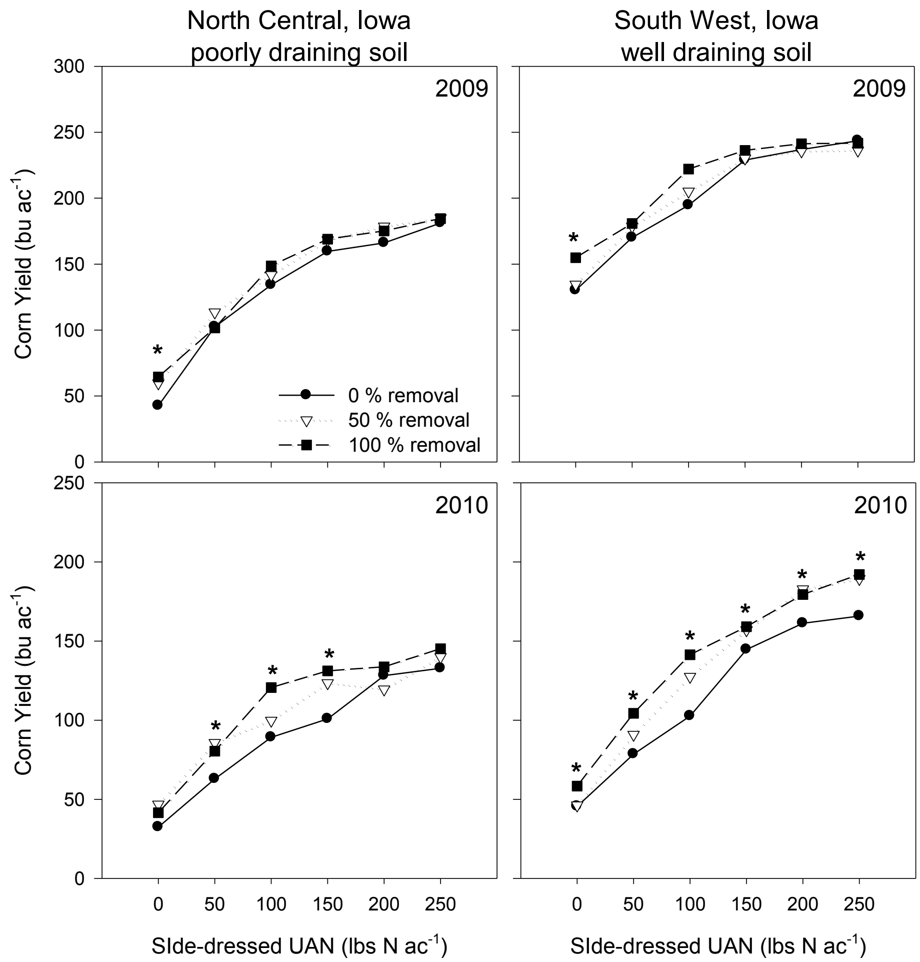

Figure 1. Residue removal effects on corn yields as affected by N rate in 2009 and 2010 for poorly and well-drained soils. Asterisk indicates significant difference between residue removal within each N rate at p=0.05.

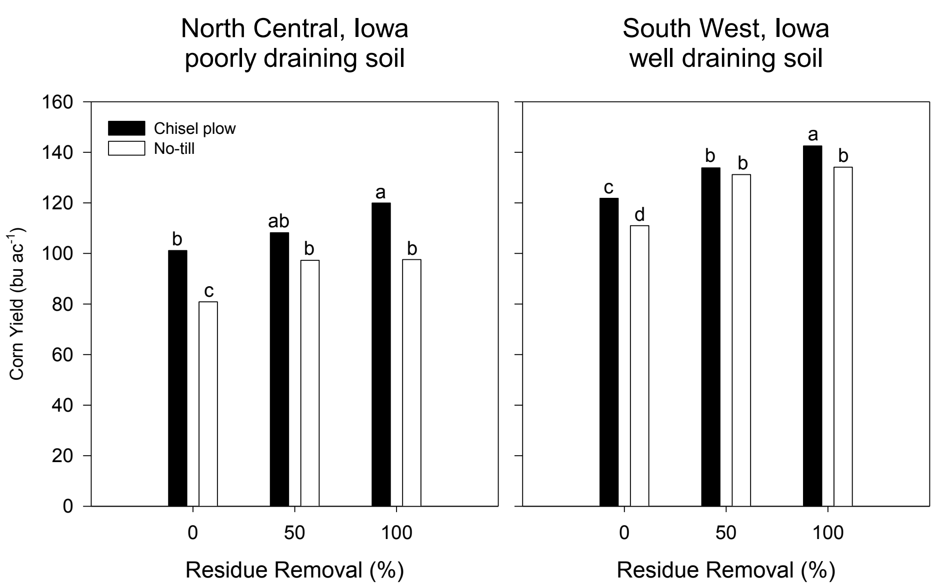

Figure 2. Residue removal effects on corn yields as affected by tillage in 2010 for poorly and well-drained soils. Different letters indicate significant difference between residue removal and tillage at p=0.05.

Residue removal effects on total soil carbon

After two years of residue removal and under different N rates and tillage practices, there were no significant differences in total soil C compared to the baseline year in 2008 for both sites (Figure 3). This was not entirely unexpected, since total soil C in these sites are relatively high and ranged from 2.3 to 4.5 %. Any changes in total soil C would be difficult to detect after only two years, where maximum increases in total soil C have been recorded to be as high as 0.06 % in one year. This is often masked by natural soil variability which in these sites, total soil C varied by 0.5 %. Residue removal effects on labile (new, easily decomposable) soil C pool are greater and much easier to detect. Soil microbial biomass-C is used as an indicator for labile C in the soil, and was done in this study.

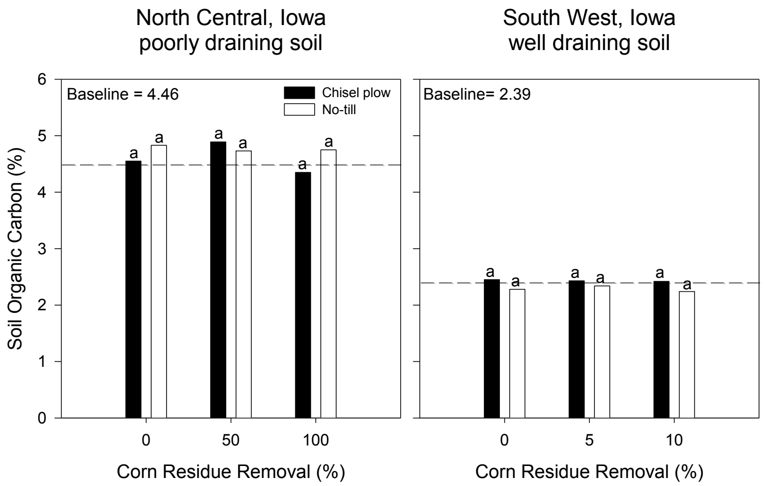

Figure 3. Total soil carbon as affected by two years of residue removal for poorly and well-drained soils. Different letters indicate significant difference between residue removal at p=0.05.

Residue removal effects on potential soil organic carbon sequestration

A carbon budget approach by estimating net ecosystem productivity was used to determine if residue removal under different N rates and tillage management had net gains or losses in potential C sequestration (Figure 4.). Results from the C budget show that only under high N rates and no-till with very little residue removal, there were potential gains in soil organic C (SOC) in poorly and well-drained soils. In the poorly-drained soil site, approximately 15 % of the residue can be removed without having a net loss in potential SOC sequestration. In the well-drained soil site, only approximately 9 % of the residue can be removed without having a net loss in potential SOC sequestration. Under typical N rates in Iowa (150 lbs N ac^{-1}) with continuous corn, even when no residue was removed and under no-till, it was observed a potential net losses of SOC. Furthermore, potential losses of SOC sequestration were greatly increased when residue was removed. The adoption of no-till did lessen the potential losses of SOC due to residue removal in the poorly-drained soil site, but not in the well-drained soil site. Potential losses of SOC sequestration were greatest under management practice with high residue removal, no N application, and chisel plow.

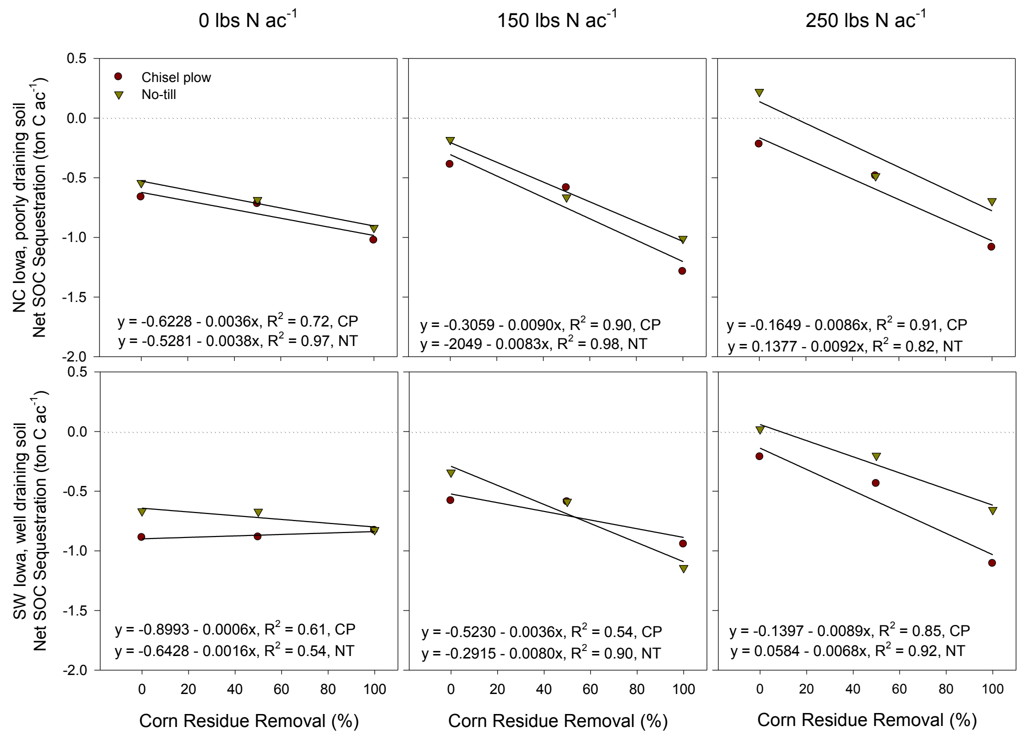

Figure 4. Potential changes to net soil organic carbon from carbon input from above- and below-ground biomass minus losses from microbial respiration to a depth of 15 cm. Carbon budget was conducted in 2010 in a well-drained soil and poorly-drained soil under different tillage and N fertilization regimes.

Residue removal effects on soil physical properties after two years of residue removal

After two years of residue removal and under different N rates and tillage practices, there were significant differences in bulk density compared to the baseline year in 2008 for both sites (Figure 5). In the poorly-drained soil site, bulk density was significantly greater when 100% of the residue was removed under both tillage systems. Similar results were observed in the well-drained soil site, except there were also significant increases in bulk density under no-till when 50% of the residue was removed. In addition, the lack of N application also significantly increased bulk density under both sites and tillage practices, where significant reduction in root biomass took place which has direct impact on soil structure and bulk density (data not shown). Corn residue removal also negatively impacted soil aggregation after only two years (Figure 6). In general, the greatest soil aggregation occurred under no-till and when no residue was removed. Significant decreases in soil aggregation occurred when 50% of residue was removed compared to 0%, and tended to further decrease with 100% residue removal, although not significantly different. The addition of higher N rates did not appear to significantly affect soil aggregation. However when no N was applied, significant decreases in soil aggregation were observed.

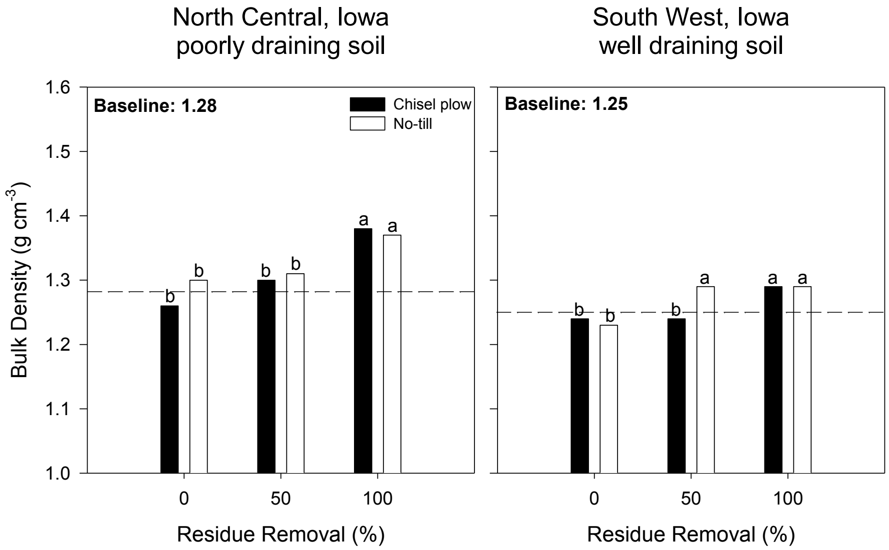

Figure 5. Soil bulk density as affected by two years of residue removal and tillage systems for poorly and well-drained soils. Different letters indicate significant difference between residue removal and tillage at p=0.05.

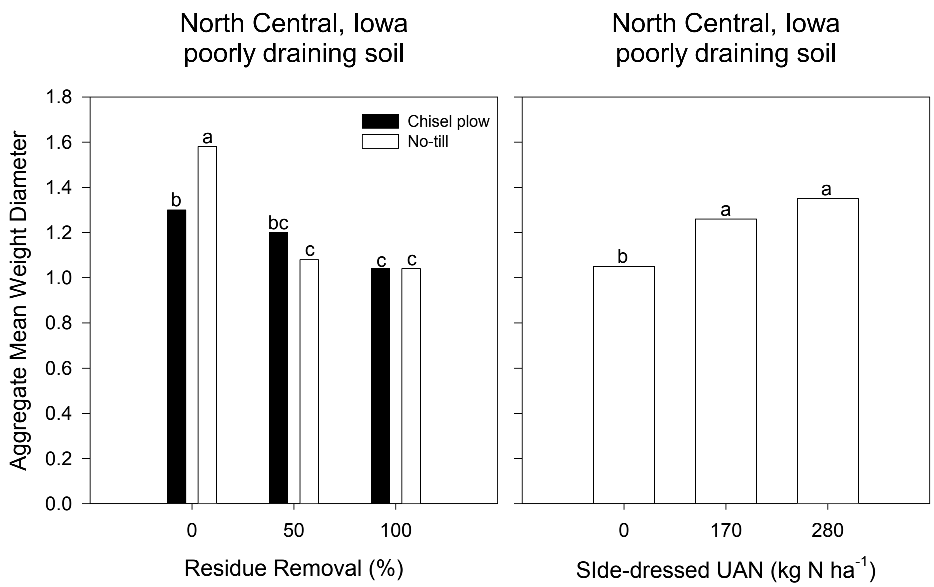

Figure 6. Aggregate mean weight diameter as affected by two years of residue removal, tillage and nitrogen rate systems for a poorly-drained soil site. Different letters indicate significant difference between residue removal, tillage and nitrogen rate at p=0.05.

The results of higher bulk density and lower soil aggregation due to residue removal and subsequently reduced steady water infiltration rates (SWIR) in the well-drained soil site only (Figure 7). These decreases in SWIR were only observed under chisel plow and 100% residue removal. Consequently, the adoption of no-till did help maintain SWIR when corn residue was removed. In the poorly-drained soil site, SWIR were already low, with only 17% of the water infiltrated into the soil and 83% as runoff when simulated rainfall rates of 0.42 cm per minute were used.

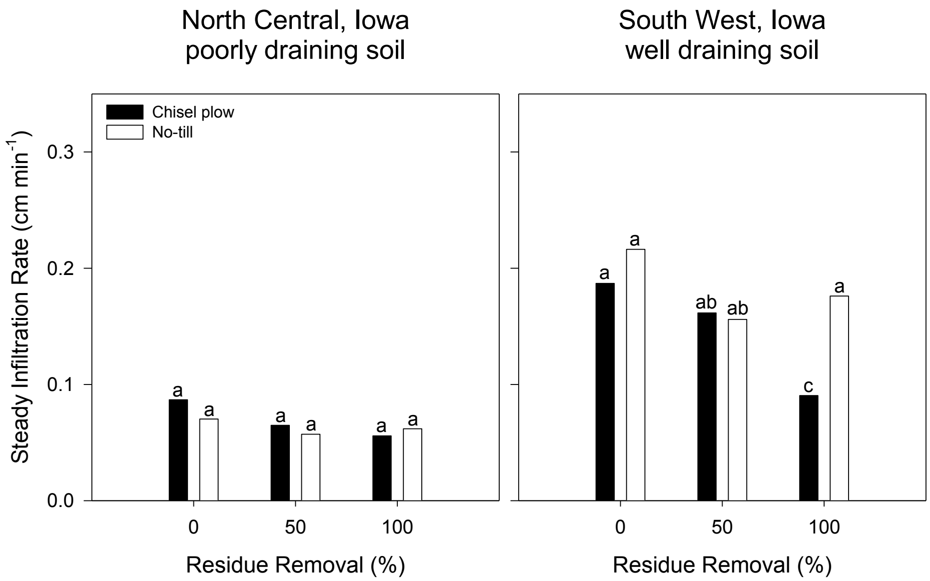

Figure 7. Steady water infiltration rates as affected by residue removal and tillage for poorly and well-drained soil sites. Different letters indicate significant difference between residue removal and tillage at p=0.05.

Summary

After two years of corn residue removal in poorly and well-drained soil sites, there were no significant decreases in grain yield. In general, removing residue increased grain yields due to soil warming under cold and wet conditions early in the spring. In addition, there were no significant decreases in total SOC concentrations compared to baseline year. However, potential decreases in SOC sequestration were observed when residue was removed. The adoption of no-till and increased N rates did reduce some of the C losses due to residue removal. However, only with adoption of no-till and N rates greater than 150 lbs N ac^{-1} with very little residue removed, potential increases in soil C were observed. In the poorly drained soil site, approximately 15% of corn residue can be removed without seeing a net loss in potential SOC sequestration. In the well-drained site, only approximately 9% of the residue can be removed without having a net loss in potential SOC sequestration. Significant short term effects of residue removal on soil physical properties were observed. Increases of bulk density were observed with 100% residue removal regardless of tillage and increased N fertilization rate. Furthermore, decreases in soil aggregation were observed with residue removal, regardless of tillage and increased N fertilization rate. Subsequently, SWIR were significantly reduced in the well-drained soil site. In general, the adoption of no-till over chisel plow and increased rates of N fertilization did offset some of the negative impacts of residue removal, but potential losses of SOC sequestration and deterioration of soil physical properties were still observed.

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