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Dust storms, drought and desertification in the Southwest of Buenos Aires Province, Argentina

Tormentas de polvo, sequía y desertificación en el sudoeste de la provincia de Buenos Aires, Argentina

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ABSTRACT

The study region is one of the most endangered area from wind erosion in the country. This process, coupled with recurrent droughts in last decades and the mishandling of productive practices have generated desertification. This study presents a review of the interaction of these processes based on literature, field survey and perception of producers. Recommendations for rehabilitation are proposed. The area covers 6.5 million hectares, hosting in 2002: 550,000 people and 7,825 farms in irrigated and non-irrigated lands. Irrigated lands are devoted to agricultural production. Non-irrigated have a mixed production system (beef cattle-wheat). Mean annual rainfall in 1940-2014 was 407 mm. In 60% of these years, rainfall was below the mean. Desertification in the area is a consequence of drought and mismanagement. In wet cycles, producers increase stocking rate and wheat-sown area using the same practices of the humid pampa. As a consequence of dry cycles, land is abandonment and fields covered by sand and invasive plants. Over 20 cm of soil has blown away and sand accumulates in fences and stays suspended in the atmosphere, reaching Bahía Blanca city and up to 400 km into the Atlantic Ocean. The area requires deep structural changes in production systems and their management. Emphasis should be on sustainable management, which involves a mentality change of producers and decision makers. Recommendations were made for cleared and non-cleared lands.

Keywords
drought • land mismanagement • soil erosion • desertification • dust storms • area recovery • sustainable management • Argentina

RESUMEN

La región estudiada es una de las áreas más amenazadas por la erosión del viento en el país. Este proceso, junto con las sequías recurrentes en las últimas décadas y el mal manejo de las prácticas productivas han generado desertificación. Este estudio presenta una revisión de la interacción de estos procesos sobre la base de la bibliografía, el relevamiento de campo y la percepción de los productores. Propone recomendaciones para su rehabilitación. El área cubre 6,5 millones de hectáreas, albergando en 2002 a 550.000 personas y 7.825 explotaciones en tierras irrigadas y no irrigadas. Las tierras irrigadas están dedicadas a la producción agrícola. Las tierras no irrigadas poseen un sistema de producción mixto (bovinos de carne- trigo). La lluvia media anual entre los años 1940 y 2014 fue de 407 mm. En el 60% de los años del período indicado fue menor que la media. La desertificación en el área es una consecuencia de la sequía y el mal manejo. En los ciclos húmedos, los productores incrementan la carga animal y el área sembrada con trigo usando las mismas prácticas de la pampa húmeda. Más de 20 cm de suelo se ha perdido debido a la erosión eólica y la arena se acumula en los alambrados y además permanece suspendida en la atmósfera, avanzando sobre la ciudad de Bahía Blanca y hasta 400 km en el Océano Atlántico. El área requiere cambios estructurales profundos en los sistemas de producción y su manejo. El énfasis debería estar en el manejo sustentable, que involucra un cambio de mentalidad de productores y tomadores de decisiones.

Palabras clave
sequía • mal manejo de la tierra • erosión del suelo • desertificación • tormentas de polvo • recuperación del área • manejo sustentable • Argentina

INTRODUCTION

Arid and semiarid regions comprise about 70% of Argentina's territory. This reality ranks Argentina as the ninth country in the world in terms of percentage of drylands and as one of the 14 countries where these lands occupy over 1 million km^2. The popular image of Argentina is that of "Humid Pampas". This image is distorted. Reality is that three-quarters of the country are drylands and face desertification. Of the 276 million ha that make up Argentina's continental territory, 60 million ha are affected by different soil degradation and desertification processes, with progress estimated at 650,000 ha year^{-1}.

About 30% of Argentina's total population lives in regions under moderate to severe erosion (1). In this context, Southwest of Buenos Aires Province (SW BAP) becomes a paradigmatic place in South America, where the dust bowls processes that had manifested between the 30's and 50's in Argentina's pampas got magnified in recent years, transforming the area into one comparable to USA's 30's dust bowl, with similar effects upon producers' impoverishment, productive soil loss and damage to infrastructure and urban areas.

This work is based on the hypothesis that desertification in SW BAP depends on the relationship between recurrent droughts and desertification processes, whose most striking manifestation are the dust storms that affect the region and surrounding territories. Knowing and controlling desertification in places where dust storms originate would help mitigate the intensity and magnitude of dust bowls, which deteriorate habitat at the global scale.

Knowing the dynamics, causes, symptoms and consequences of desertification processes in their places of origin makes it possible to design strategies for recovering and controlling desertification-affected areas. Local recovery measures are the only mechanism able to reduce soil particle emissions and the magnitude and impact of dust bowl phenomena at planetary and local scales.

This study describes the area's current situation related to its generalized drought and desertification, designs actions, and contributes with recommendations for implementing a program for the area’s gradual recovery.

SOME DEFINITIONS

Desertification

Means land degradation in arid, semiarid and dry sub-humid areas resulting from various factors, including climatic variations and human activities (43).

Desertification processes involve environmental, economic and social factors and its treatment requires combined efforts to each of these aspects and their relationships.

Desertification results from degradation of the vegetation cover by overgrazing, overtrampling, clearing, fuelwood collection, repeated burning, and inappropriate agricultural practices. It leads to a general decrease in productivity of the land and in accelerated degradation of the soil erosion, siltation, salinization and alkalinization of irrigated lands, or dryland salting. The excessive loss of soil nutrients, and depletion of the soil seed bank, affects the capacity of the vegetation to recover and constitutes the main mechanism of irreversible damage to the environment to which is added the known impact of grazing on pastoral rangelands (40, 41).

Land degradation

Means reduction of the biological or economic productivity and complexity of rain fed cropland, irrigated cropland or range, pasture, forests and woodlands resulting from land use or from a process or combination of processes, including those arising from human activities and habitation patterns, such as soil erosion caused by wind and/or water, deterioration of the physical, chemical and biological or economic properties of soil, and long-term loss of natural vegetation.

Arid, semiarid and dry sub-humid areas

Means areas -other than polar and sub-polar regions- in which the ratio of annual precipitation to potential evapotranspiration falls within the range from 0.05 to 0.65. Hyper-arid areas were excluded from the official United Nations Convention to Combat Desertification and Drought.

The combination of progressive desertification and drought can be severely crippling to the environment, as the stress created by human overexploitation of the land becomes especially visible during severe drought. Droughts and desertification can amplify each other's impacts.

The meteorological phenomenon known as *"dust storms"* or *"sand storms"* is common in hyperarid, arid and semiarid regions, resulting from a combination of climate, weather and substratum. Indeed, the first element needed for any dust storm -a source of dust- depends largely on climate. Ideal dust sources occur in areas where the composition of the soil is very dry and loosely held on the surface. This commonly occurs in arid and semiarid regions, usually after a prolonged drought.

Moisture keeps soil compact and helps maintain vegetation, which protects it from being swept up into passing winds. Not surprisingly, dust storms frequently occur in the desert. However, marginal dry lands are increasingly a source of major dust storms. These areas have fragile, delicately balanced ecosystems (12).

Aeolian processes, involving erosion, wind transport and sediment deposition, occur in coastal areas, semiarid and arid regions and agricultural fields, and are responsible for emission and/or mobilization of dust and formation of sand dune areas (23).

STUDY AREA

The study area in SW BAP (Southwest Buenos Aires Province) comprises Adolfo Alsina, Coronel Dorrego, Saavedra, Tornquist, Puán, Coronel Rosales, Bahía Blanca, Villarino and Carmen de Patagones districts, and Guaminí, Coronel Suárez and Coronel Pringles divisions (figure 1, page 225). It covers an area of 6.5 million ha where 550,000 people live, *i.e.* 4% of BAP population (37).

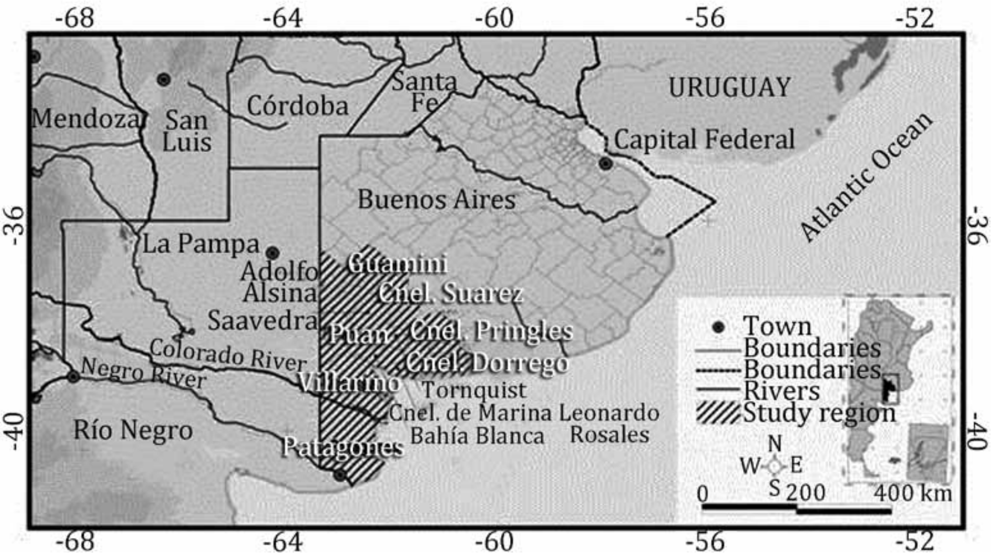

Figure 1. Study region in the Southwest of Buenos Aires Province.

Figura 1. Región de estudio en el Sudoeste de la provincia de Buenos Aires.

It has own climatic and edaphic characteristics and therefore its possibilities and restrictions for primary productivity are clearly lower than in the rest of the BAP.

Soils are Mollisols. These are steppe or grassland soils, located in temperate climates. This large soil order is divided into suborders based on their evolution degree, climate characteristics and landscape diversity. In the area, according to Sánchez and Pezzola (2007), soils have predominance of aeolian material and presence of a petrocalcic layer of various thicknesses ("tosca") generated by $CaCO_3$ migration in the soil profile by action of water infiltration.

The area is a transition between ecological systems of semiarid and humid climates, and belongs to the Monte and Espinal phytogeographic provinces. Climate is dry, with mean annual temperature below 18°C, classified according to Köppen-Geigen as the Bsk type (36). Land supports livestock production systems and irrigated and rainfed agriculture.

The region extends in a sort of Mesopotamian area between two major rivers: Colorado and Negro. The latter, at the "Primera Angostura" gauging station, recorded an annual average flow of 845.8 m^3 $second^{-1}$. There is an old irrigation project that intends to use most of their water currently discharged into the Atlantic Ocean ("Project 0", with several alternatives that would use 300 m^3 $second^{-1}$). This project, in its most ambitious goal would incorporate about 200,000 ha to the irrigation system. Because the project was not implemented, fragmentation of the Patagones district responded with small fields (<200ha) devoted to wheat and livestock production in drylands.

In 2002 there were 7,825 agricultural farms (7) in irrigated and non-irrigated areas. The irrigated zone is devoted to horticultural production (onion, pepper, pumpkin, etc.) for local and export markets, and sunflower, wheat, and corn and sorghum for silage.

The organization regulating the irrigation system is the Development Corporation of the Colorado River (CORFO). Water has a high salt content because of its passage through "Salinas Grandes" (36). Colorado River provides water which is conducted through channels without waterproofing and consequently water loss reaches 15-33%.

Non-irrigated areas have a mixed production system (beef cattle-wheat) because of rainfall variability. Producers surveyed are unaware of studies on groundwater availability, information that specialized agencies would have. Beef cattle (mainly Polled Hereford), representing 15% of the total in BAP, was introduced to the area in the mid 70's because, at the beginning of this decade, sheep were not reared mainly due to low wool and lamb prices. Farms in Bahía Blanca and Coronel Rosales, from 50 to 500 ha represented 62.0% and 54.4%, respectively (26). There is no income diversification and this favors overexploitation and land abandonment.

From cattle health perspective, the area is a buffer zone, *i.e.* it is a Foot and Mouth Disease (FMD)-free zone with vaccination. Farmers wish the area to be a FMD-free zone with no vaccination.

Data was obtained from the authors' direct from field survey, analysis of primary and secondary sources (climate, statistics, censuses, etc), and interviews with representatives of the Rural Associations of Carmen de Patagones, Stroeder and Villalonga, producers and key informants from the study area.

The rainfall cycle

Mean annual rainfall recorded in Stroeder (40°11'09" S, 62°37'12" W) over the last 75 years (1940-2014) was 407 mm (figure 2, page 227). In 60% of years, rainfall was below the mean. Since 1992 there have been 12 years with annual rainfall exceeding the mean. During the analyzed period, some values duplicated the annual average (851, 850 and 821 mm in 2001, 2004 and 2014, respectively).

In 2004, wheat yield, according to interviewed producers, was exceptional (3,000 kg ha^{-1} *vs.* a mean of 1,000 to 1,200 kg ha^{-1}). From 2005 to 2009, the rainfall cycle was below the average, except in 2006 when it exceeded the mean by 59 mm, but according to Pezzola and Winschel (2004), its distribution was inadequate for winter crops. In 1942, 1949, 1971 and 1982 rainfall was 213, 214, 216 and 215, respectively, the lowest values of the past 75 years. This situation reflects the natural pattern of high rainfall variability in drylands within and between years.

The area has dry summers and rainy autumns, which is the pattern to which the traditional agricultural system was adapted. In wet cycles, producers increase stocking rate and wheat-sown area. In the latter case by using tillage methods (disk plough) inappropriate for the area, because this leaves the soil exposed to wind action. This technique is practiced in the area since field cultivation began 100 years ago, reproducing the same agricultural practices as in the neighboring humid pampas (1,081 mm $year^{-1}$ in 1951-2000) (9).

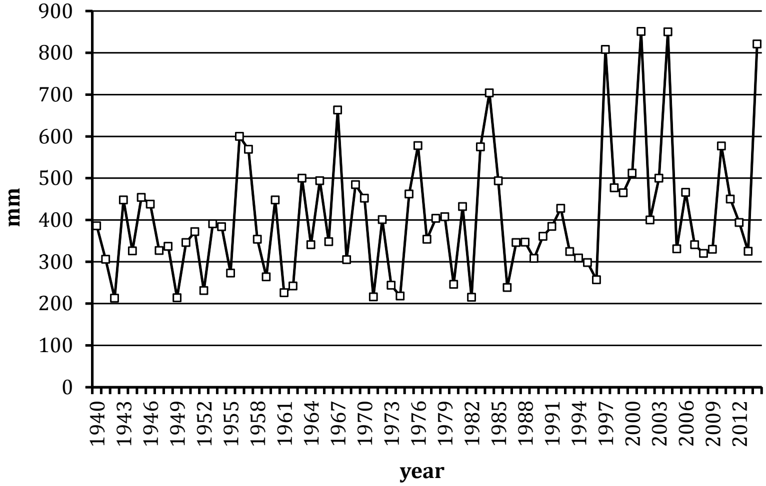

Figure 2. Annual precipitation in Stroeder during the 1940-2014 period.
Figura 2. La precipitación anual en Stroeder durante el período 1940-2014.

INTERACTIONS AMONG DESERTIFICATION, DROUGHT AND DUST STORMS

The SW BAP becomes an important center of particle emission, comparable to other internationally well-known areas like the Sahara, the main terrestrial source of airborne dust, particularly the Bodélé Depression and the drylands of Mauritania, Mali and Algeria in the Sahel (29). The dry environments of China, Arabian Peninsula, Iran, Pakistan and India also contribute greatly to dust storm formation (45, 47).

This is a well described process for many parts of the world. Among other, the Department of Environment and Resource Management (DERM) of the Queensland Government (8), reported that wind erosion is a common cause of land degradation in the arid and semiarid grazing lands of inland Queensland; it is one of the processes leading to desertification; significant wind erosion occurs when strong wind blows over light-textured soils that have been heavy grazed during periods of drought. Understanding wind erosion is important as it provides a foundation for developing appropriate and effective land management and erosion control processes and to control wind erosion; DERM encourages the adoption of sustainable management practices in the grazing and cropping industries.

Wind erosion may have the following impacts (8):

a) soil fertility is reduced because of the loss of the plants nutrients that are concentrated on fine soil particles and organic matter in the topsoil. This reduces the soil capacity to support productive pastures and sustain biodiversity;

b) the erosion at the base of bushes and plants can result in the plant being isolated and ground cover being thinned out;

c) the erosion of light-textured topsoil can expose dense clay subsoils. These smooth and bare areas, called claypans or scalds can cover hundred or even thousands of hectares. They are difficult to revegetate due to the lack of topsoil, low permeability and their often saline nature;

d) the buildup of soil particles against obstacles may bury fences and roads;

e) sand grains transported by strong winds can damage vegetation in their path by sandblasting;

f) air pollution caused by fine particles in suspension can affect people' health and cause other problems.

When winds are strong, large amounts of sand and dust can be lifted from bare, dry soils into the atmosphere and transported downwind affecting regions for hundreds to thousands of kilometers. A dust storm is a meteorological phenomenon that arises when a gust front passes or when wind force exceeds the threshold value where loose sand and dust are removed from the dry ground. In desert areas, dust and sand storms are most commonly caused by either thunderstorm outflows or strong pressure gradients which cause increased wind velocity over a wide area. Drought and wind contribute to emergence of dust storms, as do poor farming and grazing practices by exposing dust and sand to wind. For countries downwind of arid regions, airborne sand and dust present serious risks to environment, farmers and human health (44, 46).

According to Millennium Ecosystem Assessment (30) desertification affects global climate change through soil and vegetation losses. Dryland soils contain over a quarter of all of the organic carbon stores in the world as well as nearly all the inorganic carbon. Unimpeded desertification may release a major fraction of this carbon to the global atmosphere, with significant feedback consequences to the global climate system. It is estimated that 300 million tons of carbon are lost to the atmosphere from drylands as a result of desertification each year (about 4% of the total global emissions from all sources combined (30).

The effect of global climate change on desertification is complex and not sufficiently understood. Climate change may adversely affect biodiversity and exacerbate desertification due to increase in evapotranspiration and a likely decrease in rainfall in drylands (although it may increase globally).

However, since carbon dioxide is also a major resource for plant productivity, water use efficiency will significantly improve for some dryland species that can favorably respond to its increase. These contrasting responses of different dryland plants to the increasing carbon dioxide and temperatures may lead to changes in species composition and abundances.

Therefore, although climate change may increase aridity and desertification risk in many areas, the consequent effects on services driven by biodiversity loss and, hence, on desertification are difficult to predict.

Due to strongly interlinked issues and policies between desertification, biodiversity loss, and climate change, joint implementation of the UNCCD, the Convention on Biological Diversity, and the Framework Convention on Climate Change can yield multiple benefits. Environmental management approaches for combating desertification, conserving biodiversity, and mitigating climate change are linked in numerous ways.

Typically, these issues were dealt with separately by different conventions and policy fore, which were negotiated and implemented independently of one another, often by different departments or agencies within national governments. Thus, joint implementation and further strengthening of ongoing collaborations can increase synergies and effectiveness (30).

Southwest of Buenos Aires Province is one of the most endangered areas from wind erosion (5). Potential wind erosion indicates that this area has light, moderate, high, and very high wind erosion classes (2.8%, 42.3%, 40.2% and 14.7%, respectively) (39).

To the west of BAP, more than eight dust storms are reported per year (28, cited by 42). Winter (June to August for the South Hemisphere) is a peak season for South American dust storms (11).

Wind erosion was measured in a smooth field on a site in Bahía Blanca (38°44' S, 62°28' W) with no vegetation cover during April-November 2009 (5). Wind mean speed at 2 m height, for 14 recorded storms, was 32.5 km h^{-1} and ranged from 25.9 to 40.6 km h^{-1}. In about 70% of cases, prevailing wind direction was NNW. Rainfall reached 143 mm over this period, which represents 21% of the historical average (1991-2000). According to Bouza *et al.* (2012), this situation indicates a strongly negative water balance and an edaphic condition favorable to deflation. Soil loss for the sampled period was 56.8 t ha^{-1}.

Wind erosion risk (WER) was determined in SW of BAP using the wind erosion equation (WEQ) model (39); WER results from multiplying the soil erodibility index ("I") of the soil by the climatic factor (C). Results indicated that WER (Mg ha^{-1} $year^{-1}$) ranged from 104.6 in Patagones to 3.0 in Guaminí and Saavedra districts.

The loss of 1 cm of soil in SW BAP produces an average wheat yield reduction of 50 kg ha^{-1}. Of the 3,161,403 ha used for wheat cropping, 20.2% presented a historical loss of about 10 cm of soil. As a consequence, mean annual reduction in wheat yield was about 320,000 t, equivalent to U$S 58.5 million (wheat price in December 2016 = U$S 182.7 t^{-1}). Within this framework, Patagones district stands out with 69% of the 222,620 ha under wheat cropping affected by wind erosion. As a consequence of wind erosion and strong droughts of the last years, this district shows a widespread desertification process (38). There are examples in other areas of the world where there have been decreases in crop yields as a consequence of soil erosion. It has been proposed a procedure for evaluating the effects of wind erosion on soil loss and subsequent crop yields. The procedure uses the wind erosion equation to predict potential annual soil loss, which is converted to the crop yield reduction per inch of erosion for corn, grain sorghum, and wheat. When applied in 13 southwestern Kansas counties, the procedure resulted in estimated annual yield reductions of 339,000 bushels of wheat and 543,000 bushels of grain sorghum on 1.2 million acres of sandy surface soils (27).

A most outstanding example of the relationship between dust storms and desertification is the "Dust bowl" that affected the Great Plains of USA in the 1930's. It was caused by a combination of natural drought and poor farming practices (19).

ORIGIN OF DESERTIFICATION IN SWBAP

Desertification in the area corresponds with the definition proposed by the United Nations International Convention to Combat Desertification and Drought: Desertification is land degradation in arid, semiarid and dry sub-humid areas, responding to two factors:

a) climate variability in drylands, expressed mainly by drought;

b) mismanagement of these ecosystems by human groups, overloading the land, reducing its productivity and forcing people to migrate or fall into poverty (41). This definition contains two aspects to be highlighted in the case of desertification in SW BAP: drought and mismanagement. Then we analyze each of the processes that have led to the area desertification.

Unplanned woody species removal

When woody species were removed, there began conventional tillage cultivation in drought conditions like those present in the area, accompanied by strong winds, resulting in loss of large amounts of soil by deflation and, moreover, loss of the seed bank. According to the study by Pezzola *et al.* (2009), of the total area of Patagones district, about 1,36 million hectares, 28.9% of its soils, have varying degrees of erosion: 3.5% slight to moderate, 16.1% moderate to severe and severe, and 9.3% severe to serious.

Clearing of the area was not only the result of producers' actions but was also encouraged by the State that provided assistance and equipment to agricultural corporations created in the 70's. Also, banking institutions developed credit lines to finance clearing costs. Rational strip clearing was recommended but controls failed. There is a proposed law on land clearing, agreed with all production sectors, which will contribute to managing this process.

Uncontrolled fires

Encroachment and proliferation of aggressive woody plants has become a serious problem in several rangelands of the world, leading to significant reduction in available forage production. This is attributed to disruption of the natural balance between woody and herbaceous plants and is caused by irrational and selective grazing by livestock and a change in intensity and frequency of natural fires due to human intervention (33).

Arid and semiarid ecosystems are the most affected by fire in Argentina. Most fires are caused by man, either accidentally or intentionally.

The effect of both a non-prescribed summer fire and grazing at high stocking rate following fire contributes to occurrence of bare soil and desertification.

The role of prescribed fire in promoting grass growth at the expense of woody vegetation has been well documented worldwide (15).

Areas affected by fires in Patagones and Villarino during 2002-2004 were identified by Pezzola and Winschel (2004).

The study area covers approximately 2.4 million hectares, of which 839,251 ha correspond to rangelands. Results obtained are summarized in table 1 (page 231).

Areas most affected by fire coincided with those devoted primarily to livestock, mainly located to the west of each district. In many cases, because of its magnitude, fire affected homes, agricultural tools, cattle, alfalfa rolls, fences and beehives. Asset loss was estimated at U$S 8.5 million, without including economic evaluation of natural resources affected by fire (34).

THE ECONOMIC, INSTITUTIONAL, PRODUCTIVE AND POLITICAL PROCESSES CAUSING THE DESERTIFICATION IN THE SW BAP FROM THE PERCEPTION OF PRODUCERS

The desertification process in the area was the result of macroeconomic and social policies not designed for the particular conditions of the region's fragility.

Table 1. Effect of fires in Villarino and Patagones districts in Southwest of Buenos Aires Province.

Tabla 1. Efecto de los fuegos en los distritos de Villarino y Patagones en el sudoeste de la provincia de Buenos Aires.

District	**Number of affected fields**	**Compromised area (ha)**	**Burned area (ha)**	**Number of blazes**	**Burned wires (km)**
Villarino	242	300.136	53.236	120	3.145
Patagones	214	485.961	136.881	99	1.861

This situation is attested by information gathered in interviews with key informants. It is a clear example of how environmental conditions and extraterritorially generated social policies trigger an environmental crisis of magnitude, with enormous costs to be first assumed by local producers, and then affecting areas such as urban settlements in the region and their adjacent areas.

Producers face not only the current climate emergency but decades of impoverishment and decapitalization. Currently, a large percentage of them have left the fields and are dedicated to providing services. In 2008, farmers received subsidies to alleviate the crisis because emergency had been declared in the area four years earlier. However, subsidies did not reach all producers and were not enough.

The Secretariat of Environment and Sustainable Development, dependent on the Ministry of Social Development of Argentina issued the Resolution 250/03 which aims to combat desertification and mitigate the drought effects in order to contribute to the achievement of sustainable development. It has its own monetary resources included in the budged of the National Direction of Environmental Management and Biodiversity Conservation and resources from external donations. In 2012 the projected credit for this Direction was 1.127.175 Argentinean pesos (U$S 233,370) (40).

The Agricultural Emergency Law N° 26509 of August 2009 created a Commission of Emergency and Disasters and a National System for Disaster Prevention and Agricultural Emergency, with an annual fund of 500 million Argentinean pesos (U$S 130.5 million).

The region has a Regional Development Plan, with inputs from all stakeholders and the science and technology organizations operating in the region, which includes in-depth studies on various problems affecting the area, but it has partial funding until now. This work was used to support Law 13647/2006-2007 of BAP.

The process of impoverishment of farmers deepened since the mid 70's as a result of Implementation of Circular 1050 by the Argentinean Central Bank in January 1980. This circular instituted a type of loan in which the debts were indexed by the rate of interest prevailing in the market. But as these interests were for years very high in real terms, the growth of debts far exceeded the progress of income and other prices in the economy.

The producers purchased tools but since debts increased with indexation, their value exceeded those of tools. Onset of hyperinflation with the advent of democracy in 1983 initially helped producers to survive because credit lines were granted but most of the fields were mortgaged.

In 1991, Argentina's National Government launched a new economic plan based on free peso-dollar convertibility, with one-to-one parity.

From this plan there ensued a sharp intensification of economic concentration in agriculture which led to relative increase in agricultural production accompanied by growing unemployment, indebtedness of small and medium producers and increasing rural flight (26).

Convertibility in the 90's left producers in debt, with little production capacity. Upon the exit of convertibility, medium and large producers could pay their debts, aided by good crops and high prices.

However, wheat producers lent wheat to farmers, generating additional extra-bank debts. Many producers had to pay those debts and bank loans remained unpaid. Conversion to pesos and reduction of debts by the Argentinean National Bank, which in many cases reached 50%, cleaned up the situation for large and medium producers.

Mortgage bonds issued in the mid-90's (1993-94) tempted producers with their interest rates and terms. At that time, lands were mortgaged and again favored the debt. Since advent of mortgage bonds, medium and small producers (< 500 ha) could no longer get over their losses.

The Stroeder Cooperative building, built in 1973, appears as witness of a golden age. At that time this cooperative promoted fair auctions, a cereal plant, a silo plant, etc. Climatically unfavorable years and the country's situation (hyperinflation, convertibility) produced the same financial debt phenomenon that had affected producers, and in 1994 the cooperative went bankrupt and was absorbed by the cooperative of Carmen de Patagones and Viedma. Producers viewed this as a great failure and a great loss.

CONSEQUENCES OF DESERTIFICATION

As mentioned above, the main consequences of desertification are the soil lost, the abandonment of farms, the impoverishment of the producers and the migration of local population. The following aspects are referred to the number of livestock decrease, the invasion of plant species in the fields and the place where the phenomenon manifests the highest intensity.

Cattle number decrease

In Stroeder, in 2004-05, 90,000 cattle were vaccinated against Foot and Mouth Disease and only 30,000 in 2010. In Patagones, the highest cattle stock was recorded in 2005 with 381.3 thousand heads, and in 2009 there were just 232.8 thousand heads (35). Most of these animals are now in the irrigated area, near the Colorado River. Moreover, rangeland stocking rate was 5 ha cow^{-1} and currently is 10 ha cow^{-1}.

Field state

It has been an extreme situation where fields were protected from soil blowing only by coverage of invasive plant species such as *Salsola kali* L. that cattle eat when it is in vegetative state.

Other fields were invaded by yellow flower [*Diplotaxis tenuifolia* (L.) DC.] and other species. When fresh, yellow flower has bitter taste and unpleasant odor, so cattle do not consume it. However, once cut and dried in the field for 1 to 3 days depending on climate conditions, the substance causing those sensations evaporates or is processed and cattle consume it in large amounts (10).

The desertification process is at its highest intensity at km 928 of National Road N° 3, Spot "La Querencia" (figure 3). In this place, blasting soil reaches a large scale, affecting 15 km of the road. Vehicle transit is commonly cut off because of visibility problems and sand encroachment on the road.

During the visit to the area, the authors of this study were informed that more than 20 cm of soil have blown away, and they verified that sand accumulates in fences, generating dried clumps of *Salsola kali* which are blown from the field and get trapped in fences (figure 4). Also, the sand affected the farm infrastructure such as water tanks (figure 5, page 234).

The remaining fine material stays suspended in the atmosphere and usually reaches Bahía Blanca city, whose airport was closed on more than one occasion, and sometimes up to 400 km into the Atlantic Ocean (figure 6, page 234). The blowing soil reveals in many cases the bare rock or "plow pan", forming the so-called "desert pavement" by embeddedness of gravels and clasts, in addition to typical features of desert-like morphology such as "micro-yardangs" (figure 7, page 234). It is well known that yardangs are formed on rock formations, although similar micro-forms can occur on fine sediments, as seen in the area, characteristically shaped by erosion caused by wind almost always blowing from the same point.

The material is lengthened and takes various shapes over time. Yardangs are formed exclusively in desert areas, in places where wind rapidly lifts large amounts of sand and fine sediments. These landforms are added to the characteristic mounds, dunes and nebkas (figure 8, page 234) (a word of Arabic origin that means a mound of sand and fine sediment accumulation retained by shrubs) (2).

The latter are desertification indicators and can reach dimensions of up to several meters.

Figure 3. Dust bowl affecting road infrastructure and vehicle transit in "La Querencia".

Figura 3. Tormenta de arena que afecta la infraestructura vial y el tránsito de vehículos en "La Querencia".

Figure 4. Sand accumulation on fences and wind-blown *Salsola kali* trapped in them.

Figura 4. Acumulación de arena en los alambrados y *Salsola kali* transportado por el viento atrapado en ellos.

Figure 5. Water storage tank for livestock affected by soil erosion and sand accumulation in abandoned productive farms.

Figura 5. Tanque de almacenamiento de agua para el ganado afectado por la erosión del suelo y la acumulación de arena en predios productivos abandonados.

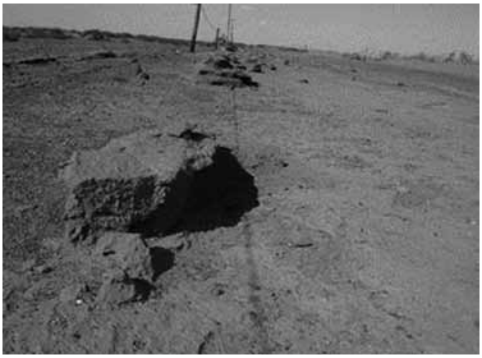

Figure 7. Soil erosion testimonial image.

Figura 7. Imagen testimonial de la erosión del suelo.

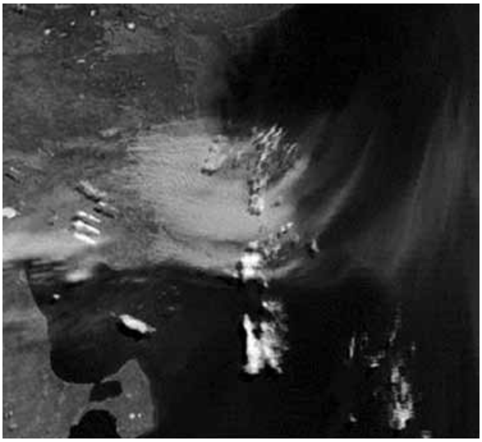

Figure 6. NASA satellite image showing the effects of blasted material transported to the Atlantic Ocean.

Figura 6. Imagen satelital de la NASA que muestra los efectos del material expulsado, transportado al Océano Atlántico.

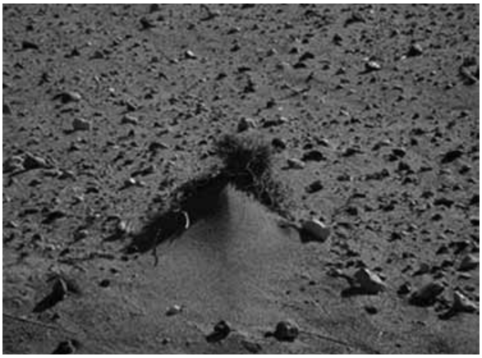

Figure 8. Nebka and desert pavement in formerly productive farms.

Figura 8. Nebka y el pavimento de desierto en predios anteriormente productivos.

In the field also is possible to find indicators of ancient blasting (sand dunes, mounds), with varying degrees of recovery.

Perception of change by farmers

Producers do not relate the current crisis to overloading or mismanagement of fields. Most of them prefer to think that the crisis is a consequence of climate change. Some of the producers' remarks are as follows. "This drought is extraordinary, comparable only to the events of 1942 and 1961-62 (a situation that can be verified from above shown rainfall data)". "There is no seasonality, we pass directly from winter to summer and vice versa, fall and spring have gone. From dry summers and rainy autumns we have passed to dry autumn (February-March). The wind has increased in intensity, showing a strong diurnal atypical rotation, sometimes blowing from the four quadrants on the same day. Almost no clouds but clear skies most of the year and eddies and hurricanes appear more frequently". The above remarks are perceived primarily by older and more experienced producers.

RECOMMENDATIONS FOR DECISION-MAKING

It is convenient to separate, for making management recommendations, older cleared fields, most of them located east of Route N° 3, from non-cleared fields, predominantly to the west of it.

In cleared fields, with somewhat lower water limitations and fertile soils, the appropriate production system, *i.e.* one that achieves ecologic, economic and social sustainability, would be mixed production (agriculture and livestock).

In non-cleared fields, with higher water limitations and fragile soils, livestock would be the most advisable production system.

In cleared fields that will be devoted to cultivation, conventional tillage should be replaced by conservation tillage. The slogan should be "zero bare ground". This is supported by the results of trials conducted by Agamennoni and Vanzolini (2012). These authors performed two experiments between 2005 and 2011, one in the EEA INTA Ascasubi and the other one in a private field near Algarrobo town (Villarino district).

At both sites, soil cover at wheat-sowing time was estimated in three treatments defined by tillage type: a) conventional tillage (2 to 3 passes of disk tool), b) vertical tillage (chisel and chemical fallow), and c) direct sowing (chemical fallow only). Table 2 (page 236), shows the results of the treatments.

In conventional tillage, soil cover was very much below the critical limit (1,000 kg ha^{-1}) to prevent wind soil erosion. This type of tillage, coupled with livestock overgrazing, is a very bad combination that explains the serious problems encountered in the study area in recent years. At both sites, cover achieved by direct sowing widely exceeded that limit.

In contrast, vertical tillage cover barely reached the specified limit. Cover achieved by direct sowing, despite the adverse climatic 5-year period covered by the study, suggests that this feature will be one of the most important to keep in mind to control wind erosion in SW BAP.

According to figures on potential wind erosion reported by Silenzi *et al.* (2012) and with the aim to control wind erosion, these authors recommended that 55% of the total area should be used for livestock production, avoiding overgrazing, and that the remaining 45% may be used for agriculture with conservation tillage.

Table 2. Mean values of dry matter of crop residues (stubble and weeds) determined at two study sites at wheat seeding time.

Tabla 2. Valores medios de materia seca de residuos de cultivos (rastrojo y malezas) determinados en dos sitios de estudio al tiempo de la siembra de trigo.

Site	Tillage type	Crop residues (DM, kg ha^{-1})
H. Ascasubi	Conventional	218
	Vertical	892
	Direct sowing	1.846
Algarrobo	Conventional	328
	Vertical	1.070
	Direct sowing	1.808

Fields with the first 20 to 30 cm of soil blown deserve special consideration.

Given the re-establishment of a protective vegetation cover is regarded as the most effective strategy against wind erosion and desertification (6), one of the alternatives for restoration would be introducing rustic plant species, tolerant to the conditions of the remaining "soil". Reforestation tasks have begun using *Robinia pseudoacacia* L., A*cacia visco* Lorentz ex Griseb. and *Tamaric* spp., although in very small areas and without technical assistance.

The previous general recommendations are complementary to those related to the following specific areas.

Integration of livestock production

The most appropriate and profitable alternative for beef cattle production was cow-calf production in rangelands, post-weaning in cultivated pastures under irrigation combined with feedlot (13). An also profitable alternative is a production system associating early weaning of beef calves and their post-weaning until reaching 320-kg-liveweight in cultivated pastures under irrigation (18).

Use of appropriate stocking rate

Stocking rate is the most important aspect for successful rangeland management (21). It is the main factor influencing performance of forage plants and economic results of livestock enterprises (20). It should be in accordance with the carrying capacity of a given site. It is important to incorporate the concept of "minimal residual biomass" in planning rangeland management. Under proper stocking rates, in rangelands with perennial herbage, it has been suggested that approximately 25% of the total usable forage produced can be consumed by grazing animals (22)

PLANTATIONS OF *OPUNTIA* SPS.

In arid lands subject to wind erosion, cactus-planted alone as biological barrier or together with physical barrier (*i.e.* cement) is an easy, cheap and efficient way to prevent and to control top-soil loss and facilitates the accumulation of wind-borne deposits. Good results have been obtained in Tunisia where cactus is used to control wind erosion and to orient sand movement. It fixes the soil and enhances the restoration of vegetative plant cover (31).

Cacti and *Opuntia* sps. in particular can prevent or reverses desertification in different ways: cacti are drought tolerant species, they are used in watershed management and in water harvesting and their efficient use, in wind and water erosion control, in rangeland and marginal land rehabilitation, in cropland management and crop diversification can contribute to alleviating poverty and to reach better livehood of rural poor in dryland areas (32).

On the other hand, *Opuntia* species have been established as buffer feed reserve, as a strategy for mitigating drought effects on animal production systems of various arid and semiarid zones in the world. In this strategy, this reserve was aimed not only as "drought insurance" for inter-annual drought but also to bridge up a recurrent annual period of feed scarcity (14, 24).

The thermal limit for cultivating frost-sensitive species such as *Opuntia ficus-indica* (L.) Mill. is indicated by a mean daily minimum temperature of the coldest month (*m*) of 1.5 to 2.0°C (25). For this reason, this species could be cultivated in Carmen de Patagones where *m* is about 2.5°C (16). Spineless progeny of *Opuntia ficus-indica* 1281 x *O. lindheimerii* 1250 cross that has cold tolerance (17) could be cultivated in areas of SW BAP with *m* lower than 1.5-2.0°C.

Agriculture

The most important recommendation is to stop using conventional tillage methods and use conservation ones (chisel plow, direct seeding) in agricultural crops and pasture cultivation. Because of the predominant wind direction (NNW), wind erosion control practices such as deep-furrow seeding, strip cropping and windbreaks must be located as perpendicular as possible to this sector (5).

In the short term, use of conservation tillage with a surface cover of 30% must be promoted, or else systems that leave rough soil such as chisel tillage.

In the long term, besides tillage practices, work must be done on crop rotation to increase soil organic matter levels and improve soil structure. In soils more liable to suffer wind erosion, there must be permanent pastures not requiring soil removal every year, and windbreaks (4). Direct seeding has begun to be practiced in some farms at present.

CONCLUSIONS

Given the data on the area's natural reality, where the only certainty is rainfall variability, emphasis should be on sustainable management, which involves a change of producer’s and decision maker’s mentality. Both have had the responsibility for the profound landscape shape changes observed.

The area requires deep structural changes in production systems and their management, including the need to immediately protect zones unaffected by desertification and prevent soil blasting, and to continue to protect and recover moderately affected fields.

Soil degradation caused by wind erosion in SW BAP is a very complex problem; therefore it requires solutions conceived with criterion and knowledge. In addition to climatic aspects, there are social, economic, technological and political causes.

Field size, tradition and customs, lack of knowledge and technological development, research policies, among others, are aspects that have great incidence on soil degradation. At request of producers, an intensive awareness campaign has recently been launched, where society and decision makers, accompanied by organizations like INTA, Universities and CONICET's Research Centers, start designing regulatory tools and implementing sustainable planning and management practices to prevent desertification risk. It is a slow process that prioritizes preventing loss of unaffected fields and working on the recovery of degraded ones.

The problem of fire in the area's ecosystems must also be understood from a holistic approach to rural development. That means the integration of strategies and actions for improving management, land use and natural resources, assuming shared responsibility for fire management and protection against catastrophic fires.

The importance of the desertification process described for SW BAP is manifested by the speed with which it happened and the serious consequences it had on natural and social systems in a short period of time.

Events such as those described can be compared in their causes and consequences to the well-known dust bowl of the United States, where in the 30's, for reasons very similar to those present in the study area, environmental crisis and soil blasting began in a large portion of the fertile prairies of the American West. This event generated an environmental and social catastrophe of national importance, and marked the beginning of the design and implementation strategies for recovery, prevention and control of land degradation which systematize rapidly in the first land conservation organization: the Soil Conservation Service (SCS) of USA. In 1994, SCS’s name was changed to the Natural Resources Conservation Service to better reflect the broadened of the agency's concerns.

In the case of SW BAP, given the gravity of the situation in the area and the mobilization of producers, in recent years also an important answer to these problems is seen by decision makers at provincial and national level. It is relevant to the creation of the Provincial Agency for Sustainable Development (OPDS) of the government of the Buenos Aires province, which together with the Ministry of Environment and Sustainable Development of Argentina and numerous organizations of science and technology as well as civil society organizations are generating actions to recover the area.

With the creation of OPDS is beginning to be perceived a mobilization of resources and sufficient knowledge to mitigate the situation.

As an interesting fact it is worth mentioning that from 2010 to date there have been at least three scientific meetings over the area.

Because this study was conducted at the request of the producers concerned, there is a great potential for the implementation of the recommendations made, which are consistent with those of degraded sites in the country and the world then allow extrapolation to other areas subjected to similar pressures.

REFERENCES

1. Abraham, E. M. 2011. Desertification assessment and monitoring in Argentina, in: Winslow, M.; Sommer, S.; Bigas, H.; Martius, C.; Vogt, J.; Akhtar-Schuster, M.; Thomas, R. (Eds.), Understanding desertification and land degradation trends. Proceedings of the UNCCD First Scientific Conference. Office for Official Publications of the European Communities. Luxembourg: 6-11.
2. Abraham, E. M.; Brunotte, E.; Stingl, H. 1987. Geomorphologische Karte 1:100.000 Bajada amarilla, Provinz Mendoza, Argentinien. Berliner Geographisches Abhandlungen. Berlin. 42**:** 65-76.
3. Agamennoni, R.; Vanzolini, J. I. 2012. Labranzas en el sur de Buenos Aires. Efecto en la cobertura del suelo. Available on line at: http://inta.gob.ar/documentos/labranzas-en-el-sur-de-buenos-aires-i.-efecto-en-la-cobertura-del-suelo (Accessed: August 2014).
4. Bouza, M. E.; Silenzi, J. C.; Echeverría, N. E.; De Lucía, M. P. 2011. Monitoring station of wind erosion in southwest of Buenos Aires province, in: Winslow, M.; Sommer, S.; Bigas, H.; Martius, C.; Vogt, J.; Akhtar-Schuster, M.; Thomas, R. (Eds.). Understanding desertification and land degradation trends. Proceedings of the UNCCD First Scientific Conference. Office for Official Publications of the European Communities. Luxembourg. 136-137.
5. Bouza, M. E.; Silenzi, J. C.; Echeverría, N. E.; De Lucía, M. P. 2012. Analysis of erosive events for a soil in the southwest of Buenos Aires Province, Argentina. Aeolian Research. 3: 427-435.
6. Burri, K.; Gromke, C.; Graf, F. 2013. Micorrhizal fungi protect the soil from wind erosion: a wind tunnel study. Land Degradation and Development. 24: 385-392.
7. Censo Nacional Agropecuario 2002. Ministerio de Economía. Subsecretaría de Coordinación Económica Provincia de Buenos Aires. Available on line at: www.indec.mecon.gov.ar/agropecuario/cna_2index.asp?mode=06 (accessed: September 2014).
8. Department of Environment and Resource Management. Queensland Government. 2011. Wind erosion. Available on line at: www.qld.gov.au/dsiti/assets/soil/wind-erosion.pdf (accessed: December 2015).
9. Deschamps, J. R.; Otero, O.; Tonni, E. P. 2003. Cambio climático en la pampa bonaerense: las precipitaciones desde los siglos XVIII al XX. Universidad de Belgrano, Documento de Trabajo N° 109. 20 p. Available on line at: http://www.ub.edu.ar/investigaciones/dt_nuevos/109_deschamps.pdf (acccessed: July 2014).
10. Fernández Mayer, A. 2009. Flor amarilla: de la maleza al forraje. INTA Newsletter N° 565.
11. Gaiero, D. M.; Simonella, L.; Gassó, S.; Gili, S.; Stein, A. F.; Sosa, P.; Becchio, R.; Arce, J.; Marelli, H. 2013. Ground/satellite observations and atmospheric modelling of dust storms originating in the high Puna-Altiplano desert (South America): Implications for the interpretation of paleo-climate archives. Journal of Geophysical Research: Atmospheres. 118: 3817-3831.
12. Giuggio, V. M. 2012. How dust storms work. Available on line at: http://science.howstuffwoks.com/nature/climate-wheather/storms/dust-storm1.htm (accessed: December 2015).
13. Grünwaldt, E. G.; Guevara, J. C. 2012. Rentabilidad de la actividad conjunta de recría y engorde a corral de bovinos para carne en la provincia de Mendoza, Argentina. Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. Mendoza. Argentina. 44(2): 145-155.
14. Grünwaldt, J. M.; Guevara, J. C.; Grunwaldt, E. G.; Martínez Carretero, E. 2015. Cacti (*Opuntia* sps.) as forage in Argentina dry lands. Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. Mendoza. Argentina. 47(2): 145-170.
15. Guevara, J. C.; Stasi, C. R.; Wuilloud, C. F.; Estevez, O. R. 1999. Effects of fire on rangeland vegetation in south-western Mendoza plains, Argentina: composition, frequency, biomass productivity and carrying capacity. Journal of Arid Environments. 41: 27-35.
16. Guevara, J. C.; Estevez, O. R. 2001. *Opuntia* spp. for fodder and forage production in Argentina: experiences and prospects, in: Mondragón-Jacobo, C.; Pérez-González, S. (Eds.), Cactus (*Opuntia* spp.) as forage. FAO, Rome. 63-71.

17. Guevara, J. C.; Felker, P.; Balzarini, M. G.; Paez, S. A.; Estevez, O. R.; Paez, M. N.; Antúnez, J. C. 2011. Productivity, cold hardiness and forage quality of spineless progeny of the *Opuntia ficus-indica* 1281 x *O. lindheimerii* 1250 cross in Mendoza plain, Argentina. Journal of the Professional Association for Cactus Development. 13: 48-62.
18. Guevara, J. C.; Grünwaldt, E. G. 2012. The desert environment of Mendoza, Argentina: status and prospects for sustainable beef cattle production, in Guevara, J. C.; Grünwaldt, E. G.; Sivaperuman, C. (Eds.), Deserts: Flora, Fauna and Environment. Nova Science Publishers Inc.: New York. N. Y. 115-127.
19. Hansen, Z. K.; Libecap, G. D. 2004. Small farms, externalities and the Dust Bowl of the 1930s. Journal of Political Economy. 112: 665-694.
20. Heitschmidt, R. K.; Conner, J. R.; Canon, S. K.; Pinchak, W. E.; Walker, J. W.; Dowhower, S. L. 1990. Cow/calf production and economic returns from yearlong continuous, deferred rotation and rotational grazing treatments. Journal of Production Agriculture. 3: 92-99.
21. Holechek, J. L.; Pieper, R. D. 1992. Estimation of stocking rate on New Mexico rangelands. Journal of Soil and Water Conservation. 47: 116-119.
22. Kothmann, M. M. 1992. Nutrition for livestock grazing rangelands and pasturelands, in: Howard, J. L. (Ed.), Current Veterinary Therapy 3: Food Animal Practice, W. B. Saunders Co., Philadelphia. 285-293.
23. Lancaster, N.; Gillies, J. A.; Nickling, W. G. 2006. Recent progress in Aeolian research. EOS, Transactions American Geophysical Union. 87(45): 496.
24. Le Houérou, H. N. 1991. Feeding shrubs to sheep in the Mediterranean arid zone: intake, performance and feed value in: Gaston, A.; Kernick, M.; Le Houérou, H. N. (Eds.), Proceedings of the Fourth International Rangeland Congress, CIRAD (SCIST): Montpellier, France. 639-644.
25. Le Houérou. H. N. 1995. Bioclimatologie et biogéographie des steppes du Nord de l' Afrique. Diversité biologique, développement durable et désertisation. Options Méditerranéennes, Série B, N° 10. CIHEAM: Montpellier, France. 396 p.
26. Luque, N.; Alamo, M. 2011. Procesos socio-espaciales en el sudoeste bonaerense y su incidencia en el espacio rural. Los casos de Bahía Blanca y Coronel de Marina Leonardo Rosales a fines del siglo XX. Available on line at: http://es.scribd.com/doc/53167125/Procesos-Socio-Espaciales-en-el-Sudoeste-Bonaerense-Alamo-Luque (accessed: September 2014).
27. Lyles, L. 1975. Possible effects of wind erosion of soil productivity. Journal of Soil and Water Conservation. 30: 279-283.
28. Middleton, N. J. 1986. The geography of dust storms. Unpublished D Phil Thesis. University of Oxford.
29. Middleton, N. J.; Goudie, A. S. 2001. Saharan dust: sources and trajectories. Transactions of the Institute of British Geographers. 26: 165-181.
30. Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Desertification Synthesis. Work Resources Institute, Washington, D. C. 26 p.
31. Nefzaoui, A.; Ben Salem, H. 2002. Forage, fodder, and animal nutrition. Chapter 12, in: Nobel, P. S. (Ed.), Cacti, biology and uses. University of California Press. 280 p.
32. Nefzaoui, A.; El Mourid, M. 2009. Cacti: A Key-Stone for the Development of Marginal Lands and to Combat Desertification. Acta Horticulturae. 811: 365-372.
33. Papanastasis, V. 1991. Control and utilization of woody rangelands, in: Gaston, A.; Kernick, M.; Le Houérou, H. N. (Eds.), Proceedings of the Fourth International Rangeland Congress, CIRAD (SCIST): Montpellier, France. 1168-1172.
34. Pezzola. A.; Winschel, C. 2004. Estudio espacio-temporal de incendios rurales utilizando percepción remota y SIG. EEA H. Ascasubi INTA, Laboratorio de Teledetección. Boletín Técnico N° 20. 12 p.
35. Pezzola, A.; Agamennoni, R.; Winschel, C.; Sánchez, R.; Enrique, M.; Giorgetti, H. 2009. Estimación expeditiva de suelos erosionados del partido de Patagones- Prov. de Buenos Aires. Available on line at: INTA_erosion_patagones[1].pdf (accessed: November 2014).
36. Sánchez, R. M.; Pezzola, A. 2007. Plan de desarrollo del sudoeste bonaerense. El agua superficial en la región semiárida bonaerense. Informe preliminar. 13 p.

37. Secretaría de Ambiente y Desarrollo Sustentable de la Nación (SAyDS). 2011. Análisis y evaluación social. Proyecto "Incremento de la resiliencia climática y mejora de la gestión sustentable del suelo del Sudoeste de la Provincia de Buenos Aires". 124 p.
38. Silenzi, J. C.; Echeverría, N. E.; Bouza, M. E.; De Lucía, M. P. 2011. The cost of wind erosion in the southwest of Buenos Aires province, in: Winslow, M.; Sommer, S.; Bigas, H.; Martius, C.; Vogt, J.; Akhtar-Schuster, M.; Thomas, R. (Eds.),Understanding Desertification and Land Degradation Trends. Proceedings of the UNCCD First Scientific Conference. Office for Official Publications of the European Communities. Luxembourg: 138-139.
39. Silenzi, J. C.; Echeverría, N. E.; Vallejos, A. G.; Bouza, M. E.; DeLucía, M. P. 2012. Wind erosion risks in the southwest of Buenos Aires Province, Argentina, and its relationship to the productivity index. Aeolian Research. 3: 419-425.
40. Squires, V. R. 2010. Desert transformation or desertification control? Journal of Rangeland Science. 1: 17-21.
41. Squires, V.; Sidahmed, A. E. (Eds.). 1998. Drylands: Sustainable use of rangelands into the twenty-first century. IFAD Series: Technical Reports. Rome: IFAD. 407 p.
42. Tercera Comunicación Nacional de la República Argentina a la Convención Marco de Naciones Unidas sobre Cambio Climático. 2015. 223 p. Available on line at: www.ambiente.gov.ar/archivos/web/ProyTerceraCNCC/file/InformeFinal_20150701_1244.pdf (accessed: December 2015).
43. United Nations Convention to Combat Desertification and Drought (UNCCD) - PNUMA. 1995. Convención de las Naciones Unidas de lucha contra la desertificación en los países afectados por sequía grave o desertificación, en particular en África. Texto con Anexos, Documento Oficial de la UNCCD, Suiza.
44. Wang, T. 2000. Land use and sandy desertification in the North China. Journal of Desert Research. 20: 103-107.
45. Wang, J. X. L. 2015. Mapping of global dust storm records: review of dust data sources in supporting modelling/climate study. Current Pollution Reports. 1: 82-94.
46. WMO Secretariat. 2009. WMO Sand and dust storms. Warning advisory and assessment system (SDS- WAS): Implementation plan 2009-2013. 20 p. Available online at: http://www.preventionweb.net/files/11309_SDSWASdraftimplementationplan1.pdf(accessed: September 2014).
47. Zhang. X. Y.; Gong, S. L.; Zhao, T. L.; Arimoto, R.; Wang, Y. Q.; Zhou Z. J. 2003. Sources of Asian dust and role of climate change versus desertification in Asia dust emission. Geophysical Research Letters. 30: 2272. ASC 8-4.

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