Shadow analysis field measurements related to soil surface roughness

R. Garcia Moreno[A], A.M. Tarquis[B], M.C. Diaz Álvarez[B], A. Paz González[A], E. Vidal Vázquez[A] and A. Saa Requejo[B]

[A]Facultad de Ciencias. Universidad de La Coruña- UDC, Email Spain (rgarciam@udc.es)
[B]CEIGRAM (Centre for Studies and Research on Agricultural and Environmental Risk Management), Universidad Politécnica de Madrid, SPAIN

Abstract
The present study aimed to fill the need for a reliable, low-cost and convenient method to measure soil surface roughness. Based on the interpretation of micro-topographic shadows, this procedure is primarily designed for use in the field. The principle underlying shadow analysis is the direct relationship between SSR and the shadows cast by soil structures under fixed sunlight conditions. The results obtained with this method were compared to the statistical indexes used to express field readings recorded by pin meter and chain set methods. The tests were conducted on 4-m^2 sandy clay loam plots divided into 1-m^2 subplots tilled with three different implements: chisel, tiller and roller. The highly significant correlation between the statistical indexes and shadow analysis results proved that both variability (CV) and dispersion (SD) are accommodated by the new method. The method also showed a good proportionality with the chain roughness (CR). The SSR obtained for the different methods is mainly related to the presence of aggregates. The shadow analysis simplifies the interpretation of soil surface roughness and shortens the time involved in field operations by a factor ranging from 4 to 20.

Key Words
Shadow analysis, soil surface roughness, chain method, pin meter, erosion

Introduction
Soil surface roughness describes the micro variation in the surface elevation across a field resulting mainly from tillage practices and soil texture and is a major factor influencing wind and water erosion (Vidal *et al.* 2005).Soil surface roughness can predict wind erosion, by defining the potential for soil particle retention, emission and saltation (Hagen 1988; Potter *et al.* 1990). The soils of semi arid regions such as Central Spain suffer mainly from wind erosion where the loss of both organic matter and nutrient-rich topsoil affects soil productivity and air and water quality (Cihacek *et al.* 1993; Larney *et al.* 1999; Saxton 1995). The quantification of soil surface roughness requires field techniques capable of measuring accurately the soil micro relief to capture and analyse data. Therefore, based on previous work (Garcia Moreno 2006; Garcia Moreno *et al.* 2008a, 2008b) the main objective of the project was to study shadow analysis comparing the data to the one obtained from the pin meter technique and the chain set method in a darker soil than in previous field experiments. In this new analysis, shadow analysis method proved again to meet field testing requirements, being simpler, more convenient and quicker than the techniques presently in use. Moreover, when this procedure was calibrated under different roughness conditions the data collected were found to be more readily analyzed and interpreted than the data gathered with existing techniques.

Methods
After laboratory and field validation of the shadows analysis method (García Moreno *et al.* 2008a; 2008b) a test was conducted on 4-m^2 sandy clay loam plots divided into 1-m^2 subplots tilled with three different implements: chisel, tiller and roller. Also the method was used to measure the roughness of a control connsiting of the same soil without tillage. The SSR obtained using shadows analysis was compared to the data obtained from pin meter and chain roller set. The control was measured only with the chain method. The soil had darker color than in previous studies (García Moreno *et al.* 2008a) to obtain different SSR scenarios during the spring of 2009. The experimental field was located on the campus of the Agricultural Engineering Faculty (E.T.S.I.A.) of the Polytechnic University of Madrid (U.P.M.). The resulting SSR after passage of the tillage implements is illustrated in Figure 1. For the capture of the images, a digital camera DC 4800 was used in all the methods. A frame of 1 m^2 was used to take the images assuring that the same area was chosen for every subplot reading.

Shadows analysis images were taken before other measurements to avoid any kind of disturbance produced by other methods of capturing the values (Figure 1). All the images to analyze shadows were taken with a solar angle of 45º to avoid any interference by differences on the shadows. The shadows projected by soil surface roughness were analyzed on byte map histograms using Corel Draw Photo Paint (© 1992–1996 Corel Corporation) software. The points representing shadows on the histogram were identified and converted into a black surface against a white background. The shadow index was then computed as the percentage of black pixels over the total number of pixels.

The pin meter method (Figure 2) was selected as a reference to the field shadow analysis measurements in light of the reliability of this technique (García Moreno *et al.* 2008b). The prototype consisted in a row of 35-cm high pins, placed in a frame in which they could slide up or down to conform to surface irregularities. The pin heads were marked with a blue band to better visualize their respective positions when in contact with the soil. The device was designed to be moved horizontally without disturbing pin patterns. With rows containing 50 pins spaced at 2-cm intervals, each x-axis reading covered one full metre of ground. The images displayed by the pin meter at the different positions, parallel to direction of tillage, were recorded with the camera installed in a Silk tripod adjusted at the middle of the vertical and horizontal distance of the device, in order to avoid the distortion of the images. A program in visual basic was developed to translate the different pin positions of the different images into soil micro relief data.

Figure 1. Shadow analysis, sandy clay loam soil tilled with chisel, tiller and roller, and control, left to right.

Figure 2. Experimental pin-meter.

Figure 3.Chain set. Field measurements. Soil tilled with chisel.

In order to express the results obtained from pin meter as SSR, as global soil surface roughness over an area of 1.0 m^2, the present study used the standard deviation (SD) measured between all the data points. The SD accounts for the random and oriented soil roughness. A second index, the coefficient of variation (CV), was used in addition to standard deviation. While the SD results were expressed in cm, CV was expressed as a percentage.

The chain method used a chain set constructed from six ANSI standard roller chains, Figure 3. All the chains were 1 m long. The chains had different links: 0.476 cm, 0.953 cm, 1.91 cm, 3.81 cm 7.62 cm and 15.24 cm. The last four chains were formed after a 0.953 cm linked chain was welded every 2, 4, 8 and 16 links (Figure 3). Then, the soil surface roughness was represented calculating Chain Roughness, CR, and plotted as a log function of the link length (Merrill *et al.* 2001; Saleh 1993). In order to compare the soil surface roughness obtained from the chain set to the shadows analysis, the measurements were taken perpendicular and parallel to tillage; in the first case it represents a combination of oriented and random roughness, while in the second case the data represents the random roughness alone, mainly the aggregates.

Results

Figure 4 shows the results from the pin meter method, SD and CV, and the percentage of shadows. Both methods expressed similar results for the SSR resulting from each tilling tool. The highest roughness is expected with chisel, followed by tiller, roller and control. Even if the correlation between percentage of shadows and CV and SD seems to be high in both cases, the percentage of shadows proved to be closely correlated to CV and SD (99%). Consequently, roughness is influenced by variability and dispersion and the surface roughness observed in the field after tilling is the result of both a large number of low-relief structures associated with the disturbance generated by the tilling tool and a few larger scale structures such as clods or aggregates, as it can be corroborated with the images (Figure 1).The results of the soil surface roughness measured with the chain set, Chain Roughness CR, for the different tilling tools are expressed as function of the chain link in Figure 5. Since the parallel and perpendicular measurements were similar, only the first data were reported.

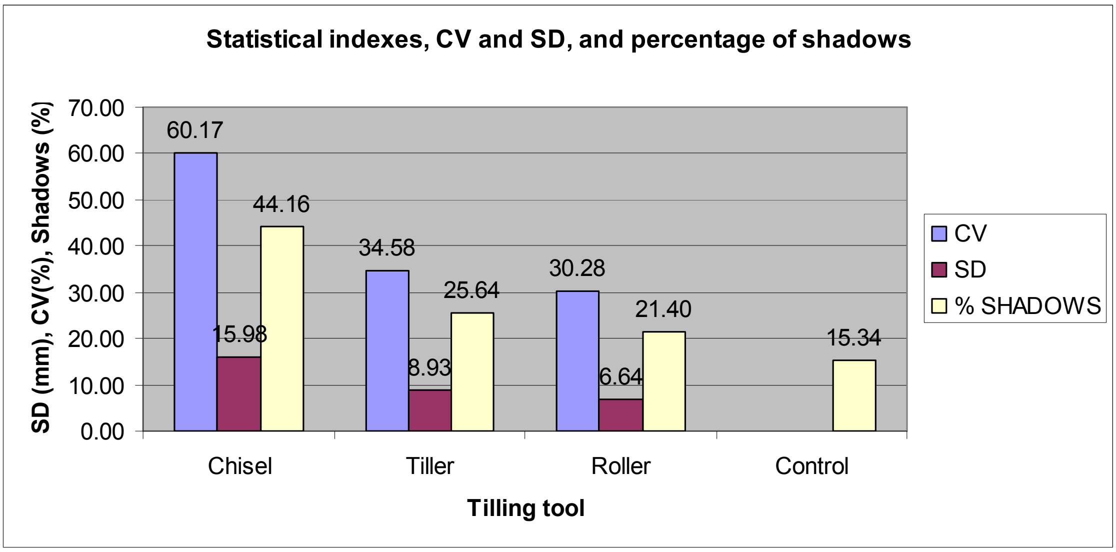

Figure 4. Shadow analysis and pin meter results, percentage of shadows and CV and SD as surface roughness measurements in relation to method of tillage.

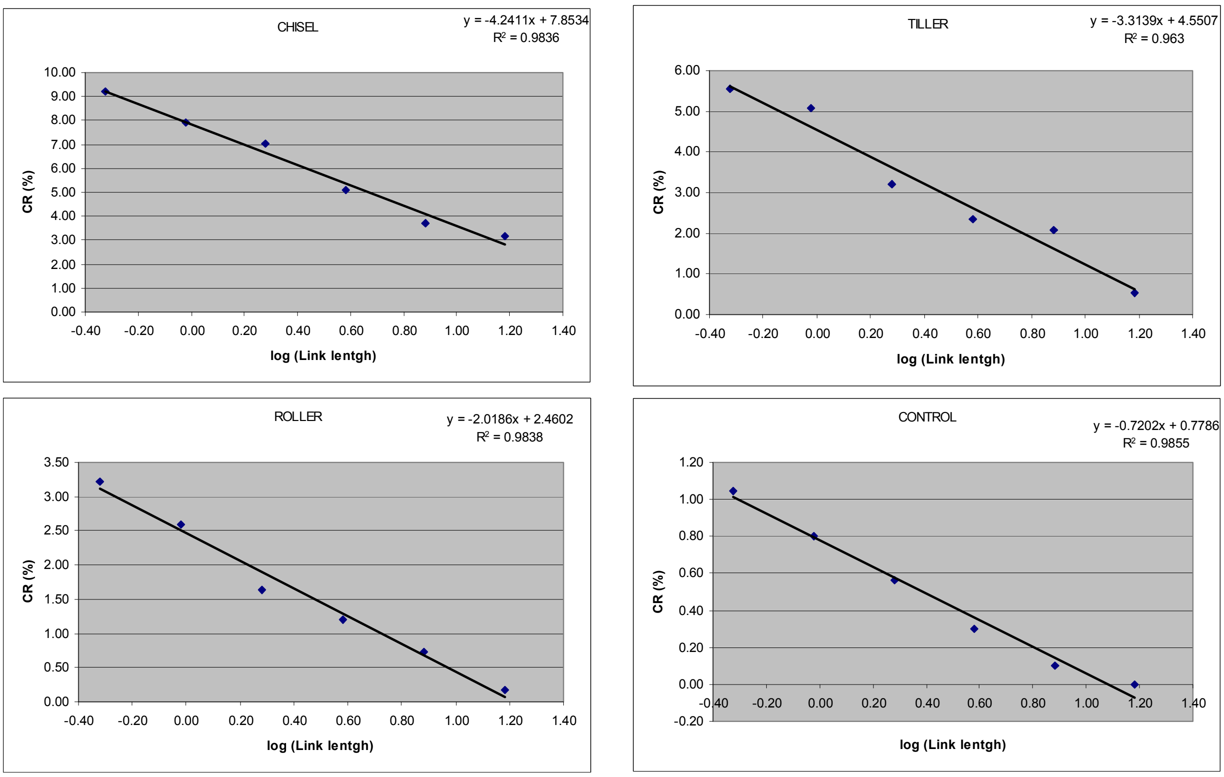

Figure 5. Chain roughness after tilling with different tools and a control.

These results demonstrated that there were no obvious tillage ridges at the site and the predominant soil surface roughness was random, related to the aggregates. However, as it can be observed the steepest absolute slope is obtained with the chisel, being significantly different followed by tiller, roller, and control, since the roughness decay is proportional to the expected result for each tillage tool (Garcia Moreno *et al.* 2008). The results are correlated to the measurements obtained from the shadows analysis. These results seem to be mainly produced by the formation of aggregates which increase the random roughness; however an induced roughness is associated with each tillage method. The data obtained with this new method yielded results significantly correlated to the pin meter findings and chain set values, but with the advantage that the time invested in gathering field data was 4 to 20 times shorter. Image interpretation is likewise less time-consuming and the instruments needed are easier to use and more portable.

Conclusions

The aim of the present study was to develop further a method for measuring soil surface roughness that would be more reliable, reproducible and convenient to use in the field than existing procedures. Other features sought were low development and maintenance costs and adaptability to the climate and soil conditions prevailing in arid and semi-arid regions, where moisture, organic content, soil colour and weather conditions ensure the success of the method. Overall, the results for the soil surface roughness obtained from the microrelief show the following conclusions:

1. The shadow analysis gives results proportional to the expected measurements as compared to other proven methods such as pin meter and chain set methods, with the advantage of being the easiest to handle in field.
2. In the present case, SSR resulting from tilling with different tools seems to demonstrate that as the tillage tool increases the presence of aggregates, so SSR increases.
3. Further research is needed to validate shadows analysis in darker soils and higher moisture conditions than the present work.

References

Cihacek LJ, Sweeney MD, Deibert EJ (1993) Characterization of wind erosion sediments in the Red River Valley of North Dakota. *J. Environ. Qual.* 22, 305-310.

García Moreno R, Saa Requejo A, Tarquis AM, Barrington S, Díaz Álvarez MC (2008a) A shadow analysis method to measure soil surface roughness. *Geoderma* 146, 201-208.

García Moreno R, Díaz Álvarez MC, Saa Requejo A, Tarquis AM (2008b) Soil surface roughness analyzed as a multifractal measure. *Vadose Zone Journal* 7, 512-520.

Hagen LJ (1988) New wind erosion model developments in the USDA. In 1988 Wind Erosion Conference Proceedings. Texas Tech. University, Lubbock, 11-13 April.

Larney FJ, Cessna AJ, Bullock MS (1999) Herbicide transport on wind-eroded sediment. *J. Environ. Qual.* **28**, 1412-1421.

Merrill SD, Huang CH, Zobeck TM, Tanaka DL (2001) Use of the Chain set for scale-sensitive and erosion relevant measurement of soil surface roughness. In ‘Sustaining the Global Farm’ (Eds. Stott DE, Mohtar RH, Steinhardt GC), pp. 594-600.

Potter KN, Zobeck TM, Hagen LJ (1990) A microrrelief index to estimate soil erodibility by wind. *Trasns. of the ASAE* **33**, 151-155.

Saleh A (1993) Soil roughness measurement: chain method. *J. Soil Water Conserv.* **48**, 527-529.

Saxton KE (1995) Wind erosion and its impact on off-site air quality in the Columbia plateau—An integrated research plan. *Trans. of the ASAE* **38**, 1031-1038.

Vidal Vázquez E, Vivas Miranda JG, Paz Gónzalez A (2005) Characterizing anisotropy and heterogeneity of soil surface microtopography using fractal models. *Ecological Modelling* **182**, 337-353.