Agricultural Water Management 176 (2016) 1–8

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Combined effects of runoff and soil erodibility on available nitrogen losses from sloping farmland affected by agricultural practices

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ARTICLE INFO

Article history:
Received 23 January 2016
Received in revised form 2 May 2016
Accepted 11 May 2016
Available online 26 May 2016

Keywords:
Available nitrogen
Sloping cropland
Overland runoff
Soil erodibility
Agricultural practices

ABSTRACT

The susceptibility of purple soil and intensive tillage render the land prone to erosion under heavy precipitations in a sloping cropland in southwestern China. This study aimed to improve the evaluation of the potential benefits of surface protection tillage and organic matter addition to decreasing nutrient losses. A field plot experiment under natural rainfall conditions was conducted, which employed four management practices: conventional downslope tillage system as control (CK), contour tillage (CT) with organic matter addition (CT + OM), CT with wheat straw mulching (CT + SM), and CT combining straw mulching and organic matter addition (CT + OM + SM). Runoff depth, nutrient loads, and soil erodibility were used to estimate the effects of straw mulching and organic matter addition. Results indicated that the runoff depth under CK was largest during the experimental period, with an average of 16.91 mm, and runoff coefficient average was 32%. Compared with CK, the runoff depth under CT + OM, CT + SM, and CT + OM + SM were reduced by 19%, 34%, and 50%, respectively. A significant difference in soil erodibility indicator among the four treatments was indicated ($p < 0.05$); CK achieved the highest value, whereas CT + OM + SM obtained the least value. In addition, the contour cultivation (i.e., CT approaches) were more sustainable than the downslope tillage system (i.e., CK). Soil erodibility under CK was 9.83 kg ha^{-1} mm^{-1}. Meanwhile, soil erodibility under CT + OM, CT + SM, and CT + OM + SM were 8.49, 6.99, and 6.87 kg ha^{-1} mm^{-1}, respectively. These values were 14%, 29%, and 30% lower than that of CK, respectively. CK was more susceptible to accelerated erosion compared with the plots with a surface cover or organic addition. This greater erodibility resulted in higher runoff, sediment yield, and associated nutrient loss for CK. The runoff-associated nitrogen losses were mainly controlled by the runoff rate and soil erodibility ($p < 0.05$). Variations in NO_3^-–N and NH_4^+–N concentration in runoff water were markedly affected by rainfall events and agricultural practice. A significant logarithmic correlation between NO_3^-–N load and runoff depth was identified. NO_3^-–N was proven to be the main form of inorganic nitrogen loss; therefore, fertilizer application of NO_3^-–N should be reduced in the purple soil region. Soil erodibility significantly influenced the available N losses ($p < 0.01$), which was best described by a positive logarithmic correlation. Soil nutrient concentration also played an important role in nitrogen loss. However, further research is needed to understand the dynamic interactions between soil erodibility as well as soil and nutrient losses. Results indicated that surface protection by CT + OM + SM is one of the good management practices to reduce soil loss by water erosion in regions with intense agricultural activity.

1. Introduction

Deteriorating soil erosion is becoming a global concern in the preservation of ecosystem functions and services (Pimentel and Kounang, 1998; Fu et al., 2011; Lal, 2014 Lal, 2014). Approximately 90% of agricultural land worldwide suffers moderate to severe erosion impact (Speth, 1994). Soil and water erosion is primarily responsible for arable land degradation by reducing nutrient-rich on-site soil and available water and off-site environmental impact (Pimentel et al., 1995; Quinton et al., 2010; Wang et al., 2014). According to statistics, annual soil erosion in China amounts to 4.52 billion tons, equivalent to a loss of organic matter twice the national production of chemical fertilizers (Liu, 2004). Nitrogen losses from agricultural non-point source (NPS) pollution are major

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http://dx.doi.org/10.1016/j.agwat.2016.05.018
0378-3774/

factors contributing to excessive nutrients in surface water, leading to subsequent eutrophication (Cao et al., 2003; Christina, 2013; Jia et al., 2007; Li et al., 2009).

NPS pollution by agrochemicals due to soil erosion has emerged as a major threat to the surface water in the Three Gorges Reservoir (TGR) Region. Purple soil is widely distributed in the hilly areas of the TGR Region and estimated to be about 78.7% of the total cropland (Zhu and Zhu, 2015). Zhu et al. (2006) estimated that soil nitrogen was lost at an average rate of 44.34 $\mathrm{kg\,h^{-1}\,year^{-1}}$ in the purple soil regions. About 40% of the N load in the surface water could be attributed to the agricultural activity in the TGR Region. Hydrological processes and biogeochemical transformations govern the nitrogen (N) losses from the sloping farmlands to the surface waters in the TGR Region. Purple rocks are characterized fast physical weathering and are broken up by anthropic activities into rock fragments or gravels, in which crops are directly planted. The combination of this purple soil, which is rich in mineral nutrients, with the subtropical monsoon climate has allowed this area to be widely cultivated and to produce abundant agricultural products. It is the most important agricultural zone in southwestern China. However, purple soil is deficient in organic matter and nitrogen because of extensive soil erosion and degradation. Intense tillage, poor soil cover, low organic carbon inputs, and frequent cultivation have accelerated water, soil, and nutrient losses.

Intensive agricultural managements and lack of site-specific best management practices could explain accelerated soil erosion and other soil degradation processes in the rural areas (Cerdà, 2007). In particular, intensity tillage and increased rainfall intensity contribute to the removal of crops at the surface, resulting in increased bare areas and consequently, soil losses (Cerdà et al., 2009). This occurrence explains why soil erosion rate is greater in land used as agricultural fields than other land uses. Therefore, controlling agricultural NPS pollution is crucial. To control this nutrient pollution, extensive research efforts have evaluated the effects of various factors in agricultural management. To reduce the runoff rates and soil losses in agricultural fields, various studies have been conducted (Faucette et al., 2004; Pote et al., 2004; Tiscareno-Lopez et al., 2004). According to these studies, sediment discharge from fields varied widely depending on the surface cover and tillage implemented Casermeiro et al. (2003). Many practices have been recommended to reduce soil erosion and trap nutrients in southwestern China. Soil surface protection by crop residue covers has proven to be one of the best management practices for the maintenance of soil health and soil water content according to studies and practical applications (Pollock and Reeder, 2010; Wang et al., 2015). The reason is that pores in the soil surface are protected from clogging by small clumps of soil and organic particles detached from the soil matrix by raindrop impact. With farming activities starting in spring, the soil surface is completely disturbed by conventional tillage and is exposed to rainfall before the crop canopy fully develops. Serious soil erosion and sediment discharge additionally occur during rainstorms. Increasing crop cover on the soil surface to slow down flow velocities, as well as adding organic matter to decrease soil erodibility, may be more appropriate regulatory measures for reducing pollutant and sediment inflow into aquatic environments (Benik et al., 2003; Ramos and Martínez-Casasnovas, 2006; Gilley et al., 2012; Shipitalo et al., 2013). Land surface cover affects runoff generation and soil loss. The straw mulch effectively reduced the runoff coefficient, splash erosion in both up and down directions, and sediment yield (Gholami et al., 2013). Regardless, a few studies showed negative or no significant effects on soil losses under mulching treatment tillage systems compared with conventional tillage systems (Hösl and Strauss, 2016).

Numerous studies in China have mainly focused on sediment-associated total nitrogen and total phosphorus losses, as well as related influencing factors for the development of soil conservation measures (Flanagan et al., 2002; Faucette et al., 2004; Pan and Shangguan, 2006; Shipitalo et al., 2013; Zhang et al., 2004; Zhang et al., 2011). Nitrogen loss in runoff water is mainly lost as nitrate nitrogen (NO_3^-) and ammonium nitrogen (NH_4^+) (Udawatta et al., 2006). However, few studies have been conducted regarding available nutrients through runoff from sloping farmland, which are more important for soil productivity and crop growth (Zhang et al., 2011; Gilley et al., 2012). Runoff flow contributed to nutrient transport depending on the rainfall amount (Liu et al., 2002). Nutrient loss is heavily influenced by farming practices and cropping systems under different rainfall events. In addition, watershed managers should have a clear understanding of the effect of rainfall event on nutrient transport. The available nutrients are mainly dissolved in the soil solution or adsorbed on clay-humus complexes (Bormann and Likens, 1967), and its dissolution and desorption in runoff are affected by agricultural practices. Understanding the impacts of runoff on available nutrient loss and loads of inorganic nutrients loss through runoff is important to improve the efficiency of agricultural practice that could effectively control the potential pollution hazards in a watershed.

Soil erodibility conceptually represents soil resistance to detachment and transport, which is an important parameter for estimating soil loss caused by agricultural practices (Borselli et al., 2012; Morgan and Nearing, 2011; Torri and Borselli, 2011). Several studies have concentrated on evaluating and calculating soil erodibility and determining its influencing factors (Coote et al., 1988; Knapen et al., 2008). Various benefits of straw mulching, such as decreased soil erodibility, provide physical soil protection against water and soil loss. Crop residues in conservation tillage systems are known to reduce the erosive runoff power and increase topsoil erosion resistance (Knapen et al., 2008). The high water and soil losses for treatment without surface residue were likely attributable to the increased soil erodibility with hardening of the soil surface caused by rain impact in the absence of ground cover. Results obtained from Nwachokor and Erhabor (2011) indicated that soil erodibility was highest where the presence of cover was poorest and lowest where cropping systems and management practices provided more vegetative cover and surface roughness. In addition, contour cultivation is a more sustainable practice than along-slope tillage operations, whereas farming on steep slopes invariably increases the erodibility of the soils. Related to intrinsic soil properties that change during storm events and due to exogenic erosional forces (Wang and Zheng, 2013), soil erodibility could be used as a parameter to assess the impacts of runoff and sediment on available nutrient loss. Agricultural practices can inevitably lead to changes in the physical, chemical, and biological properties of soil and thus affect soil erodibility. Regarding purple soils, research has yet to be conducted on the role that soil conservation plays with respect to changes in soil erodibility, as well as the effects of soil erodibility on loads of available nutrient loss through runoff resulting from agricultural practices coupled with straw cover and organic matter inputs.

Therefore, the main objectives of this study were as follows: (1) to investigate the variation in the loss of NO_3^- and NH_4^+ in runoff waters during different rainstorms and to compare the effects of four treatments combined with wheat straw mulching and organic matter input on nutrient loss in an agricultural plot and (2) to evaluate the effects of soil erodibility on inorganic nitrogen loss in sloping farmlands in the purple soil region. This study provides a scientific evaluation and a theoretical basis for agricultural practices to control agricultural NPS pollution in the upper reaches of the TGR Region.