Soil & Tillage Research 122 (2012) 22–35

Contents lists available at SciVerse ScienceDirect

Soil & Tillage Research

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

The effects of grass hedges and micro-basins on reducing soil and water loss in temperate regions: A case study of Northern China

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ARTICLE INFO

Article history:
Received 20 September 2011
Received in revised form 15 February 2012
Accepted 26 February 2012

Keywords:
Furrow diking
Narrow grass strip
Pennisetum grass
Arundinella grass
VFSMOD
Soil and water conservation

ABSTRACT

Soil and water loss from sloping croplands is a major environmental problem that is attracting widespread attention across the world. Various soil protection techniques, such as terrace and contour tillage, have been used in recent years with limited results. Grass hedges and micro-basins are effective for reducing soil and water loss on sloping croplands in tropical and subtropical regions. However, grass hedges and micro-basins have not been adequately evaluated in temperate climatic regions (for example, in Northern China); thus, they would not be readily accepted by local farmers. In this study, the soil and water conservation effects of two native grass hedges (*Pennisetum alopecuroides* (Linn.) Spreng. and *Arundinella hirta* (Thunb.) C. Tanaka) and micro-basins were studied in the temperate regions of Northern China using simulated rainfall. The experiment included two parts: trial I and trial II. In trial I, three independent variables, including grass hedges (the Arundinella, the Pennisetum, and the control), slope gradient (5%, 10%, 15%, and 20%), and rainfall intensity (36 mm h^{-1} and 63 mm h^{-1}) were considered. In trial II, the independent variables were changed to soil protective practice (the grass hedges, the micro-basins, and the control), slope gradient (5%, 10%, 15%, and 20%), and rainfall intensity (36 mm h^{-1} and 63 mm h^{-1}). Next, the Vegetative Filter Strip Modeling System (VFSMOD) model was introduced to simulate the runoff and sediment intercepted by the grass hedges. Lastly, cost analysis was conducted based on the cost of labor and seeds or plants for the grass hedge and micro-basin trials. The use of Pennisetum hedges decreased the mean runoff and soil loss by 56% and 81%, the Arundinella hedges decreased the runoff and soil loss by 55% and 67%, and the micro-basins decreased the runoff and soil loss by 70% and 62%, respectively. Moreover, the runoff and sediment that passed through the grass hedges can be reasonably simulated with the VFSMOD model (the relative errors for runoff and sediment content were −19.1% and −14.6%, and the Nash–Sutcliffe efficiencies for runoff and sediment content were 0.91 and 0.85, respectively). Conversely, the grass hedges occupied 9% of the farmland in the study area and cost 5864 CNY per hectare. In addition, the micro-basins occupied 7% of the farmland and cost 3000 CNY per hectare. These results imply that grass hedges and micro-basins are cost-effective when compared with terraces, which cost more than 7401 CNY per hectare and typically occupy 18% of farmland. Overall, we conclude that the soil protective practices of using grass hedges or micro-basins are effective and efficient for decreasing soil and water loss on sloping croplands in temperate regions. Thus, these practices should be intensively recommended and used widely in similar climatic regions.

1. Introduction

Soil and water loss is a major environmental problem that is attracting widespread attention across the world. In China, nearly one third of the land is impacted by soil and water loss (E, 2008; Li et al., 2008). Serious soil and water loss problems occur in the southern part of China due to abundant precipitation. Soil and water loss problems also occur in the north and are generally due to drought periods followed by periods of concentrated and intense rainfall, sparse vegetation, loose soil particles, complex landforms, and long-term improper land use (Cha and Tang, 2000; Shi and Shao, 2000; E, 2008; Li et al., 2008). The Loess Plateau in Northern China is well known across the world for its high erosion rates that range from 15,000 to 20,000 t km^{-2} a^{-1} (Cha and Tang, 2000). The large amount of transported sediment results in serious damage to the middle and lower reaches of the Yellow River (Milliman et al., 1987; Saito et al., 2001). According to Xu et al. (2004) and Bennett

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doi:10.1016/j.still.2012.02.006

(2008), 28% of the soil loss results from sloping croplands, which account for only 7% of the Yellow River watershed in China. In other words, sloping croplands are the primary source of runoff and sediment. Therefore, soil and water loss on these sloping croplands should be adequately controlled.

Narrow grass hedges, defined as dense, erect, vegetative barriers made of stiff-stemmed grass that slow-down runoff and reduce erosion (Kemper et al., 1992; Dabney et al., 1999; Baudry et al., 2000; Dorioz et al., 2006), are used to prevent soil and water loss from sloping croplands in several countries and regions (Kemper et al., 1992; Dalton et al., 1996; Raffaelle et al., 1997; McGregor et al., 1999; Gilley et al., 2000; Ghadiri et al., 2001; Golabi et al., 2005; Cullum et al., 2007; Lin et al., 2009; Huang et al., 2010; Xiao et al., 2011b). Grass hedges potentially reduce runoff and soil loss by up to 60% and 80%, respectively, by filtration, deposition, and infiltration (Gilley et al., 2000; Koelsch et al., 2006; Bhattarai et al., 2009; Wu et al., 2010; Xiao et al., 2010, 2011a). However, the effectiveness of grass hedges is site-specific and depends mostly on slope gradient, runoff volume and flow rate, size and density of sediment particles, grass species, density, interval and width of grass strips, underlying soil properties, and rainfall intensity and duration (Robinson et al., 1996; Gilley et al., 2000; Deletic, 2001; Xiao et al., 2010). In previous research tests, vetiver grass (*Chrysopogon zizanioides*), switchgrass (*Panicum virgatum* L.), tall fescue (*Festuca arundinacea* Schreb), and Achnathemps pendens (*Achnatherum extremiorientale* (Hara) Keng) were very effective in reducing soil and water loss (Magette et al., 1989; Dabney et al., 1995; Smolikowski et al., 2001; Angima et al., 2002; Dercon et al., 2006; Babalola et al., 2007; Pansak et al., 2008). Among these grasses, vetiver grass has often been suggested in the tropical and subtropical regions due to its unique characteristics, which include fast growth, deep and penetrating root systems, and high tolerance to adverse conditions (World Bank, 1993). However, vetiver is a warm-season grass that cannot be used in temperate regions (e.g. the Northern China) because it cannot withstand the low winter temperatures (the temperature in this region can drop below −30 °C, and the lowest temperature that vetiver grass can survive at is −9 °C) (World Bank, 1993; Wu et al., 2008). In temperate regions, other native and cool-season grass species should be used to establish hedges. These grass species should be studied to evaluate their effectiveness (Lee et al., 1998). According to Wu et al. (2008) and Huang et al. (2010), Pennisetum (*Pennisetum alopecuroides* (Linn.) Spreng.) and Arundinella (*Arundinella hirta* (Thunb.) C. Tanaka) grasses are probably the most promising candidates because they are native perennials, tolerant to the local climatic extremes (drought and low temperature in winter), and possess sufficient stem strength to remain erect against flowing water. Currently, the effectiveness of grass hedges can only be assessed with field experiments, and few specialized models can be used to predict their performance (Cai et al., 2005; Herbst et al., 2006). However, the Vegetative Filter Strip Modeling System (VFSMOD) model is a successful design-oriented model that simulates the runoff and the sediment and contaminant transport in vegetative filter strips (Muñoz-Carpena et al., 1999; Kuo and Muñoz-Carpena, 2009). Because grass hedges and vegetative filter strips are very similar except for their width (the width of grass hedges is usually less than 1.5 m, while the width of vegetative filter strips is usually more than 10 m (Blanco-Canqui et al., 2004b; Dorioz et al., 2006)), the VFSMOD model may be used to predict the effectiveness of grass hedges. Therefore, validating the VFSMOD model for simulating runoff and sediment retention by grass hedges is logical.

Micro-basins, also called tied ridges or diked furrows, have also been considered to be a cost-effective soil management practice (Wiyo et al., 2000; Nuti et al., 2009; Temesgen et al., 2009; Previati et al., 2010). Micro-basins (0.2–0.3 m in depth) are constructed by connecting ridges every 2–3 m to overcome furrow drawback, which refers to the process by which unlevel ridges funnel and concentrate overland flow and cause soil rill erosion (Nuti et al., 2009; Temesgen et al., 2009). Micro-basins enhanced infiltration and the ability of soil to capture precipitation, reduced runoff and evaporation, and increased water availability and subsequent crop yield improvement (Jones and Clark, 1987; Tewolde et al., 1993; Jones and Baumhardt, 2003). Thus, the use of micro-basins is currently spreading and is widely recommended by NGOs, agricultural extension services, and government agencies (Vohland and Barry, 2009). Jones and Stewart (1990) provided a review of micro-basins and reported that micro-basins had a water holding capacity of 25–150 mm of rainfall, depending on field slope, rainfall characteristics, intrinsic soil properties, and cropping/tillage systems. Many studies have concluded that fields with micro-basins capture more precipitation and/or irrigation water than conventionally cultivated land and reduce runoff and erosion by enhancing infiltration (Hackwell et al., 1991; Unger, 1992; Hasheminia, 1994; Truman and Nuti, 2009; Araya and Stroosnijder, 2010). Truman and Nuti (2009) noted that runoff and erosion from land without micro-basins was 3 and 3.5 times greater, respectively, than the runoff and erosion from a micro-basin control. Similarly, Rawitz et al. (1983) stated that erosion was 3–25 times greater in lands without micro-basins. Most research indicates that micro-basins are one of the most effective practices for controlling soil and water loss from sloping croplands; however, this practice has not been adopted extensively in Northern China due to the use of donkeys for furrowing and diking. Thus, it is necessary to adequately evaluate the functions of micro-basins and their cost-benefits.

We hypothesize that grass hedges and micro-basins reduce soil and water loss from sloping lands in temperate regions and that their effects are significantly impacted by slope gradient and rainfall intensity. Based on these hypotheses, we established Pennisetum and Arundinella grass hedges and micro-basins on plots with slope gradients ranging from 5% to 20%. Next, the runoff and soil loss were measured under simulated rainfall with different intensities (36 mm h^{-1} and 63 mm h^{-1}). The objectives of this research were as follows: (1) to evaluate the effectiveness of grass hedges and micro-basins in reducing runoff and soil loss in temperate regions; (2) to define the correlations among the dependent variables (runoff, soil loss) and the independent variables (slope gradient, rainfall intensity, and soil protective practices); (3) to analyze the mechanisms by which grass hedges and micro-basins reduce soil and water loss; (4) to validate the feasibility of the VFSMOD model for simulating the runoff and sediment passing through the grass hedges; and finally, (5) to conduct a cost analysis of using grass hedges and micro-basins in the study area.

2. Materials and methods

2.1. Study area

Experiments were conducted at the National Experimental Station for Precision Agriculture (116°26′E, 40°10′N) in Xiaotangshan, north of Beijing, P.R. China. The study area is located in the Northern China Plain temperate zone and is characterized by a continental, semi-humid, and monsoon climate. The mean annual precipitation is 640 mm (80% occurring between June and August), and the mean annual temperature is 11.5 °C. The soil is a clay loam with 41% sand, 24% silt and 35% clay. The steady infiltration rate, as measured by means of a double ring infiltrometer, is approximately 13.0 mm h^{-1}, and the bulk density is 1.37 g cm^{-3}. The percent organic matter and the total nitrogen and phosphorus