Soil & Tillage Research 168 (2017) 11–19

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Assessment of gravelly soil redistribution caused by a two-tooth harrow in mountainous landscapes of the Yunnan-Guizhou Plateau, China

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ARTICLE INFO

Article history:
Received 4 January 2016
Received in revised form 11 November 2016
Accepted 20 December 2016
Available online 27 December 2016

Keywords:
Gravelly soil
Muddy soil
Two-tooth harrow
Tillage erosion
Rocky mountainous area

ABSTRACT

The processes of soil redistribution caused by hoeing tillage in hilly areas have been increasingly recognized for nearly two decades. Yet, few studies have examined the effects of hoeing tillage on soil redistribution in rocky mountainous areas. Due to a high rock fragments content of gravelly soils, a special type of hoe called the two-tooth harrow has been widely used in the Yunnan-Guizhou Plateau, China. In order to assess gravelly soil redistribution, a series of tillage experiments were set up and the subsequent data were compared with those acquired previously in hilly areas. The displacement distance of gravelly soils increased with slope gradient linearly in the range of 0.05 to 0.69 m m^{-1}; however, when the slope gradient extended further, an exponential equation could better describe the relationship between them. The repose angle of gravelly soils was approximately 0.69–0.70 m m^{-1}. Large-size rock contents and implement types are two important factors affecting tillage depth. Tillage transport coefficients (k_3 and k_4) of gravelly soil in rocky mountainous areas were 40 and 78 kg m^{-1} tillage $pass^{-1}$, respectively, displaying a slightly large k_3 value but a significantly small k_4 value compared with those in hilly areas. Due to its energy saving and applicability to gravelly soils, the two-tooth harrow is more attractive to farmers than the normal hoe in rocky mountainous areas. Moreover, the two-tooth harrow is proved to be efficient and effective in reducing tillage erosion than the normal hoe.

1. Introduction

Soils are the material basis for the survival of human being since their function of providing essential nutrients, promoting nutrition circulation, purifying groundwater and buffering the changes of environment (Brevik et al., 2015; Decock et al., 2015; Novara et al., 2015; Smith et al., 2015; Keesstra et al., 2016). Hence soils are important natural resources on earth which should be responsibly managed (Montanarella, 2015). Many researches demonstrated that soil erosion caused by human activity is a severe threat to soil resources on cultivated lands (Cerdà et al., 2009; Lieskovský and Kenderessy, 2014; Yuan et al., 2015; Prosdocimi et al., 2016). Ploughing of soil has been proved to be one of the driving factors of geomorphologic disturbance and soil degradation since the development of agriculture (Mandal and Sharda, 2013; Arjmand Sajjadi and Mahmoodabadi, 2015; Novara et al., 2015). Tillage can not only cause the disturbance of soil structure and the mixture of soil at different soil layers, but also accelerate the removal of SOM (soil organic matter) and nutrients from cultivated lands (Keesstra et al., 2012; Zhang and Li, 2013; Berendse et al., 2015). However, there is still a great gap in knowledge about soil translocation and redistribution caused by tillage erosion within agriculture fields (De Alba, 2001; Van Oost et al., 2003; Zhang and Li, 2013; Wildemeersch et al., 2014). Tillage erosion can not only cause considerable soil loss at topographic convexities (often summit and shoulder slope positions) but also a significant sediment accumulation in topographic concavities (often backslope and toeslope positions) or even at the lower field boundaries (Govers et al., 1994; Papiernik et al., 2007). In recent years, many studies have focused on tillage erosion caused by tractor-plough both on gentle and steep slopes in mechanized agricultural areas of Europe and North America (Quine and Zhang, 2004; Li et al., 2007; Van Oost et al., 2009; Logsdon, 2013); however, manual hoeing tillage can also result in soil translocation and erosion in non-mechanized

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http://dx.doi.org/10.1016/j.still.2016.12.010

agricultural areas. In a previous report (Poesen et al., 1997), the displacement distances of rock fragments created by tractor-drawn plough tillage (duckfoot chisel) were detected using the tracer method in the Murcia Region, Spain. The spatial pattern of rock fragment coverage can be explained by downslope movement of soil created by tillage erosion, and furthermore intensive tillage also contributes to the increase in soil degradation and changes in hillslope morphology.

Soil translocation caused by tillage erosion can be affected by many factors such as topography, tillage speed, tillage direction, cultivation practice, implement type, and soil conditions. Van Muysen et al. (1999) studied the effect of initial soil condition on the soil translocation and erosion of a stony loam soil by the mouldboard plough. For a ploughed field, the tillage transport coefficient k for pre-tillage conditions is about 2 times larger than that for grass fallow because of the greater plough depth and much more friable soil on the pre-tilled treatment. A series of mouldboard tillage experiments conducted in Belgium (Van Muysen et al., 2002) have demonstrated that k-values increase exponentially with tillage depth for up- and downslope tillage, while the increase is linear for contour tillage. Zhang et al. (2004b) assessed tillage erosion caused by manual hoeing tillage on the steep hillslopes in hilly areas of Sichuan, southwestern China. The downslope soil displacement distance is significantly positively correlated with slope gradient, while the lateral soil displacement distance decreases with increasing slope gradients. Previous studies have also confirmed that the variation in tillage speed can contribute to the variation in tillage erosion (Van Muysen et al., 2000; Tiessen et al., 2007a,b). Quine et al. (2003) estimated that the tillage erosion intensity was reduced by 30% with the reduction of tillage speed from 7 km h^{-1} to 4 km h^{-1}.

In the Yunnan-Guizhou Plateau of China, soil takes on distinct characteristics of vertical zones due to the influence of special climate conditions such as rainfall, air temperature and humidity. For example, soil at the lower toposequence of the Dasong Mountain contains significantly high (more than 45%) rock fragment contents (mineral particles >2 mm) (Miller and Guthrie, 1984) due to the underdeveloped soil and frequent occurrence of gravity erosion such as landslide and collapse; thus, it is classified as gravelly soil based on a criteria of more than 30% rock fragment contents (Gee and Or, 2002). However, at the upper toposequence of the Dasong Mountain, soil is known as muddy soil (yellow–brown soil), whose texture is silty clay with a small number of rocks (approximate to zero). Steep slopes with wild grass were reclaimed and converted into farmland due to serious shortage of land resources and strong population pressure. Agricultural equipment cannot be applied due to the limitation of steep topography; thus, hoeing tillage is predominant in this area. With the traditional hoe (normal hoe) used in the hilly areas such as the Sichuan Basin, it is difficult to till the soil layer due to high rock fragment contents. Thus, a special type of hoe called the two-tooth harrow has been widely used in rocky mountainous areas. The shape of the two-tooth harrow differs from that of the normal hoe whose blade is about 24 cm long and 9 cm wide. The two-tooth harrow consists of two tines with an interval of about 10 cm that are about 32 cm long, 1.5 cm wide and 1 cm thick each (Fig. 1). For the normal hoe, the field was tilled from the bottom of the slope and go upslope step by step, thus soil is turned and pulled by the blade downslope. However, for the two-tooth harrow, the soil is only loosened and pulled downslope without being overturned because of the narrow area of two tines. Under these conditions, a series of on-site tillage experiments were performed to obtain the relevant data on gravelly soils tilled with the two-tooth harrow. These new data will be compared with the data acquired by using the normal hoe in a previous study (Zhang et al., 2009) to recognize the features of soil redistribution in rocky mountainous areas.

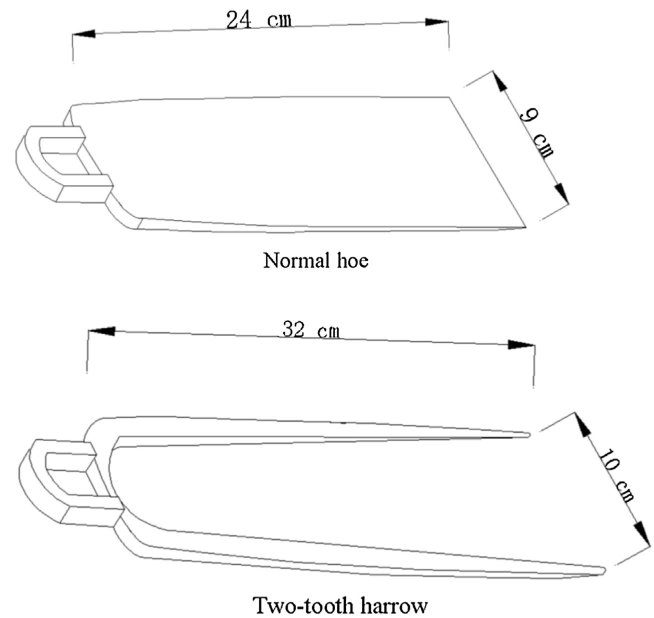

Fig. 1. Comparison of the normal hoe and the two-tooth harrow.

Specific objectives of this study were (1) to ascertain the relationship between the displacement distance of gravelly soils and slope gradient in different slope ranges and the repose angle of gravelly soils; (2) to assess soil translocation and tillage erosion by the two-tooth harrow on steep slopes of rocky mountainous areas.

2. Materials and methods

2.1. Study site

The study site is located in the Dongchuan district (25°57′–26°32′N and 102°47′–103°18′E) Kunming City, Yunnan Province, belonging to the downstream of the Jinsha River south bank in the Upper Yangtze River Basin, southwestern China (Fig. 2). The total area is about 1858.79 square kilometers, 95% of which is occupied by mountains. The elevation in this area varies between 695 and 4344.1 masl. The study area has a subtropical climate with an annual temperature of 14.9 °C (range −7.8 °C to 42 °C). The mean annual precipitation is about 1000.5 mm, whereas the mean annual evaporation is 1856.4 mm which is approximately 1.8 times of the mean annual precipitation. The mean annual sunshine duration is about 2327.5 h and the frost-free period averages 317 days per year. Dominant crops grown in this area are wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), potato (*Solanum tuberosum* L.) and sweet potato (*Ipomoea batatas* (L.) Lam).

Twenty five slopes were selected to carry out tillage experiments with twenty one for gravelly soils and four for muddy soils (yellow–brown soils) in the Dasong Mountain. The distance of the plots ranged from 50 to 200 m for both gravelly soils and yellow–brown soils. The slope gradient for gravelly soils ranged from 0.05 to 0.75 m m^{-1}, and muddy soils (yellow–brown soils) ranged from 0.13 to 0.47 m m^{-1}. The soils at the two experimental sites had totally different physical properties (Table 1). Both soil moisture and SOM contents of muddy soils (yellow–brown soils) were significantly higher ($P < 0.01$) than those of gravelly soils. Furthermore, the distribution of particle-size fractions of gravelly soils did not follow a similar pattern to that of muddy soils (yellow–brown soils). The >2 mm-size gravel content averagely reached 57.76% for gravelly soils, but was measured as zero for muddy soils (yellow–brown soils). No significant differences in the silt fraction were found between gravelly soils and muddy soils