Agricultural and Forest Meteorology 204 (2015) 37–45

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Aerodynamic properties of agricultural and natural surfaces in northwestern Tarim Basin

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ARTICLE INFO

Article history:
Received 25 June 2014
Received in revised form 19 December 2014
Accepted 6 January 2015
Available online 4 February 2015

Keywords:
Cotton
Desert soils
Red date
Wind erosion
Zero plane displacement

ABSTRACT

Friction velocity (u^*) and aerodynamic roughness (z_0) are atmospheric parameters that influence the flux of windblown dust. These parameters have not been quantified for different land use types in the Tarim Basin of China, one of the largest sources of atmospheric dust in the world. Wind speed profiles were measured and used to determine d, u^* and z_0 of a cotton (*Gossypium hirsutum* L.) field, red date (*Ziziphus jujuba* L.) orchard and native desert during the spring wind erosion season of 2012 and 2013. In addition, d, u^* and z_0 were estimated using Raupach's model. During periods of high winds sufficient to cause erosion in spring, d averaged 0.28, 0.067 and 0 m; u^* averaged 0.39, 0.51 and 0.35 m s^{-1}; and z_0 averaged 7.0, 17.0 and 1.2 mm for respectively the cotton field, red date orchard and desert. Estimates of d, u^* and z_0 according to Raupach's model during the same periods of high winds were 0.10, 0.16 and 0 m; 0.56, 0.73 and 0.49 m s^{-1}; and 12.6, 21.9 and 1.8 mm for respectively the cotton field, red date orchard and desert. The Raupach model, which depends on canopy height and area index, overestimated u^* and z_0 for the three land use types during most high wind events. The desert had the greatest potential for flux of windblown dust (due to the lowest z_0) while the red date orchard has the lowest potential for dust flux (due to the highest z_0).

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1. Introduction

In arid and semi-arid regions, wind erosion is a major cause of land degradation. Dust emitted from exposed surfaces and suspended in the atmosphere during high winds can also impact air quality (Husar et al., 2001), human health (Schwartz, 1994), and regional temperatures (Overpeck et al., 1996). Wind erosion removes the uppermost part of the soil profile which is typically enriched in nutrients and is therefore a concern for farmers in maintaining soil health and crop production (Sterk and Raats, 1996; Bielders et al., 2002).

Near-surface wind speed profiles are dependent on the interactions between atmospheric airflow and land surface characteristics (Marshall, 1971). Wind erosion begins at the moment the friction velocity (u^*) exceeds the threshold friction velocity. Threshold friction velocity is defined as the minimum u^* at which an aggregate or particle starts to move from its resting position on the soil surface. Friction velocity, as well as aerodynamic roughness (z_0), is influenced by surface characteristics of windblown soils. Sharratt and Feng (2009) report that u^* and z_0 were influenced by the type of tillage operations performed during the fallow phase of a wheat-fallow rotation in the Pacific Northwest United States. They found that undercutter tillage resulted in a higher u^* and z_0 as compared with conventional tillage because undercutter tillage created greater surface roughness. Copeland et al. (2009) reported differences in u^* and z_0 of a soil amended with agricultural straw and wood-straw materials. Wang et al. (2011) reported that the u^* of crusted sands increased with wind speed in the Gurbantunggut Desert of China.

Flux of windblown dust is dependent on u^* with greater fluxes being generated at higher u^*. Zhu and Zhang (2010) indicate that dust concentrations are low during the pre-emission stage of a dust storm; however, the rapid increase in u^* during this stage provides favorable dynamic conditions for dust emission. During the emission stage of a dust storm, dust concentrations increase sharply due to mechanical and thermal turbulent mixing. Theoretical calculations by Schonfeldt (2003) reveal that sediment transport rate increases with u^*, but transport is influenced by the variance in the horizontal wind speed distribution.

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http://dx.doi.org/10.1016/j.agrformet.2015.01.005
0168-1923/Published by Elsevier B.V.

Table 1
Geographical coordinates and management of the experimental sites.

Land use type	Location	Management
Cotton field	40°37′15.48″ N80°49′48.00″ E	Cotton is sown in late April and harvested in late September every year. Fields are flood irrigated to leach salts from the soil in early spring and late autumn. Plastic mulch is installed in the crop row after sowing to minimize evaporation from in-row drip irrigation systems used during the growing season.
Red date orchard	40°35′14.46″ N80°51′34.10″ E	The red date orchard was planted in 2006. The orchard is pruned to a height of about 1 m and then rotary tilled in spring. The orchard is flood irrigated during the growing season.
Desert	40°27′30.65″ N81°19′27.86″ E	The experiment site was located at the edge of the Taklamakan Desert and had sparse vegetation cover. The major type of vegetation was rose willow.

Friction velocity is a parameter used to describe the shear stress near the surface. Shear stress, or the force imposed by wind shear on a surface, is influenced by winds aloft as well as surface roughness (Sharratt and Vaddella, 2012). Surface roughness, as applied to agricultural fields, constitutes various forms of roughness created by aggregates lying on the soil surface, depressions or ridges remaining after the passage of tillage implements, and biomass that projects into the atmosphere (Sharratt and Feng, 2009). Aerodynamic roughness is an important parameter that describes the impact of surface roughness on the wind speed profile (Kardous et al., 2005). Kardous et al. (2005) observed the influence of tillage ridges on z_0 and found that ridge height and spacing are critical parameters controlling z_0. Saleh et al. (1997) measured z_0 of surfaces roughened with various tillage implements, including a disc plow, moldboard plow, chisel and lister. They found that z_0 varied from 0.16 to 4.22 cm for surfaces tilled with these implements and was most affected by aggregates and ridges on the surface. He et al. (2012) measured z_0 of 0.05 mm in level sand and 0.08 mm at the top of a dune. The association between u^* and z_0 is complex and is dependent on vegetation type (Zhang et al., 2012). Atmospheric winds can change the structure of flexible roughness elements, thus affecting the magnitude of z_0 (Zhou et al., 2006).

Tarim Basin in northwestern China is one of the primary dust sources in arid and semiarid regions of the world. Dust emitted from the Tarim Basin can be transported by winds across Asia and the Pacific Ocean (Husar et al., 2001; Yu et al., 2012). The Akesu area, located in the northwestern Tarim Basin at the edge of the Taklimakan Desert, is very susceptible to wind erosion. In recent years (1991–2005), the area under cultivation has increased by 38×10^3 ha (Zhou et al., 2010). Cotton and red date are the principle economic crops grown in the region.

Few studies have investigated the aerodynamic characteristics of agricultural crops in China and no studies have examined u^* and z_0 of cotton fields, red date orchards and deserts in the Tarim Basin. In an effort to reduce dust emissions from the region, knowledge must be acquired concerning aerodynamic factors that affect the flux of windblown dust in the Tarim Basin. Therefore, the objective of our research was to assess u^* and z_0 of a cotton field, red date orchard and desert in the Tarim Basin for determining the relative susceptibility of these land use types to wind erosion.

2. Methods and materials

2.1. Study area

The study area was located near Akesu along the upper Tarim River in the northwestern Tarim Basin, Xinjiang Province, of China. Mountains to the north, west and east encompass Tarim Basin and the vast expanse of the Taklimakan Desert dominates much of the Basin. The warm, temperate, and arid desert climate of Akesu is characterized by annual mean precipitation of 52 mm and annual potential evaporation of 1991 mm. The economy of Akesu is largely dependent on irrigated agriculture with cotton as the main crop. This area also produces grain, fruits, oils, and beets. The desert comprises 60.3% and cotton and red dates are grown on respectively 1.31% and 0.47% of the total land in Tarim Basin.

2.2. Experimental design

We assessed u^* and z_0 from a cotton field, red date orchard, and desert during March through June of 2012 and 2013. Spring is the time of the year when soils are most susceptible to erosion in northern China due to little precipitation, scant vegetative cover, and frequent high winds (Zhao et al., 2002). The location of our experimental sites in the Tarim Basin is provided in Fig. 1 and a brief description of the sites is provided in Table 1.

Field operations performed at the cotton field and red date orchard sites during our study are listed in Table 2. The texture of soil was sand at the three sites. The cotton field had 89% sand and 11% silt, red date orchard had 87% sand and 13% silt, and the desert had 100% sand.

The sites were instrumented (Fig. 2) in March 2012 and 2013 to measure wind speed and air temperature 0.5, 1, 2, and 3.5 m above the soil surface at one location in the cotton field; 0.2, 0.5 1, and 2 m above the surface at one location in the red date orchard; and 0.1, 0.5, 2 and 10 m above the surface at one location in the desert. Thermistors (model 107L, Campbell Scientific) and 3-cup anemometers (model 010c, Met One, Grants Pass, OR) were used to respectively measure air temperature and wind speed. Standing biomass was removed in the immediate vicinity (<0.2 m) of the anemometers and thermistors in the cotton field whereas anemometers and thermistors in the red date orchard were placed between two tree rows at the maximum distance (about 1 m) from surrounding trees. Extensive pruning of trees in early spring created an open, sparse, and upright canopy about 0.5 m in diameter (Fig. 1). A datalogger (Model CR10x, Campbell Scientific) was used to monitor sensors every 10 s and record data every minute during a high wind event.

The cotton was sown in April and irrigated by drip irrigation. Drip emitters were located under a plastic film layer which was installed over the crop row. The row spacing was 0.7 m and maximum height of the crop during our study was 0.5 m. The red date orchard was flood irrigated and tilled in mid-April 2012 and

Table 2
Dates of field operations during the 2012 and 2013 campaigns.

Year	Calendar date	Day of year	Field operations	
			Cotton field	Red date orchard
2012	03.01	60	Flood irrigation	
	03.25	84		Prune
	04.18	108		Flood irrigation
	04.25	116	Tillage	Tillage
	04.26	117	Sowing	
2013	02.20	51	Flood irrigation	
	03.20	79		Prune
	03.25	84		Flood irrigation
	04.03	93		Tillage
	04.16	106	Tillage	
	04.18	108	Sowing	