Soil & Tillage Research 118 (2012) 1–10

Contents lists available at SciVerse ScienceDirect

Soil & Tillage Research

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

A device for mechanical remediation of degraded grasslands

Yong You [a], Decheng Wang [a], Jude Liu [b,*]

[a] College of Engineering, China Agricultural University, 17 Qinghua East road, Haidian District, Beijing,100083, China
[b] Department of Agricultural and Biological Engineering, Pennsylvania State University, 227 Agricultural Engineering Building, University Park, PA, 16802, USA

ARTICLE INFO

Article history:
Received 14 December 2010
Received in revised form 26 August 2011
Accepted 11 October 2011
Available online 10 November 2011

Keywords:
Soil gashing
Soil cutting
Soil properties
Tool
Design

ABSTRACT

Conventional tillage practices are traditional methods to restore the degraded grasslands. However, the risk of wind and water erosion increases dramatically. To remedy these degraded grasslands and conserve soil and water, a rotary cutting mechanism named soil-gashing and root-cutting device was designed and tested in typical degraded grassland. The grass specie was leymus-chinensis, which is the main forage in Northern China. This device consisted of eight sets of cutting tools, and each set of tools had three identical crescent cutting blades. It can create consecutive openings in compacted soil. These openings provided soil aeration and promoted the growth of leymus-chinensis. Field experiments indicated that the maximum cutting depth was 200 mm while the average width of slits was 12.8 mm. No soil overturning was observed. To reduce the torque required to drive this cutting mechanism, the crescent cutting blade was optimized through indoor soil bin tests. Field tests were then conducted to evaluate the effect of this cutting mechanism on the soil physical and chemical properties and the crop yield of a degraded grassland. Results showed that soil organic matter and total nitrogen were significantly increased in the second year of soil-gashing and root-cutting treatment, and the soil pH value was reduced to the suitable level for the growth of leymus-chinensis. The soil bulk density was reduced, and the soil porosity increased after a one-year period though these changes were not statistically significant. Grass yield was increased by 94.8% in the second year.

1. Introduction

Leymus-chinensis (Trin.) Tzvelev, referred to as L-C hereafter, is dominant grass specie of typical grasslands widely distributed in an area of 9,774,013 km^2 in Northern China, Mongolia, and Southern Russia. It is a popular fodder grass due to its nutrition and fine palatability (MOA, 1996). Most of these grasslands are located in semi-arid or arid zones, where livestocks are the primary agricultural products. Therefore, grass yield is essential. As a perennial grass and a typical clonal plant, L-C tolerates drought, cold and alkali stresses. Its reproduction mainly depends on vegetative propagation (rhizome reproduction). Breaking its roots could promote grass reproduction or rejuvenation (Zhu, 2004). Besides, the growth of L-C requires appropriate soil pH level, bulk density, and permeability. The highly branched rhizomes of L-C lie horizontally at a depth between 50 mm and 150 mm from the soil surface.

Generally, soil compaction by animal trampling and soil fertility reduction strongly influence pasture degradation (Martinez and Zinck, 2004). Compacted soil limit nutrient availability for plant growth and increase surface runoff (Tardieu, 1994). Ilstedt et al. (2006) studied crawler tractor's track on soil compaction and nutrients. They reported that SOC was 25% lower on tracks compared to unaffected soils by the tractor; and nitrogen and phosphorous availability were approximately 50% lower. Soil and vegetation degradation in L-C grasslands has been extremely serious due to soil compaction. Compared to soil compaction caused by vehicular traffic, the grassland degradation in these grasslands is caused by the lack of sustainable management knowledge and skills. Hence, overstocking, overgrazing, and thus continuous livestock trampling over years plus special climate are the main reasons of degradation (Han et al., 2008; Martinez and Zinck, 2004). Field survey showed that compacted soil layer is approximately from the surface to 150-mm deep in those areas used for cow and sheep grazing over 30 years. In addition, tangled long roots in this compacted layer might reduce the flowability of soil during compression that could accelerate soil compaction and increase soil hardness. Compaction reduced soil permeability and infiltration, and then soil pH level also becomes higher. Intensive and controlled livestock grazing and trampling treatments showed that intensive grazing tended to increase soil acidity over four years period; soil acidity continued to decrease in controlled grazing plots in next 9 years (Hiernaux et al., 1999). All of these plus crop aging, the yield of L-C decreases over the years. Compacted top soil and low crop coverage reduced the water holding capacity of soil and accelerated grassland degradation,

* Corresponding author. Tel.: +1 814 863 6844; fax: +1 814 863 1031.
E-mail address: jliu@engr.psu.edu (J. Liu).

0167-1987/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.still.2011.10.007

which in turn impacts the sustainability of entire grassland ecosystem (e.g. Snyman and du Preez, 2005).

Tillage practices can change soil physical and chemical properties (e.g. Alvarez and Steinbach, 2009; Mueller et al., 2009). Conventional tillage, such as moldboard ploughing, disking, and other special practices, can remove soil hardpan, reduce soil bulk density, and increase porosity (e.g. Hamza and Anderson, 2003, 2005; Burgess et al., 2000). All of these tillage tools have been used to improve degraded grasslands in Northern China (Yang and Taogetao, 2008; Yan et al., 2002). However, tillage operations in grasslands have been recognized as one of the most important causes of desertification of the semi-arid zones in China (Zhao et al., 2000). Using conventional tillage tools to improve degraded L-C grasslands in arid and semi-arid regions of China resulted in soil nutrition loss and severe soil erosion problems (Zhao et al., 2006; Su et al., 2004). Most importantly, vegetation was totally destroyed by conventional tillage operations. Hence, replanting is needed, and livestock feed supply is interrupted. Costs of replanting and forage purchasing are not affordable for most of the farmers in these regions.

To increase the grass yield of these degraded L-C grasslands, soil conditions need to be amended with consideration of soil and water conservation. Therefore, soil-engaging tools with negligible soil disturbance, deep soil-penetrating and root-cutting functions are needed. The goal of this study was to design a soil-engaging tool to meet these needs.

Previous studies have found that soil-penetrating operation could break roots and produce new shoots (e.g. Yan et al., 2002). Slits or openings created by the cutting mechanism also worked as soil aeration. Hence, a rotary cutting mechanism, named soil-gashing and root-cutting device, could be the most possible solution to remedy the degraded grassland soil. To minimize soil surface shear deformation and the surface crop damage caused by the wheel slip of the tractor, traction needed to pull this cutting device should be minimized if possible. Researchers have found that draft requirement could be less when the soil engaging tools were powered (Marenya et al., 2006). Therefore, powered rotary cutting tools were selected as a base model of this soil/root-cutting mechanism in this research.

Tillage implement tools with low soil disturbance were tested to reduce grassland runoff and inject manure into soil. Under certain soil and environmental conditions, properly practiced mechanical aeration operations could increase grass yield by improving the infiltration and aeration of soil (Shah et al., 2004). Chen et al. (2001) found that aeration operations did not significantly increase the yield without manure application compared to those non-aerated plots. Research conducted by Harrigan et al. (2006) indicated that aeration operations reduced 10% surface residue and the angle of those soil cutting bars affected the degree of soil disturbance and soil loosening. Soil aeration tools are popularly used in developed countries to manage turfgrass. However, these tools do not produce continuous openings in top soil. Root-cutting effect would be very limited. In addition, these turfgrass equipment normally aerate surface soil no deeper than 100 mm. Cutting crop roots was not needed for annual crop lands. No literature was found on design and test of mechanical devices, which have deep and continuous soil-gashing and root-cutting functions and minimal soil disturbance, from available resources.

2. Goal, objectives and preliminary results

2.1. Goal and objectives

The goal of this research was to develop a deep soil-gashing and continuous root-cutting tool for remedying degraded L-C grasslands. The specific objectives were:

(a) To design a rotary soil cutting mechanism, which should have functions of soil-gashing and root-cutting to increase L-C yield with negligible soil disturbance.
(b) To design and test different cutting tools for this mechanism to minimize the torque requirement, soil surface damage, and soil disturbance.
(c) To evaluate the effect of the cutting mechanism designed on physical and chemical properties of soil and crop yield in a typical degraded L-C grassland.

2.2. Preliminary results

A rotary cutting mechanism (as shown in Fig. 1) was designed and fabricated to observe the field performance of four cutting tools (Fig. 2) through field trials and to examine if these design goals can be achieved. This device consisted of eight sets of cutting tools, a tool shaft, a main frame, a final drive, and two gauge wheels. The cutting tool was a key component which could have significant impact on the performance of the soil-gashing and root-cutting device. Different cutting tools were made to conduct field observation. There were four conceptually designed tools including three blades (Fig. 2a–c) and one disk (Fig. 2d). Every blade had only one sharpened edge. All blade bodies had the same thickness of 6 mm. Once mounted on the rotary cutting device (Fig. 1), each type of blades had the same maximum rotational radius of 325 mm. The steel disk is referred to as cutaway disk. Its radius and thickness were 325 mm and 6-mm, respectively. Those openings on the disk edge were 60-mm deep and 10-mm wide.

Each set of blades consisted of 3 identical blades, and any two adjacent blades were 120° apart. Three cutting tools were installed on the tool shaft through a flange hub, which was keyed on the tool shaft. The tool shaft was powered by a final drive which was driven by a universal shaft connected to the tractor PTO (Fig. 1). The cutting tools rotated in the same direction with the tractor drive wheels. The spacing between any two adjacent tool sets was 300 mm that was kept constant over the course of field tests. The cutting depth was controlled by the two gauge wheels mounted on the rear end of the main frame. Designed maximum cutting depth was 200 mm. This device was attached to a 65 kW tractor through its three-point hitch. The final drive of the device was located at the center of the main frame. Designed rotational speed of the tool shaft was 280 rpm when tractor PTO was 540 rpm.

The three different blades and the disk were tested with the device shown in Fig. 2. Field trials showed that a 65 kW tractor could power the device with eight cutaway disks at the cutting depth of 100 mm or less. When the depth was increased to 150 mm, the tractor encountered excessive wheel slip. The tractor

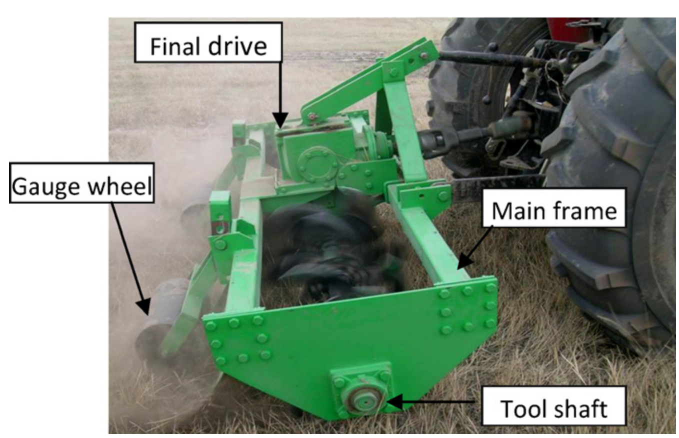

Fig. 1. The prototype of the soil-gashing and root-cutting device used in the experimental studies.