Editorial Manager(tm) for Soil Science
Manuscript Draft

Manuscript Number: SS-07-93R2

Title: DERIVATION OF PLANT GROWTH COEFFICIENTS FOR THE USE IN WIND EROSION MODELS IN ARGENTINA

Article Type: Technical Article

Section/Category:

Keywords: Wind Erosion, Soil Canopy Cover, Soil Plant Residue Cover, Semiarid Regions

Corresponding Author: Ing. Agr. Daniel Eduardo Buschiazzo, Dr. Sc.

Corresponding Author's Institution: Universidad Nacional de La Pampa

First Author: Mariano J Mendez, Ing. Agr.

Order of Authors: Mariano J Mendez, Ing. Agr.; Daniel Eduardo Buschiazzo, Dr. Sc.

Manuscript Region of Origin: ARGENTINA

Abstract: Relationships between the wind erosion soil loss ratio (SLR, the quotient between the soil loss in a ground cover and a bare and smooth soil) and the percent of soil coverage with plant residues or canopy, have been mostly obtained by means of wind tunnel experiments where fluid-dynamic parameters, driven in the nature by climatic conditions, can be maintained constant. In order to test the behavior of SLR under natural conditions we compared wind erosion measured in the field in a semiarid environment of Argentina, during three sunflower (Heliantus annus) and three corn (Zea mays) growth periods with wind erosion calculated with available equations. Results showed that the relationship between measured SLR and percentage of soil cover with flat residues fitted well to the already available equation , where SC is the soil cover with flat residues and a is a constant, but with an a coefficient of 0.0605 instead of the originally provided 0.0438. This resulted in a difference in the SLR of about 10 % at soil coverage of 5 to 30%. These differences were attributed to the highest speeds used for the deduction of the original a coefficient (16 m s-1) than wind speeds occurred during field measurements in this study (10.8 m s-1, in average). The

relationship between SLR and soil coverage with flat residues for storms with erosion amounts higher than 100 kg ha-1 had an a coefficient of 0.039, very close to the original a coefficient. Measured SLR as a function of soil cover with corn and sunflower canopy was quite similar to calculations made with the already available equation , where cc is the fraction of soil surface covered with crop canopy. The available equation , where pgca and pgcb are constants and Pd the days after seeding, was not adequate to explain the evolution of the percentage of soil cover by the crops. This equation was replaced by where a, b and c are constants and x the days after seeding. SLR calculated on the basis of field measurements, was, as a function of the days after corn seeding, lower than SLR calculated with available equations at early crops growth stages and higher at late crop growth stages. At early crops growth stages, a critical period for wind erosion occurrence due to the low soil coverage with plants, sunflower had a better wind erosion control efficiency than corn. Sunflower also increased its wind erosion control efficiency with favorable climatic conditions, while corn efficiency remained unchanged. Such differences were attributed to the canopy leaf arrangement of each crop (planophyles in sunflower and erectophyles in corn), which resulted in a more effective reduction of wind speed by suflower leaves than by the narrow leaves of the corn at same growth stages. On the other hand, sunflower had a more efficient use of the solar radiation and a faster canopy growth. We concluded that the equations developed here for their use in empirical wind erosion prediction models produce reliable results, even under variable climatic conditions. Such models are useful for sites like the semiarid Pampas where detailed climatic information is lacking.

ANSWER TO REVIEWERS

The current version of this article was corrected on the basis of last Reviewers comments. All their suggestions were taken into account and included in the text as they were considered as relevant for improving the manuscript.

The most important changes were the inclusion of two new analyses. The first one was the relationship between the amounts of eroded material and both the wind value and the maximum wind velocity of each storm (Fig. 2), proposed by both Reviewers. These relationships were significant in all cases and had different shapes, which were related with the different effect of soil coverage on the amount of eroded soil as a function of wind speed.

The second analysis, proposed by Reviewer II, was the exclusion of storms with erosion amounts lower than 100 kg/ha from the relationship between SLR and soil coverage with flat residues (Fig 3a). This new analysis demonstrated that wind velocity affects SLR values, supporting the original discussion of this section, where differences between our data and previous reports on this issue were attributed to different wind velocities during wind erosion experiments.

All other formal changes proposed by the Reviewers were already included in the text.

Authors thank the contributions of both reviewers, as the manuscript was improved substantially.

DERIVATION OF PLANT GROWTH COEFFICIENTS FOR THE USE IN WIND EROSION MODELS IN ARGENTINA

Mariano J. Mendez[1)] and Daniel E. Buschiazzo[2)]

[1)] CONICET, Argentina, [2)] INTA Anguil, Facultad de Agronomía – UNLPam and CONICET, cc 300, 6300 Santa Rosa, Argentina. E-mail: buschiazzo@agro.unlpam.edu.ar

ABSTRACT

Relationships between wind erosion soil loss ratio (SLR, the quotient between the soil loss in a ground cover and a bare and smooth soil) and the percent of soil coverage with plant residues or canopy, have been mostly obtained by means of wind tunnel experiments where fluid-dynamic parameters, driven in the nature by climatic conditions, can be maintained constant. In order to test the behavior of SLR under natural conditions, we compared wind erosion measured in the field in a semiarid environment of Argentina, during three sunflower (*Heliantus annus)* and three corn (*Zea mays*) growth periods with wind erosion calculated with available equations. Results showed that the relationship between measured SLR and percentage of soil cover with flat residues fitted well to the already available equation $SLR_f = e^{-a\ (SC)}$, where SC is the soil cover with flat residues and *a* is a constant, but with an *a* coefficient of 0.0605 instead of the originally provided 0.0438. This resulted in an averaged difference in the SLR of 37% between both

equations. The variation in SLR was attributed to differences in the highest speeds used for the derivation of the original *a* coefficient (16 m s^{-1}) than wind speeds occurring during field measurements in this study (10.8 m s^{-1}, in average). The relationship between SLR and soil coverage with flat residues for storms with erosion amounts higher than 100 kg ha^{-1} had an *a* coefficient of 0.039, very close to the original *a* coefficient. Measured SLR as a function of soil cover with corn and sunflower canopy was quite similar to calculations made with the previously available equation $SLR_c = e^{-5.614\left(cc^{0.7366}\right)}$, where cc is the fraction of soil surface covered with crop canopy. The published equation $cc = e^{pgca + \left(\frac{pgcb}{Pd^2}\right)}$, where *pgca* and *pgcb* are constants and Pd the days after seeding, was not adequate to explain the evolution of the percentage of soil cover by the crops. This equation was replaced by $cc = \frac{a}{1 + b\ e^{-cx}}$ where a, b and c are constants and x is the days after seeding. SLR calculated on the basis of field measurements, was, as a function of the days after corn seeding, lower than SLR calculated with available equations at early crop growth stages and higher at late crop growth stages. At early crop growth stages, a critical period for wind erosion occurrence due to the low soil coverage with plants, sunflower had a better wind erosion control efficiency than corn. Sunflower also increased its wind erosion control efficiency with favorable climatic conditions, whereas corn efficiency remained unchanged. Such differences were attributed to the canopy leaf arrangement of each crop (planophyles in sunflower and erectophyles in corn), which resulted in a more effective reduction of wind speed by suflower leaves than by the narrow leaves of

the corn at same growth stages. On the other hand, sunflower had a more efficient use of the solar radiation and a faster canopy growth. We conclude that the equations developed here for use in empirical wind erosion prediction models produce reliable results, even under variable climatic conditions. Such models are useful for sites like the semiarid Pampas where detailed climatic information is lacking.

Key words: Wind Erosion, Soil Canopy Cover, Soil Plant Residue Cover, Semiarid Regions

INTRODUCTION

Wind erosion is an important degradation process of soils of semiarid environments (Peterson et al. 2006), including the semiarid Pampas of Argentina (Buschiazzo et al. 2006). Soil coverage with growing plants or decomposing plant residues is very effective in controlling this process, as they elevate the wind profile, decreasing its capacity to remove and transport soil particles from the soil surface (Bilbro and Fryrear 1994, Hagen and Armbrust 1994).

The efficiency of plant coverage in controlling wind erosion depends not only on its amount but on its quality. Similar percentages of flat or standing plant residues and growing crops can reduce wind erosion at different rates (Fryrear and Koshí 1974, Armbrust and Lyles 1985, Lyles and Allison 1981). Fryrear (1995), in a field study, showed that wind erosion was reduced by 55% with 20% of soil cover with flat residues. Armbrust and Bilbro (1997) found that growing crops are more effective than plant residues in controlling wind erosion, as 4 % of soil coverage with growing soybean decreased the erosion by 50 %. Sterk and Spaan (1997) found that 1000 kg ha^{-1} of residues were effective in controlling wind erosion at a wind speed of 8 m s^{-1}, but not at wind speeds greater than 11 m s^{-1}.

The most commonly used wind erosion prediction models, such as the wind erosion equation (WEQ, Woodruff and Siddoway 1965) or the Revised WEQ (RWEQ, Fryrear et al. 1998), relate the relative amount of eroded soil, the soil loss ratio (SLR), with the percent of growing plants or decomposing plant residues on the soil surface. The SLR is the quotient between the soil loss in a ground cover and a bare and smooth soil.

The equations resulting from the fitting of SLR with the coverage with plant residues or canopy have an exponential decay form. They have been mostly obtained from wind tunnel experiments (Bilbro and Fryrear 1994) and are strongly correlated to climatic conditions of the US. Less information exists on the relationships between SLR and plants coverage under natural conditions and for variable climatic conditions of other parts of the world. Such information, though based on empirical relationships, can be useful for sites of the world such as the semiarid Pampas, where detailed climatic and environmental information is scarce (Buschiazzo and Zobeck 2008).

One of the limiting factors for obtaining reliable relationships between both variables from field conditions is the interference with other parameters like soil roughness and soil moisture. We assume that if the effect of the interfering factors can be minimized, the fitting between SLR and soil coverage with plants obtained from field measurements should be quite similar to measurements obtained with wind tunnels.

Wind erosion prediction models simulate the evolution of crop canopy with time by relating SLR as a function of the number of days after crop planting (Fryrear et al. 1998). The influence of the climatic conditions on the variation of the soil surface covered with crop canopy is expressed by two constants, which are specific for each crop. These constants, which represent the crop growth rate, have been calculated for several crops and climatic conditions of the US. Little information is available for other parts of the world, including the semiarid region of Argentina. Also, the crop growth constants are not available for some crops, such as sunflower. We propose that the more intensive use of fertilizers in the US compared to Argentina and the growth of hybrid crops in US and of non hybrid crops in Argentina, should produce a faster crop growth in US than in Argentina. This may produce different results if the wind erosion prediction models are used in Argentina with the currently available crop growth coefficients. For example, the use of nitrogenous and phosphorous fertilizers averages, respectively, 181 kg ha^{-1} and 51 kg ha^{-1} in Texas (USDA 2006) and only 28 kg ha^{-1} and 19 kg ha^{-1} in Argentina (SAGPyA 2006). On the other hand yields of hybrid corn (*Zea mays*) average 7,500 kg ha^{-1} and hybrid sunflower (*Helianthus annus*) 1,500 kg ha^{-1} in Texas, and only 3,900 kg ha^{-1} and 1,770 kg ha^{-1}, respectively, in semiarid Argentina. All these conditions may produce faster coverage of the soil by the crops in US than in Argentina at the same growth stage, resulting in the available wind erosion prediction models underestimating wind erosion in Argentina.

The objective of this study was to determine the variations of SLR as a function of soil cover with flat residues and crops canopy in the field under different climatic conditions and to derive corn and sunflower growth coefficients in order to adopt wind erosion prediction models to an arid environment of Argentina.

MATERIALS AND METHODS

This study was carried out in a long term tillage experiment developed in 1996 in the Faculty of Agronomy of the University of La Pampa, Argentina (36º 46” lat, 64º 16” long., and 210 m above the sea level). The mean annual precipitation of this semiarid study site was 764 mm and the mean annual temperature was 15.5ºC for 1971-2001. Prevailing winds are from the North and the South, with higher speeds and gusts up to 60 km h^{-1} during the spring and the summer (Casagrande and Vergara 1996). The soil was an Entic Haplustoll with an A horizon containing 2.37 % organic matter, 12.8 % clay, 62.0 % sand and 25.2 % free lime. The aggregate size distribution determined by dry sieving with the rotary sieve (Chepil, 1962) was 8 % for aggregates coarser than 19.2 mm, 17.7 % for the 19.2 to 6.4 mm aggregates, 15.6 % for the 6.4 to 2 mm aggregates, 5.2 % for the 2 to 0.84 mm aggregates, 5 % for the 0.84 to 0.42 mm aggregates, and 48.5% for the aggregates smaller than 0.42 mm. The erodible fraction (<0.84 mm) represented 53. 5 % of the total amount of soil aggregates.

Wind erosion measurements were carried out with BSNE samplers (Fryrear 1986) in 1 ha square plots under the following management conditions: a) bare and flat soil considered as the reference plot (RP), b) growing corn (*Zea mays*) (GC), c) growing sunflower (*Helianthus annus*) (GS), d) low residues cover (LRC), e) high residues cover (HRC). Conditions for treatment a) were obtained with frequent plowing with a harrow disker. The corn of treatment b was planted on November

17, 2004, November 02, 2005 and October 30, 2006. The sunflower for treatment c was planted on November 17, 2004, October 02, 2005 and October 30, 2006 . The DK 682 RR corn variety was used in all years and the sunflower hybrid DK 3880 CL (Monsanto) was used in 2004 and 2006 and Araucano CL (Don Atilio) in 2005. Seeding density was 60,000 to 65,000 plants ha^{-1} for corn and 40,000 to 45,000 plants ha^{-1} for sunflower.

Wind erosion for treatment a was measured between September 17 2004 and November 24, 2006, for 39 storms. Wind erosion was measured on 10 storms for treatments b and c. These measurements were carried out between the planting and flowering stage of both crops when canopy cover prevented further wind erosion. Wind erosion was measured on 29 storms for treatments d and e. These measurements were done during the fallow period before the planting of corn and sunflower.

Soil surface conditions (soil roughness and residues cover) were obtained at fallow start by plowing the soil and burying the residues with a disker in treatment d and by controlling weeds with herbicides (glyphosate + 2-4-D) in treatment e. Table 1 shows the main characteristics of the eroding fields in each treatment.

Wind erosion was measured in four sampling points within each plot. The sampling points were located at the middle of each plot side (Fig. 1). Three BSNE samplers were placed at 13, 50 and 150 cm height in each sampling point.

An automatic meteorological station and a Sensit device were placed at the center of the RP in order to determine the wind speed, the wind direction and the period during which saltation occurred in some storms. Sensit is a device that electronically measures the impact of saltating particles. The storms with meteorological and Sensit data are detailed in Table 2.

All meteorological parameters and Sensit registers were measured at 1 minute intervals. Wind speed and wind direction were measured at two meter height. The combined analysis of wind direction and Sensit pulses allowed the determination of the prevailing wind direction during each storm. The wind value was calculated for each wind storm by means of equation [1] (Fryrear et al. 1998)

$$W = \sum_{i=1}^{N} V_{>6.68} \left(V_{>6.68} - \mathrm{V_u}\right)^2 \qquad [1]$$

where W is the wind value (m^3 s^{-3}) $V_{>6.68}$, are wind speeds, measured at 2 meters height, higher than 6.68 m s^{-1} V_u the threshold wind speed at 2 meters height (6.68 m s^{-1}, de Oro and Buschiazzo, 2008) *N* number of wind speed observations (i) in each storm.

The eroded soil in each storm and plot was calculated following the steps: a) calculation of the horizontal mass flux (HMF), the amount of material passing by each sampling point, using the following equation (Stout and Zobeck 1996):

$$f(z) = f_0 (1 + z/\sigma)^{-\beta} \qquad [2]$$

where $f(z)$ is the horizontal mass flux (kg m^{-2} s^{-1}) at height z, f_o is the horizontal mass flux at the soil surface, which is calculated as the squared inverse of the intersection resulted from the linear regression between the collected soil mass and the sampling height. The σ and β values are regression coefficients**;** b) calculation of the horizontal mass transport (*q*), by integrating HMF with height from the soil surface to the infinity in a 1 m wide vertical plane (kg m^{-1} s^{-1}); c) calculation of the amount of eroded material from the field, *Q*, by multiplying *q* by 100, the meters wide of the eroding field; d) calculation of the net amount of eroded material from the field (kg ha^{-1}) as the difference between *Q* of the sampling point placed windward and *Q* of sampling point placed leewards to the wind.

As shown in Figure 1, when the winds blew from the N, the eroded material was calculated as the difference between the material passing by sampling point 3 minus the material passing by sampling point 1. When the winds blew from NE, the eroded material was calculated as the difference between the averaged amount of material passing by points 3 and 4 minus the averaged amount of material passing by points 1 and 2.

The amounts of soil eroded in RP and the plots with flat residues were related to the maximum wind speed and the wind value of each storm by means of simple regression analysis.

The relative soil loss ratio (SLR) was calculated as the quotient between the eroded material in each treatment and the eroded material in RP. Table 3 shows the main characteristics of the measured storms.

The calculated change of SLR as a function of soil cover with flat residues was obtained with equation [3] (Fryrear et al. 1998):

$$SLR_f = e^{-0,0438(SC)} \qquad [3]$$

where SC is the percentage of soil cover with flat residues.

The calculated change of SLR as a function of plant canopy was obtained with Eq. [4] (Fryrear et al. 1998).

$$SLR_c = e^{-5.614\left(cc^{\ 0.7366}\right)} \quad [4]$$

where cc is the fraction of soil surface covered with crop canopy for growing crops, calculated with Eq. [5].

$$cc = e^{pgca + \left(\frac{pgcb}{Pd^2}\right)} \quad [5]$$

where Pd is the number of days after crops planting, and *pgca* and *pgcb* are crops growth coefficients.

The percentage of soil covered with plant residues or canopy of growing sunflower and corn was measured in the field as follows: digital photographs of the soil surface were taken weekly during all wind erosion measurement periods and randomly at each sampling plot from three approximately 1 m^2 soil surfaces (1.2 m long and 0.8 m wide). The photographs were taken perpendicularly to the soil surface at 1.5 m height. The Paint Shop Pro 7 PC program was used to determine soil coverage as follows: each digital photograph was divided into a 8.5 x 8.5 cm grid in the PC screen, producing a total of 126 crossing points; the percentage of soil cover was then determined as the quotient between the number of crossing points with plant residues and the total amount of crossing points of the grid.

The relationship between SLR and the percentage of soil cover with residues or crop canopy was tested by regression analysis. The relationship between corn and sunflower coverage and the days after seeding was tested using the CurveExpert 1.3 free edition program. The calculated SLR evolution with days after seeding of corn was calculated with equations [4] and [5]. These equations were not used for the calculation of SLR evolution with sunflower, as the coefficients *pgca* and *pgcb* for this crop are not provided. The calculated SLR evolution with days after seeding for corn and sunflower was calculated with equations [4] and [6], which was deduced from field measurements.

SLR evolution as a function of the days after crop seeding was related to the accumulated precipitation and temperature for the period between October and December of each year, which includes the fallow prior to each crop's seeding and its growth until the total coverage of the soil made wind erosion negligible.

The soil random roughness was estimated by comparing the digital photos used for the determination of soil cover with plant residues and canopy with reference photographs showing different surface roughness in the RWEQ manual (Fryrear et al., 1998). Random roughness was expressed in inches.

Wind erosion was simulated in the field with a portable wind tunnel in order to investigate the effect of wind speed on SLR. Wind simulations lasted 3 minutes and were carried out in the measuring fields. The eroded material was collected at the end of the wind tunnel with a 4 mm wide and 1 meter high slot sampler (Zobeck et al, 2003). The wind tunnel had a 6 m long-, 1 m height- and 0.5 m wide measuring section. A 30 HP internal combustion engine moved a 1 m wide propeller. The measuring section had a total surface of 2 m^2. More details on the portable wind tunnel are given in Mendez et al. (2006). The conditions of wind erosion simulations with the portable wind tunnel are detailed in Table 4.

RESULTS AND DISCUSSION

Table 2 shows that the maximum wind velocity of the measured storms varied between 9.8 and 15.2 m s^{-1}, with a mean value of 10.8 m s^{-1}. The averaged wind value varied between 6.6 and 126.4 and the duration of the storms between 31 and 823 minutes.

From all measured storms, 6 storms (40 %) had maximum wind speeds that varied between 7.5 and 10 m s^{-1}, 8 storms (53%) had maximum wind speeds that varied between 10 and 12.5 m s^{-1} and 1 (7%) had maximum wind speeds higher than 12.5 m s^{-1}.

The amount of eroded material varied between 0 and 1382.5 kg ha^{-1}. A 66% of the storms presented less than 100 kg ha^{-1} of eroded material, 31% between 100 and 250 kg ha^{-1} and only 3% more than 500 kg ha^{-1} (Table 3).

Figure 2 shows the relationships between measured erosion amounts and both the maximum wind speed and the wind values of each storm in RP and the plots covered with flat residues. Results indicated that these correlations were positive in all cases but linear in RP and exponential in the plot covered with residues. The linear relationships found in RP indicate that once the threshold wind velocity is reached the amount of eroded soil increases proportionally with the wind energy. The exponential relationships of the residues plots indicate a certain wind erosion control by these residues at wind speeds lower than 13 m s^{-1} and wind values lower than 100.

Corn height varied between 0 and 120 cm and sunflower between 0 and 110 cm during wind erosion measurements, covering between 0 and 100 % of the soil surface. Random roughness of the soil surface varied between 0 and 0.55. In RP random roughness was as high as 0.47 in few cases, due to the effect of the tillage machinery used for controlling weeds. Fryrear (1995) mentioned the difficulty of obtaining a flat surface in field studies.

SLR values for flat residues varied between 0 (HRC) and 0.88 (LRC). In the plots with growing crops, SLR varied between 0 and 0.46 (in both cases in GS). In some cases SLR was greater than 1, primarily when the soil surface coverage was less than 10 %. Sterk (2000) found that a lightly covered soil can be more eroded than a bare soil as a consequence of the greater turbulent movement of the air near the soil surface resulting from the plant residues. This effect increases the transport energy of the wind. SLR values greater than 1 were not considered in the analysis in our study.

Figure 3a shows that SLR and the percentage of soil covered with flat residue correlated well to an exponential decay. The fitting curve was similar to equation [3], but its shape was different. This made measured SLR, on average, 37 % lower than calculated with equation [3], with SLR 10% at 5% of soil coverage and 60% at 30% of soil coverage. Overestimation by equation [3] can be attributed to the greatest wind speeds considered for its development (16 m s^{-1}) than the wind speeds measured in the field in our case (10.8 m s^{-1} in average). It is known that higher wind speeds increase SLR values. Armbrust and Bilbro (1997) found that SLR values varied between 0.07 and 0.56 for the same percentage of soil cover when wind velocities increased from 12 to 16 m s^{-1}. Sterk and Spaan (1997) found that 1,000 kg ha^{-1} of plant residues are effective in controlling wind erosion when the wind velocity was lower than 11 m s^{-1} but not at higher wind speeds. The effect of wind speed on SLR values was confirmed by results obtained with the portable wind tunnel. Figure 3a shows that SLR data obtained with 16 m s^{-1} wind speed in the wind tunnel fitted well with SLR calculated with equation [3], whereas SLR data of wind tunnel simulations at lower wind speeds were lower than those estimated with equation [3] for the same soil coverage levels. This observation supports the hypothesis that the differences between data obtained here and those calculated with equation [3] were the result of the different wind speeds used in each case. These results indicate that for the climatic conditions of this study, where a mean wind speed of 10.8 m s^{-1} is given, SLR can be calculated with equation [3], but using an *a* coefficient value of 0.0605 instead of the original value of 0.0438.

The relationship between SLR and soil coverage with flat residues for storms with erosion amounts greater than 100 kg ha^{-1} was also explained by equation [3], but at lower significance levels (R^2=0.338, n=13, $p< 0.05$). Nevertheless, the *a* coefficient (0.039) was quite similar to the originally provided (0.0438). These results confirm the variation of SLR with wind speeds.

Figure 3b shows that SLR correlated well ($p<0.05$) with soil coverage with sunflower and corn canopy. SLR values were slightly higher for corn than for sunflower. This indicates that sunflower was a little more effective than corn in controlling wind erosion at similar soil coverage rates. Armbrust and Bilbro (1997) found that sunflower controlled erosion better than corn due to its less flexible leaves, which reduce the wind speed more effectively than the narrow leaves of the corn. Thus, differences between wind erosion occurring at same soil coverage levels of both crops should increase at higher wind speeds. Bilbro and Fryrear (1994) found that SLR values of sunflower and corn were similar at lower wind speed but they were higher for corn than for sunflower at higher wind speed.

The similar SLR values obtained with equation [4] and field measurements allow the use of this equation to predict SLR for both crops under the conditions of the current study.

Crop canopies were more effective in controlling wind erosion than flat residues. At a flat residue cover of 20 %, SLR was 0.30, whereas the same soil coverage produced a SLR of 0.16 with sunflower and 0.20 with corn. The flat residue cover must be 30% to reach similar SLR values than sunflower and 26.2% to reach similar SLR than corn. These results indicate that sunflower canopy was 50% more effective than flat residues and corn canopy 32 % more effective than flat residues in controlling wind erosion for the conditions given in this study.

The equation that better described cc variations for non hybrid corn and sunflower under the different climatic conditions (data not shown) of the study period was Equation [6]:

$$cc = \frac{a}{1 + b\, e^{-c\, x}} \qquad [6]$$

where cc is the percentage of soil surface covered with corn canopy, and *a, b* and *c* are crop coefficients. Table 5 shows the coefficient values of equation [6] for the climatic conditions of the sampling periods.

Figure 4 shows the evolution of SLRc as a function of the days after crop seeding. During early corn growth stages, the calculated SLRc, deduced from equations [4] and [5], was higher than calculated SLR deduced from equations. [4] and [6], whereas the opposite situation occurred at late growth stages in the three measurement periods. The calculated SLRc start to decrease 20 days after corn seeding, whereas calculated SLRc start to decrease 6 days after corn seeding in agreement with crop emergence. These results indicated that wind erosion predictions can be overestimated at early crop growth stages and underestimated at late crop growth stages if equations. [4] and [5], instead of equations. [4] and [6] are used in the semiarid Pampas. Such error can be particularly critical at early crop growth stages, where the low crop canopy cover increases wind erosion risks.

The shorter time until emergence when corn development is measured in the field than predicted with equation [5] can be attributed to higher temperatures at seeding time in the semiarid Pampas than in the central US, where that equation was developed. It has been widely demonstrated that corn emergence is highly dependent on soil temperature (Sawn et al., 1996). The faster corn growth between emergence and day 40 after seeding when predicted with equation [5] than with equation [6] can probably be attributed to the use of different corn genetic strains in each case. The calculated SLRc was developed on the basis of hybrid strains, while the calculated SLRc was developed on non-hybrid corn. It is known that hybrid strains show higher growth potential, size, uniformity, volume, quality in earliness, or resistance to unfavorable environmental factors than non-hybrid corn (Ashton 1949).

SLRc was similar in the three sampling periods of corn until day 38. After that date wind erosion was better controlled in 2004 than in 2005 and 2006. As shown in Figure 5, rainfall reached 300mm in 2004, 220mm in 2006 and only 120mm in 2005. On the other hand, accumulated temperature was lower in 2004 (1500ºC) than in 2005 (1650ºC) and 2006 (1800ºC). The combination of low precipitation and high temperatures of 2005 and 2006 favored a lower water balance, which decreased crop growth rate and increased wind erosion.

Figure 4b shows the evolution of SLRc as a function of the days after sunflower seeding. No comparison with predicted SLRc is possible in this case, as growth coefficients of equation [5] have been not developed for this crop. SLRc as a function of the days after sunflower seeding was lower in 2004, medium in 2006 and highest in 2005 during the whole sampling period, except for 33 days after seeding, where SLRc was lower in 2006 than in 2005. Rain that occurred few days after seeding in 2006 (Fig. 5) produced crusting of the soil surface, which delayed sunflower emergence and produced higher SLRc in relation to 2005. On the other hand, higher rains in 2006 than in 2005 at late growth stages allowed a better canopy development of sunflower in 2006 than in 2005, with SLRc of 2006 similar to that of 2004.

The better wind erosion control in 2004 than in both 2005 and 2006 was produced by a better soil coverage with sunflower as a consequence of a better crop growth under the moister and more favorable temperature conditions of 2004 (Fig. 5).

Efficiency of corn for controlling wind erosion was lower and less affected by climatic conditions than sunflower at early growth stages of the crops. For example, 20 days after seeding, corn controlled, on average of the three measurement periods, 12% (SLR = 0.88) of the erosion, while sunflower controlled 8% (SLR = 0.92) in 2006, 18% (SLR = 0.82) in 2005 and 22% (SLR = 0.78) in 2004. SLR variability between years until day 35 after seeding was lower than 7% for corn and 17% for sunflower. These results indicate that climatic conditions did not affect to a large extent SLR variations between years during the first crops development stages and that the use of equations [4] and [6] to predict the relative erosion amounts won't produce large errors in wind erosion prediction with empirical models like RWEQ.

At late crop growth stages, the response of both crops to different climatic conditions was similar, but wind erosion control by sunflower was higher than for corn, particularly under favorable climatic conditions of 2004. Forty days after seeding corn controlled 60% of wind erosion (SLR = 0.4) in 2005 and 2006 and 72% (SLR = 0.28) in 2004, while sunflower controlled 63% (SLR = 0.37) in 2005 and 86% (SLR = 0.14) in 2004 and 2006.

These results indicated that at early crops growth stages, a critical period for wind erosion occurrence because of the low soil coverage with plants, sunflower had better wind erosion control efficiencies than corn. On the other hand, sunflower increased its efficiency with favorable climatic conditions, whereas corn did not. The better wind erosion control of sunflower than of corn occurred even when seeding density was twice for corn than for sunflower. Differences in wind erosion efficiencies of both crops can be originated in the crops canopy leaf arrangement and leaf expansion. Maize, has more erectophile leaves than sunflower (Andrade, 1995), being its soil coverage lower for the same growth stage than for sunflower. It is also known that the leaves disposition of sunflower can produce a faster canopy growth of this crop, because of a higher intercepting efficiency of the solar radiation (Andrade and Sadras, 2000). Andrade et al. (2000) mentioned that sunflower needs a lower leaf area index than corn during the first growth stages to intercept the same amount of solar radiation.

CONCLUSIONS

The relationship between measured SLR and the percentage of soil covered with flat residues fitted to the equation $SLR_f = e^{-a\,(SC)}$ provided by most available wind erosion prediction models, but measured SLR was, on average, 37 % lower than calculated SLR. This difference was attributed to the lower wind speeds occurring during field measurements than wind speeds used to develop the original equation. This was confirmed by the exclusion of those storms with low erosion amounts form the relationship between SLR and soil coverage with flat residues, which produced similar SLR values than the originally provided equation. For conditions similar to those given during field measurements of this study (wind speeds averaging 10,8 m s^{-1}), the equation can be used but with an *a* coefficient of 0.0605 instead of the originally provided 0.0438.

Measured SLR as a function of soil cover with corn and sunflower canopy was quite similar to calculations made with the equation $SLR_c = e^{-5.614\,(cc^{0.7366})}$, provided by the wind erosion prediction models. At similar soil coverage percentages, flat residues were 50% less effective in controlling wind erosion than sunflower canopy and 32 % less effective than corn canopy. The evolution of the percentage of soil covered with crops canopy, the cc coverage factor of the equation $SLR_c = e^{-5.614\,(cc^{0.7366})}$, was not adequately explained by equation $cc = e^{pgca + \left(\frac{pgcb}{Pd^2}\right)}$, where *pgca* and *pgcb are* crops growth coefficients. At early growth stages, calculated SLRc with this equation was higher and at late growth stages lower than measured SLRc. The equation $cc = \frac{a}{1 + b\,e^{-c\,x}}$ where a, b and c are constants and x the days after seeding, was proposed to predict the percentage of soil cover with corn and sunflower canopy for the conditions of the semiarid Argentina. Different values of the crops growth coefficients for this equation were proposed. At early crops growth stages, a critical period for wind erosion occurrence due to the low soil coverage with plants, sunflower had better wind erosion control efficiencies than corn and increased substantially its efficiency with favorable climatic conditions, while corn did not. Such differences were attributed to the leaves architecture of each crop (lying in sunflower and standing in corn) which allowed a more effective reduction of the wind speed by sunflower leaves than the narrow leaves of the corn at same growth stages, and a more efficient use of the solar radiation and a faster canopy growth of sunflower. The equations developed here for empirical wind erosion prediction models produced reliable results, even under variable climatic conditions. Such models are useful for sites like the semiarid Pampas where detailed climatic information is lacking,

AKNOWLEDGEMENTS

CONICET, ANPCyT and Faculty of Agronomy of the National University of La Pampa, Argentina (FA-UNLPam), financed this study. Guillermo Casagrande and Graciela Vergara (FA-UNLPam) provided the climatic information.

REFERENCES

Andrade, F. H. 1995. Analysis of growth and yield of maize, sunflower and soybean grown at Balcarce, Argentina. Field Crops Res. 41: 1-12.

Andrade, F. H., and V. O. Sadras. 2000. Efectos de la sequía sobre el crecimiento y rendimiento de los cultivos. In: Andrade, F. H., and V. O. Sadras. Bases para el manejo del maíz, el girasol y la soja. EEA INTA Balcarce - Fac. Ciencias Agrarias UNMdP, Balcarce, Argentina.

Andrade, F. H., L. A. N. Agirrezábal, y R. H. Rizzalli. 2000. Crecimiento y rendimientos comparados. In: Andrade, F. H. and V. O. Sadras (Eds.) Bases para el manejo del maíz, el girasol y la soja. EEA INTA Balcarce - Fac. Ciencias Agrarias UNMdP, Balcarce, Argentina.

Armbrust, D.V., and L. Lyles. 1985. Equivalent wind-erosion protection from selected growing crops. Agron. J. 77: 703-707.

Armbrust, D. V., and J. D. Bilbro. 1997. Relating plant canopy characteristics to soil transport capacity by wind. Agron. J. 89:157-162.

Ashton, t. 1949. The use of heterosis in the production of agricultural and horticultural crops. Commonwealth Bur. Plant Breed and Genetic, 30.

Bilbro, J. D., and D. W. Fryrear. 1994. Wind erosion losses related to plant silhouette and soil cover. Agron. J. 86:550-553.

Buschiazzo, D.E. 2006. Management Systems in Southern South America. In: Peterson G.A., P.W. Unger, W.A. Payne (Eds.) Dryland Agriculture, 2nd Ed., Monograph 23. ASA/CSSA/SSSA, Madison, WI. Pp 395-426.

Buschiazzo, D.E., Zobeck, T. 2008. Wind erosion prediction using WEQ, RWEQ and WEPS in an Entic Haplustoll of the Argentinean Pampas. Accepted in Earth Surf. Proc. Land.

Casagrande, G., and G. Vergara. 1996. Características Climáticas de la Región, In: Buschiazzo, D. E., J. L. Panigatti, and F. Babinec. (Eds), Labranzas en la Región Semiárida Argentina. INTA, Santa Rosa, Argentina, pp 11-18.

Chepil, W.S., 1962. A compact rotary sieve and the importance of dry sieving in physical soil analysis. Soil Sci. Am. Proc., 26: 4-6.

de Oro L.,and D.E. Buschiazzo. 2008. Threshold wind velocity as an index of soil susceptibility to wind erosion under variable climatic conditions. Accepted for publication in Land Degrad. Dev.

Fryrear, D. W. 1986. A field dust sampler. J. Soil Water Conserv. 41:117-120.

Fryrear, D. W. 1995. Soil losses by wind erosion. Soil Sci. Soc. Am. J. 59: 668-672.

Fryrear, D. W., and P. T. Koshi. 1974. Surface mulching with cotton gin trash improves sandy soil. USDA Cons. Res. Report 18. USDA, Beltsville, MD.

Fryrear, D. W., A. Saleh, J. D. Bilbro, H. M. Schomberg, J. E. Stout, and T. M. Zobeck. 1998. Revised wind erosion equation (RWEQ) Wind erosion and Water Conservation Research Unit, USDA-ARS, Southern Plains Area Cropping Systems Research Laboratory. Tech. Bull. Nº 1.

Hagen, L. J., and D. V. Armbrust. 1994. Plant canopy effects on wind erosion saltation. Trans. ASAE 37: 461-465.

Lyles, L., and B. E. Allison.1981. Equivalent wind-erosion protection from selected crop residues. Trans. ASAE 24:405-408.

Mendez, M. J., J. De Dios Herrero, and D. E. Buschiazzo. 2006. Desarrollo de un túnel de viento portátil para la medición de erosión eólica. Proceedings of the XX Argentinian Soil Sci. Congress. Salta-Jujuy, Argentina, 18-23 September 2006. In CD.

Peterson, G. A., P. W. Unger, and W. A. Payne. 2006. Dryland Agriculture, 2nd Ed., Monograph 23. ASA/CSSA/SSSA, Madison, WI. 909 pp.

SAGPyA. 2006. http://www.sagpya.mecon.gov.ar/

Swan, J.B., T.C. Kaspar, and D.C. Erbach. 1996. Seed-row residue management for corn establishment in the northern US Corn Belt. Soil, Till. Res. 40: 55-72.

Sterk, G. 2000. Flattened residue effects on wind speed and sediment transport. Soil Sci. Soc. Am. J. 64: 852-858.

Sterk, G., and W. P. Spaan. 1997. Wind erosion control with crop residues in the Sahel. Soil Sci. Soc. Am. J. 61: 911-917.

Stout, J. E., and T. M. Zobeck. 1996. The Wolfforth field experiment: A wind erosion study. Soil Sci. 161:616-632.

USDA, 2006. http://www.usda.gov/nass/pubs/agstats.htm.

Woodruff, N. P., and F. H. Siddoway. 1965. A wind erosion equation. Soil Sci. Soc. Am. Proc. 29: 602-608.

Zobeck, T.M., J.E. Stout, R.S. van Pelt, R. Funk, J.L. Rajot, and G. Sterk. 2003. Measurement and data analysis methods for field-scale wind erosion studies. Earth Surf. Proc. Land. 28: 1163-1188.

LEGENDS OF FIGURES

Figure 1. Placement and ID Number of BSNE Samplers

Figure 2. Measured wind erosion and a) maximum wind speed in the reference plot (RP), b) maximum wind speed in the plots with flat residues (LRC and HRC), c) wind value in the reference plot (RP), and d) wind value in the plots with flat residues (LRC and HRC).

Figure 3. a) Relative soil loss (SLR) as a function of soil coverage with flat residues and b) SLR as a function of growing corn and sunflower.

Figure 4. Soil loss ratio (SLR) for a) growing corn, and b) growing sunflower as a function of the days alter seeding, for wet (2004), and dry climatic conditions (2005 and 2006).

Figure 5. a) Accumulated daily temperature and b) accumulated precipitation during three year sampling periods.

Figure 1
Click here to download high resolution image

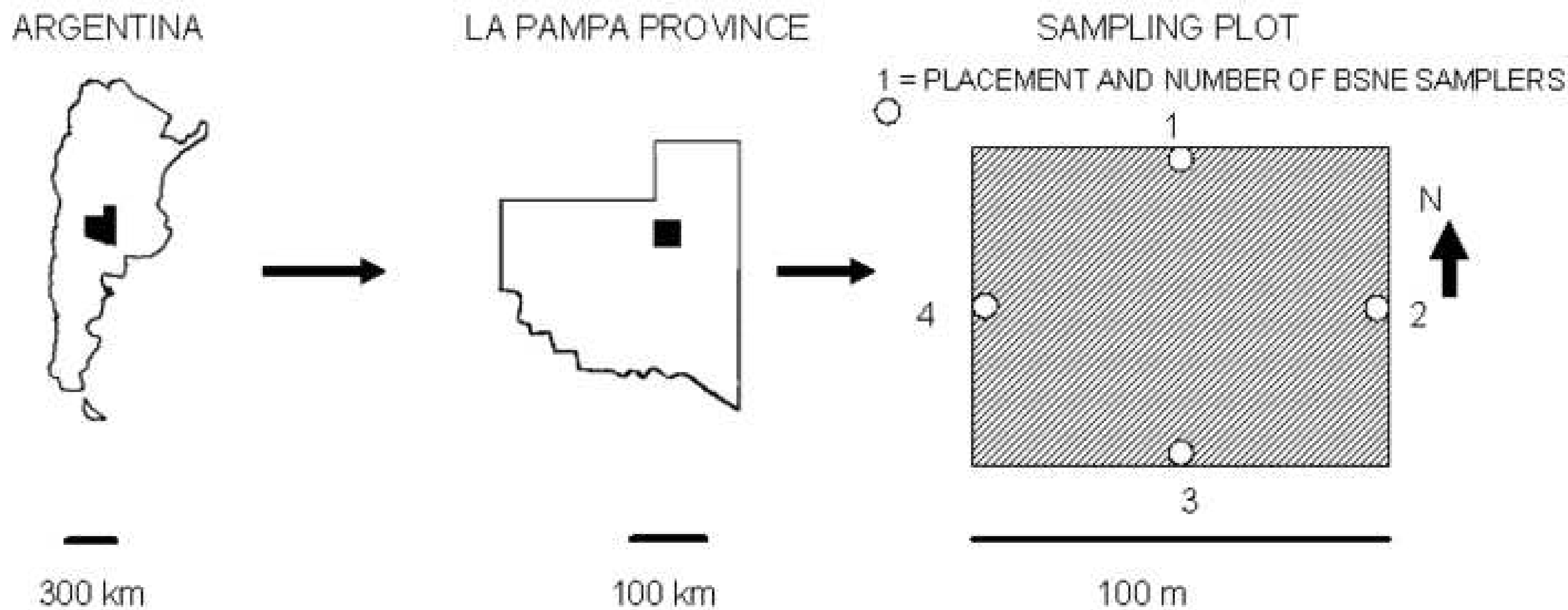


Figure 1

Figure 2

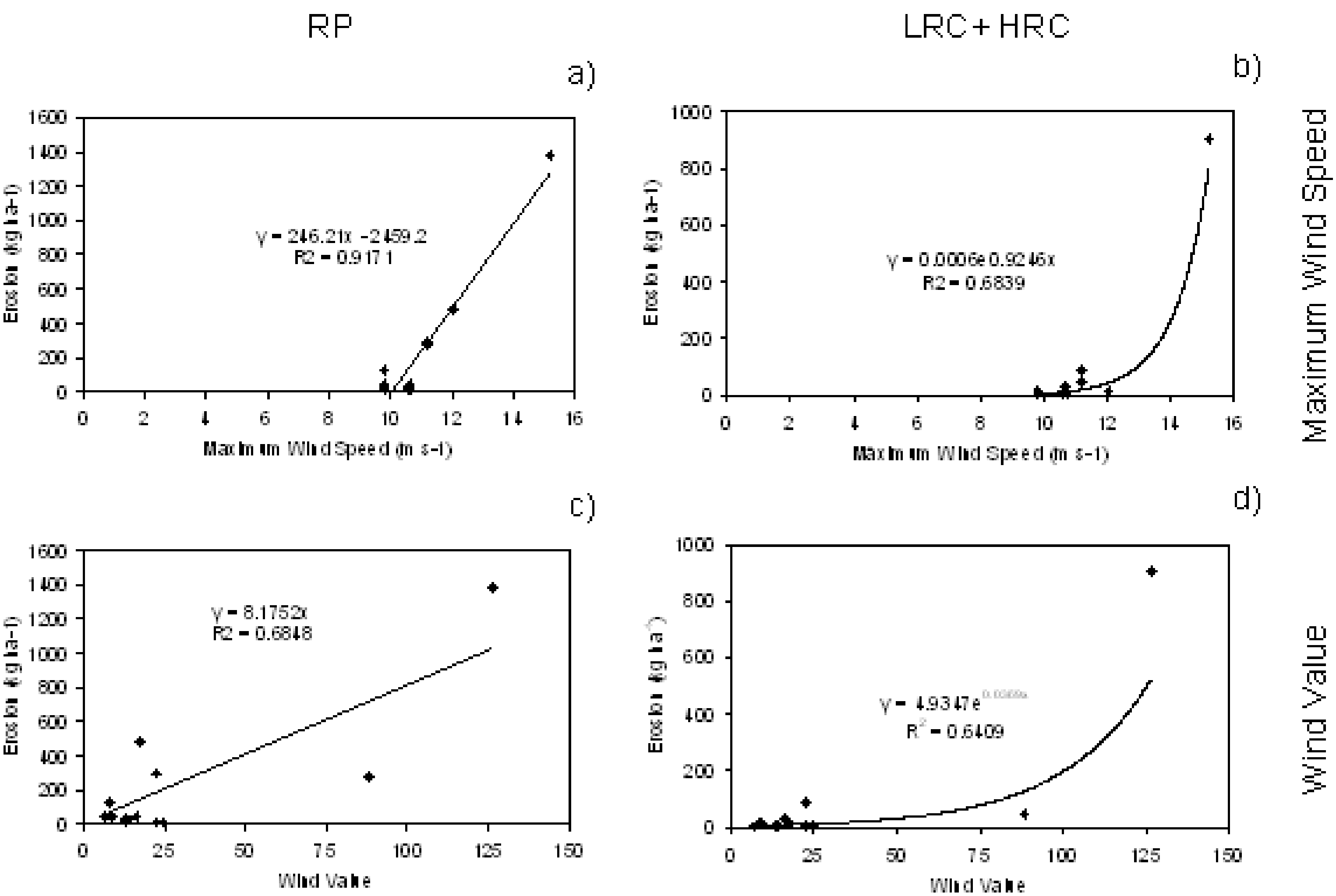


Figure 2

Figure 3

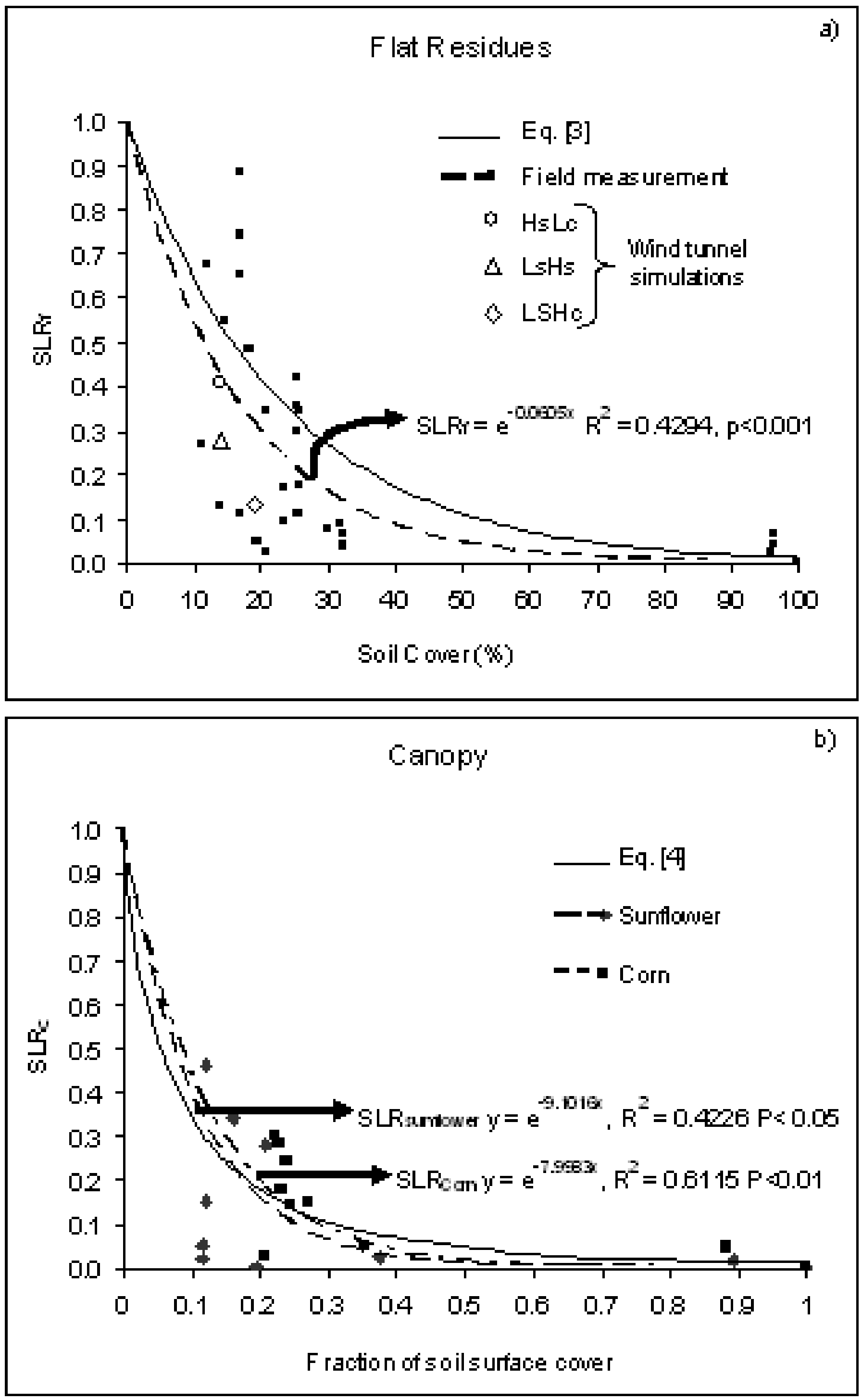
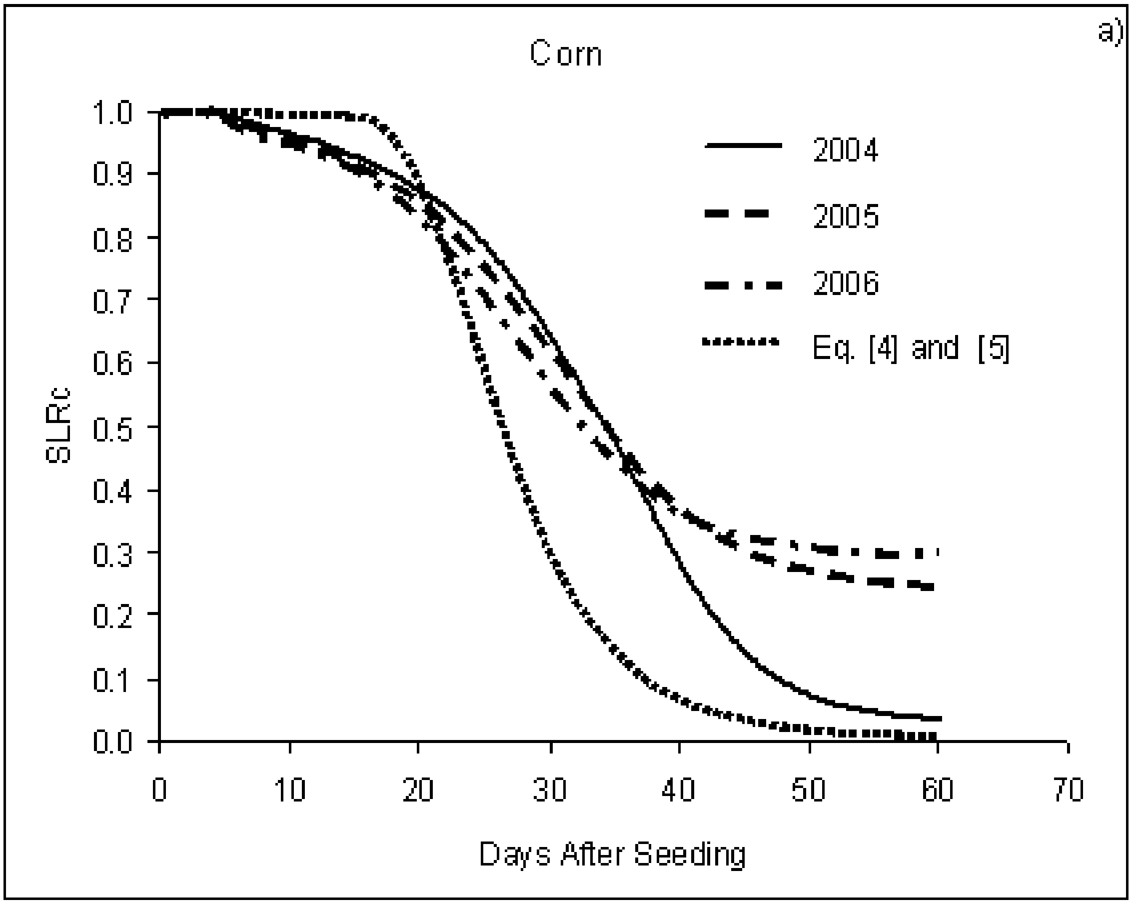


Figure 3

Figure 4



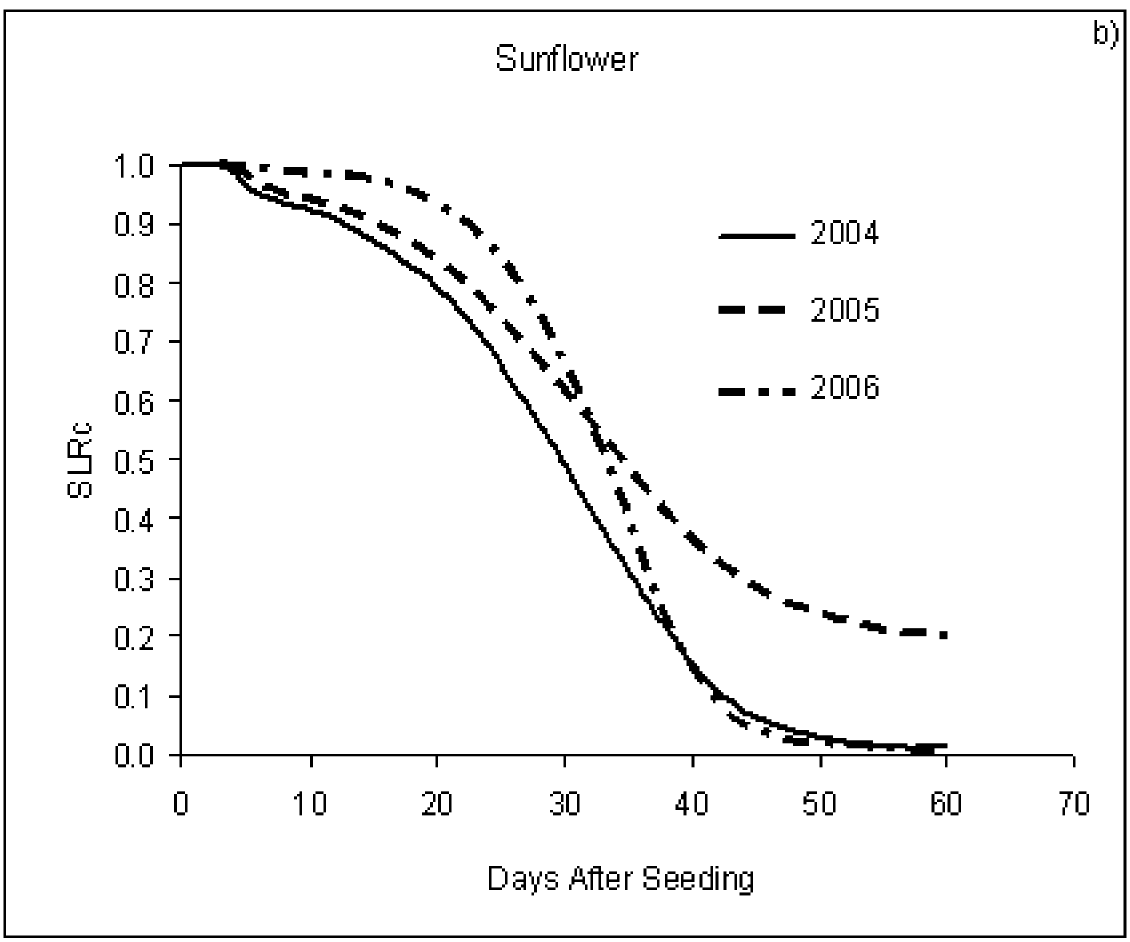


Figura 4

Figure 5

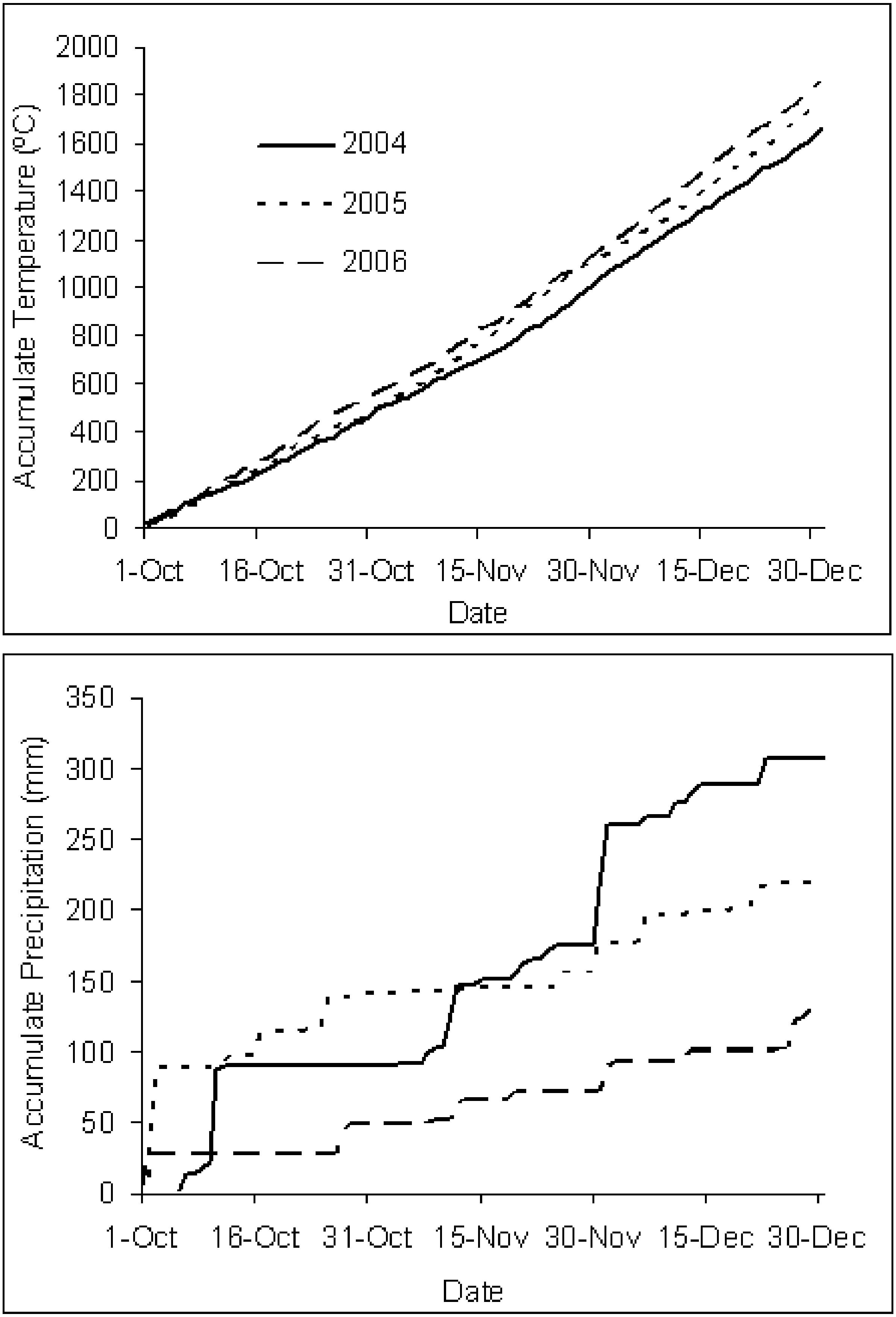


Figure 5

Table 1

Table 1. Main conditions of sampling plots.

Treatment *	Standing Residues		Flat residues		Canopy		Soil surface roughness	
	Type	Height (cm)**	Type	Coverage (%)**	Type	Coverage (%)**	Random	Oriented
RP		0-0	Weeds	0-30		0	0.05-0.47	0
GC	Corn	0-110	Corn and Weeds	5-88	Corn	0-100	0-0.55	
GS	Sunflower	0-120	Sunflower and Weeds	5-89	Sun-Flower	0-100	0.042	
LRC		0	Weeds, corn and sunflower	11-32		0	0.15-0.48	
HRC		0	Weeds, corn and sunflower	86-100		0	0-0	

*RP = reference plot, GC = growing corn, GS = growing sunflower, LRC = low residues cover, HRC = high residues cover.

** The first number indicates the soil cover at experiment start and the second the soil cover at experiment end.

Table 2

Table 2. Main characteristics of wind storms.

Date (dd/mm/yy)	Storm duration[1]	Maximum wind Speed	Wind value
	min	m/sec	$m^3 s^{-3}$
20/09/2004	814	10,6	14,1
28/10/2004	823	12,0	17,4
04/11/2004	530	10,6	13,2
23/12/2004	423	10,9	33,5
14/10/2005	114	9,8	6,6
09/11/2005	708	10,6	16,3
14/08/2006	174	9,8	13,1
17/08/2006	31	9,8	22,7
21/08/2006	173	11,2	22,5
25/09/2006	207	9,8	8,1
29/09/2006	124	11,2	88,2
06/11/2006	384	15,2	126,4
09/11/2006	82	10,7	26,2
15/11/2006	91	10,7	24,8
20/11/2006	309	9,8	9,0

[1] Number of minutes with wind speeds higher than 6.68 m s^{-1}, the threshold wind velocity (de Oro and Buschiazzo, 2006).

Table 3

Table 3. Material eroded in the reference plot (RP) and the cover plot (CP), soil cover (SC) and SLR for each storm.

Date	Residue Type	RP	CP	SC	SLR
		kg/ha		%	
20/09/2004	Flat Residue	25.1	3.2	14.1	0.127
06/10/2004	Flat Residue	428.8	288.6	11.9	0.673
06/10/2004	Flat Residue	428.8	18.0	96.3	0.042
21/10/2004	Flat Residue	346.6	166.1	18.5	0.479
21/10/2004	Flat Residue	346.6	21.7	96.6	0.062
28/10/2004	Flat Residue	480.3	11.5	96.0	0.024
28/10/2004	Flat Residue	480.3	52.3	17.0	0.109
04/11/2004	Flat Residue	13.2	7.2	14.8	0.543
04/11/2004	Flat Residue	13.2	0	100.0	0.000
16/08/2005	Flat Residue	113.4	19.3	23.8	0.170
16/08/2005	Flat Residue	113.4	7.1	32.1	0.063
22/08/2005	Flat Residue	22.8	0.9	32.1	0.038
22/08/2005	Flat Residue	22.8	2.0	23.8	0.090
14/10/2005	Flat Residue	47.7	1.1	20.9	0.023
14/10/2005	Flat Residue	47.7	2.2	19.4	0.047
14/08/2006	Flat Residue	26.9	3.0	25.4	0.113
17/08/2006	Flat Residue	11.3	4.7	25.4	0.418
21/08/2006	Flat Residue	294.2	86.4	25.4	0.294
14/09/2006	Flat Residue	57.9	19.8	25.7	0.342
25/09/2006	Flat Residue	129.3	14.0	25.7	0.108
29/09/2006	Flat Residue	280.6	48.7	25.7	0.174
06/11/2006	Flat Residue	1382.5	903.5	17.2	0.654
09/11/2006	Flat Residue	43.1	31.9	17.2	0.741
13/11/2006	Flat Residue	284.7	96.4	21.0	0.339
15/11/2006	Flat Residue	9.1	8.0	17.2	0.879
15/11/2006	Flat Residue	9.1	3.2	25.4	0.355
20/11/2006	Flat Residue	44.0	11.9	11.4	0.271
20/11/2006	Flat Residue	44.0	3.2	30.0	0.072
24/11/2006	Flat Residue	20.3	1.7	32.0	0.086
22-23/12/2004	Sunflower	191.5	4.9	3.75	0.0254
18-20/01/2005	Sunflower	52.0	0.0	100.0	0.000
18-21/10/2005	Sunflower	242.2	0.7	19.4	0.0027
26-28/10/2005	Sunflower	4.8	1.6	16.2	0.3407
2-3/11/2005	Sunflower	15.6	0.4	11.6	0.0226
3-4/11/2005	Sunflower	237.2	12.3	11.6	0.0518
4-8/11/2005	Sunflower	76.1	11.6	12.2	0.1518
8-9/11/2005	Sunflower	29.1	13.4	12.3	0.4608
9-11/11/2005	Sunflower	55.8	15.6	20.9	0.2800
22-23/12/2004	Sunflower	191.5	3.7	89.2	0.0191
22-23/12/2004	Corn	191.5	9.3	3.5	0.0485
18-20/01/2005	Corn	52.0	0.0	100.0	0.0000
18-21/10/2005	Corn	242.2	6.1	20.9	0.0251
26-28/10/2005	Corn	4.8	1.5	22.3	0.3021
3-4/11/2005	Corn	237.2	42.4	23.3	0.1787
4-8/11/2005	Corn	76.1	18.43	24.0	0.2423
8-9/11/2005	Corn	29.1	4.2	24.5	0.1436
9-11/11/2005	Corn	55.8	15.6	15.61	0.2800
1-2/12/2005	Corn	536.3	79.0	27.3	0.1473
22-23/12/04	Corn	191.5	8.6	88.4	0.0451

Table 4

Table 4. Wind speed and percentage of soil covered with flat residues during wind erosion simulations with a portable wind tunnel.

Treatment	Wind Speed	Soil cover with flat residues
	m s^{-1}	%
Low speed-low cover (LsLc)	11.3	14
High speed-low cover (HsLc)	16.7	14
Low speed-high cover (LsHc)	9.7	19

Table 5

Table 5. Regression coefficients of Eq. [6] for predicting the percentage of soil cover with corn and sunflower canopy for wet and dry weather conditions of the semiarid Pampas.

	A	B	c	N	SD	r^2
Corn, wet year	58.802238	2539.8068	0.16457089.	7	3.6323	0.98**
Corn, dry year	15.52494	547.69478	0.16851597	7	0.3773	1**
Sunflower, wet year	116.00964	1675.1796	0.14996713	7	2.0249	1**
Sunflower, dry year	19.599593	400.33926	0.1489563	10	1.4254	0.99**

a, b y c = regression coefficients, n = number of observations, SD = standard deviation, ** = P < 0.01.