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Effect of Conservation Tillage on Soil and Water Quality

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Abstract: Soil erosion from cropland has been recognized as a major problem in agricultural production. Conservation tillage is one of many conservation practices developed to reduce soil erosion. Meanwhile, many benefits from conservation tillage system beyond controlling soil loss have been reported. The objective of this work is to briefly review effect of conservation tillage on soil erosion and runoff, soil organic matter, selected soil physical properties, and water quality. Conservation tillage has inconsistent effects on surface runoff and soil loss due to differences in surface roughness and the rate of crop residue left on the soil surface. Increased soil organic carbon (SOC), mainly concentrated near soil surface, has been widely reported in the literature. However, SOC under conservation tillage is labile in topsoil and more recalcitrant in subsoil. Increased SOC leads to improved soil physical properties such as reduced bulk density, increased hydraulic conductivity and infiltration, and improved water retention capacity. Conservation tillage could improve water quality by reducing the total sediment, nitrate, ammonium, and phosphate in the runoff. However, conservation tillage may also facilitate nitrate leaching due to the increase of macropores in soil body.

Keywords: Conservation Tillage, Soil, Water, Quality.

1. Introduction

Soil erosion from cropland in the U.S. has been recognized as a major problem for more than sixty years. Much effort has been devoted to maintain healthy soils for agricultural production. Conservation tillage is one of many conservation practices developed to reduce soil erosion. The term "conservation tillage" has various interpretations in different parts of the world due to regional, technical, economical and institutional differences[1]. The U.S. Conservation Technology Information Center (CTIC) developed the first widely accepted definition of conservation tillage as "any tillage and planting system that covers at least 30% of the soil surface with crop residue, after planting, in order to reduce soil erosion by water" [2]. In publications, conservation tillage is often used interchangeably with minimum till, reduced till, no/zero till, mulch till, etc. The practical principles behind conservation tillage are minimum soil disturbance by avoiding soil inversion, permanent soil cover by managing plant residue, and crop rotation [3]. The adoption of conservation tillage in the U.S. has increased from 2% in 1968 to approximately 41% in 2004 [4].

Many benefits from conservation tillage system beyond controlling soil loss have been reported, for example, reduced labor and fuel costs, and increased soil organic matter. The objective of this term paper is to briefly review effect of conservation tillage on soil erosion and runoff, soil organic matter, selected soil physical properties, and water quality.

2. Soil Erosion and Runoff

Conservation tillage is considered as a primary means of reducing soil and water erosion on cropland. Prato and Shi[5] compared no till and minimum till to conventional tillage, each with conservation practices including contour, cross-slope or divided-slope. They found regardless of the conservation practices, conventional tillage resulted in an annual soil loss of 12-13 tons per acre, compared to 7.5-9 from minimum till and 5-6 from no till. Clearly, the choice of tillage system was more important than other conservation practice options for agricultural production.

There have been numerous reports of reduced soil loss under conservation tillage, however, the efficiency and effectiveness of conservation tillage varied greatly due to different crops grown, slope steepness, soil types, and rainfall patterns. Simulation studies were typically conducted on level slopes. Rhoton et al. [6] compared soil loss of silt loam soils under conventional tillage and no till following application of simulated rainfall at an intensity of 50 mm h-1 for 1 h. They found soil loss from conventional treatments averaged 1.7 tons per acre, compared to 0 from no-till treatments. In another rainfall simulation study (50 mm h-1 for 2 h) on two Alabama soils, interrill erosion was reduced by 10-20 folds with no till, para till, and a rye cover crop compared to conventional tillage without deep tillage or cover crop [7]. Studies performed under natural rainfall conditions have shown inconsistent results. After comparing six tillage systems on a 5% slope in Mississippi, McGregor and Mutchler[8] found continuous no till produced the lowest annual soil loss (0.13 tons per acre). Reduced till, ridge till, and conventional tillage produced annual soil losses of 1.5, 2.5, and 3.5 tons per acre, respectively. However, a study performed on 7-13% slopes in Ohio indicated that soil erosion was dominated by infrequent, severe storms, and there was no significant difference between no till, para till and chisel till on controlling soil loss [9].

Many studies have shown that conservation tillage practices were more effective in reducing runoff than conventional tillage. Mostaghimi et al. found no till reduced runoff volume by 87% with no residue cover and by 99% with 1500 kg ha-1 residue cover in a simulated rainfall study. A field research with natural rainfall in eastern Tennessee showed a 90% reduction in runoff with no till compared to conventional tillage. However, conservation tillage does not always reduce the volume of runoff as effectively as it reduces soil losses. A few studies have reported that no till, sometimes, may result in relatively higher runoff volume as compared with conventional tillage[10]. The differences in runoff volume and soil loss under various tillage treatments are possibly due to differences in surface roughness and the rate of crop residue left on the soil surface [11]

3. Soil Organic Matter

Soil erosion caused by water is primarily due to particle detachment and transport by rainfall and runoff. Increased soil organic matter as well as treatment effects on other properties that affect infiltration and surface crusting is largely responsible for the reduction in soil loss and elimination of runoff under conservation tillage.

Soil organic matter (SOM), or soil organic carbon (SOC), is the primary indicator of soil quality, and is greatly influenced by agricultural management practices such as tillage. Crop residue management practices and their effect on SOC vary greatly by region and climate. Typically, changes on SOC due to short-term tillage is spatially variable and usually small compared to background SOC level. However, in the Southeast, high temperature and precipitation allow crop residue to decompose rapidly, therefore SOC can be notably increased in a relatively short time after switching to conservation tillage. In the “Old Rotation” at Auburn, AL, the oldest continuous cotton experiment in the world, SOC content 3.5 years after adoption of conservation tillage was dramatically increased by 39% in the top 20 cm soils [12]. Another example is a 4-year cotton research on Compass loamy sand in Alabama. Result showed SOC in the top 5 cm soils under conservation tillage was 46% higher than under conventional tillage [13].

West and Post [14] reviewed several long-term tillage studies and concluded that an average of 0.57 t C ha-1 year-1 can be sequestered by converting conventional tillage to no till. However, this conclusion may be questionable since sampling procedures used in those studies could have biased the results. Baker et al. [15]argued that almost all the studies reporting higher SOC in no till soils than in plowed soils have based their conclusions on soil samples collected within 30 cm soil depth. A few studies reporting SOC for the whole soil profile have found either no difference in SOC below the 30 cm depth or even lower SOC in no till relative to plowed till soils[16]. In most cases, SOC in no till soils is concentrated near the soil surface, therefore the lower SOC in deeper layers of no till soils may offset the greater SOC in the top layers[17]. As a result, SOC in the total soil profile between no till and plowed till soils may not be significantly different. Soil organic carbon stored in the topsoil is subject to rapid decomposition due to the increased microbial activity and better thermal and moisture conditions near soil surface. Unlike the labile SOC in top soils, SOC stored in deeper layers is typically aggregate-protected and has lower turnover rates [18]. Therefore SOC in sub soils plays a more important role in long-term SOC sequestration. Another limitation is that soil bulk density were not reported in many papers. Chen et al. [19]found the correlation between estimated and actually measured bulk density is very poor (r2= 0.02), thus use of simulated bulk density to calculate SOC sequestered under contrasting tillage systems may lead to wrong conclusion.

4. Soil Physical Property

Soil porosity plays a critical role in biological productivity and hydrology of agricultural soils. Pores are of different size, shape and continuity influence the infiltration, storage and drainage of water, movement of the gas. Total porosity is normally calculated from measurements of bulk density, thus the terms total porosity and bulk density are used interchangeably in publications.

Impacts of tillage system on soil bulk density have been intensively studied, but the results are highly inconsistent. Logsdon and Cambardella [20]measured the temporal changes in bulk density in medium-textured soils in the midwestern U.S. and found bulk density measured 3 years after the implementation of no till was not significantly different from the initial sample. Increased bulk density under no till relative to conventional tillage has been reported in many studies. For example, bulk density was found greater under no till than under conventional till at 0-18 cm depth in three different soils (sand, sandy loam and silt loam) from Denmark , in the top 20 cm of soils varying from sandy loam to clay loam in southern Ontario, and in the top 8 cm of an eroded silt loam in southern Illinois. Increased bulk density usually indicates reduced soil porosity. There is also some evidence that the porosity in the top 5 cm of the profile under no till was similar to or greater than under conventional tillage [21]. The extent of increase is attributed to the build-up of SOM and enhanced macro-faunal activity such as earthworm in the top soils [22].

One of the major advantage of no till is retention of soil water. Studies have shown that water content in the upper 0-8 cm of the soils was significantly higher for no till than for conventional tillage due to significantly lower temperature and evaporation of surface soils under no till management. However, plant available water was found not different between no till and conventional tillage systems. This is probably due to different pore size distribution under different tillage systems. Soils under no till have developed a structure consisting of micro-pores (< 0.2 μm). Water in these pores is generally not available to plants. In contrast, there is greater amount of medium to large pore space (0.2-30 μm) for the storage of plant available water in conventional tilled soils [23].

Hydraulic conductivity and infiltration are good indicators of soil structure. Some studies reported saturated hydraulic conductivity was not significantly different between no till and conventional till. However, Mahboubi et al. found after 28 years’ continuous no till on two silt loam soils in Ohio, soil hydraulic conductivity was 12-times higher for no till than conventional tillage due to increased large pores and visible earthworm activities in no till. No till can also significantly improve infiltration compared with conventional tillage. A simulation rainfall study showed that about 96% of the simulated rainfall infiltrated under no till with residue cover, but only 42% infiltrated on conventional tillage without paratilling [21].

5. Water Quality

Water quality can be impaired when runoff from cropland includes sediment, pesticide, nutrients, and other contaminants is directly discharged to surface and ground water. Several studies are available that evaluate the improvements in water quality associated with the use of conservation tillage. A simulated rainfall study found no till reduced total sediment, nitrate, ammonium, and phosphate in the runoff by 98%, 86%, 57% and 58%, respectively, compared to conventional tillage [11]. Fawcett et al. [24] evaluated the effects of various best management practices, including conservation tillage, on pesticide runoff into surface water and leaching into groundwater. They conclude that no tillage systems provide a 70% reduction in runoff losses for active pesticide ingredients studied (e.g. Atrazine).

Although no till is usually beneficial, it can occasionally be detrimental to water quality. Losses of N fertilizer by denitrification may be greater in no till soils than in comparable conventionally tilled soils. No tilled soils are prone to saturation and thus anaerobic due to reduced runoff and increased infiltration during seasons of high rainfall. The population of denitrifying bacteria may increase several-fold in poorly drained soils or slowly permeable soils during rain weather[25]. This could limit the chances of success with no-till by promoting extensive denitrification losses. Another problem with no till is deep leaching of nitrate. Due to greater water content and increased total porosity under no till, a greater proportion of the rainfall moves through the macro-pores, carrying nitrate to a deeper depth than in the initially drier, conventionally tilled soil. Increased nitrate in ground water pose an increased health risk to animal and human health.

6. Summary

Producers must consider the advantage and disadvantages of a tillage systems before changing systems. There is considerably evidence that conservation tillage could provide a wide range of environmental benefits, including reduced labors and fuel requirements, less runoff and soil loss, and improved water and soil quality by adding SOM as crop residues decompose. However, conservation tillage may occasionally increase leaching of nitrate and other chemicals (e.g. pesticide and herbicide) to groundwater. With carefully and integrated field management practices, environmental risks caused by conservation tillage can be reduced to minimum.

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