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FEATURE

The Argentinean Pampas: A key region with a negative nutrient balance and soil degradation needs better nutrient management and conservation programs to sustain its future viability as a world agroresource

Raul S. Lavado and Miguel A. Taboada

Soil and water conservation is essential to the survival of humankind and the stability of society since soil and water resources interconnect life, societies, and our environment. One important use of these resources is agricultural production. Agricultural production is critical to supporting a healthy society; however, when we mismanage soil systems for agricultural production or misapply new technologies, we reduce the productivity of the soil. Soil degradation is found throughout the world, often created by humans' lack of understanding of soil science, a lack of soil and water conservation practices, a lack of conservation policies, and/or social and economic constraints. In some instances, poor or uninformed policies have exacerbated the deterioration of an important soil resource: this is the case for the Argentinean Pampas, a superb temperate agricultural land in the Southern Hemisphere.

REGIONAL CHARACTERISTICS AND HISTORY

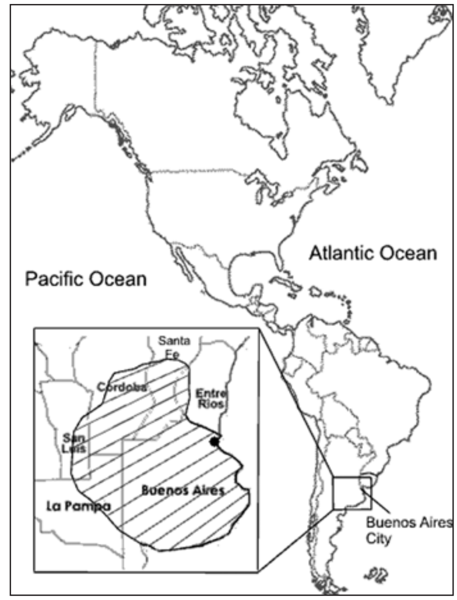
The Pampas region, located in the south cone of South America (33º–35º S, 62º–64º W), covers about 60 Mha and is part of one of the largest prairies of the world. This fertile area is suitable for temperate field crops and livestock and is the backbone of Argentinean agriculture. It is also where the main cities are concentrated and the greatest percentage of the population live. Although the Argentinean Pampas is politically divided into six Argentinean provinces, the Pampas is so large that it covers areas of Uruguay and the most southern region of Brazil.

The western Pampas region has a humid climate while the eastern region has a sub-humid/semiarid climate. Although rainfall patterns are generally dependent on time of year (fall and spring/summer are the rainy seasons), there is considerable variability in monthly and annual precipitation. The region is classified as mesothermic with cold winters, especially in the south, which has some snow precipitation but not any frozen soils.

Raul S. Lavado is a professor **and Miguel A. Taboada** is an associate professor at the College of Agronomy, University of Buenos Aires, Buenos Aires, Argentina. Both are members of the Argentinean Research Council.

The soils of the Pampas were mainly developed by aeolian loess-like sediments. The dominant soil type in this fertile region is Mollisols, with small areas covered with Alfisols and other soil orders. The western Pampas are covered with different subgroups of Argiudolls with a highly developed argillic B horizon. Further west, the dominant soils are Hapludolls with coarser texture, and shallow soils with lime layer gradually change to a cambic horizon. The extreme east side of the Pampas region predominantly consists of Haplustolls. In the center of the region, dominant soils are Natraquolls and Natraqualfs. Towards the south part of the area, there are Argiudolls, and Palleudolls and Hapludolls with a petrocalcic horizon or, in some places, a lithic contact appears.

The Pampas was originally grassland, similar to the tall prairie of North America, but it had a unique characteristic: the grassland was developed without high grazing pressures because the region did not have any large herbivores, such as those found in the equivalent prairies of African and North American grasslands. Without large herbivores, the area was not initially able to



Map of the Americas and the geographical location of the Pampas.

support a dense human population; intensive agricultural management of the region started with the arrival of the Spanish conquerors, which eventually allowed greater numbers of people to inhabit the region. The first imported crop grown in the area was wheat in 1528. However, livestock grazing started with the introduction of horses in 1536 and cattle in 1573. Some of these animals escaped from their corrals and, without any predators, their population exploded. The sudden increase in the

View of the landscape of the Pampas.

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livestock population created the foundation for the Pampas livestock industry, which absolutely dominated the Pampas for three centuries, as people transitioned from the practice of hunting wild animals to that of maintaining large ranches.

The natural grasslands were used primarily for grazing until the last quarter of the 19th century, when European immigrants began to cultivate crops. From that moment, agriculture increased in the region, and today it is a prevalent activity that displaces livestock. Agriculture at present is very competitive and in the last five years has been subjected to great technological changes like the widespread utilization of transgenic crops, herbicides, pesticides, and fertilizers, with no-till farming prevailing in about half of the cropland area. As a result of this intensification of agriculture, crop productivity has increased markedly in the last few years. At present, about half of the arable land of Argentina is cropped with soybean. The rest of the area is cropped with maize and sunflower in spring–summer and wheat and barley in winter–spring. Minor field crops are oats, rye, millet, canary grass, and rapeseed. Argentina, United States, Brazil, and China account for almost 90% of the world's soybean production, with Argentina being the first country to export soybeans.

Direct seeded Soybean in the Pampas.

SOIL EROSION

Soil erosion began when native grasslands were plowed. Plows were the main tillage instrument in this region. This type of tillage created aeolian erosion problems in the semiarid zones and hydric erosion in subhumid–humid sloped areas of the Pampas. It also contributed to a significant decline of the soil organic matter, especially in those areas that lacked crop residues for long periods of time due to residue burning. This erosion problem peaked in 1940 and generated strong efforts to reduce soil erosion losses. By the 1950s, erosion control practices based on terracing, contour cropping, and tillage practices suitable to the semiarid region were being implemented.

NUTRIENT MANAGEMENT

The initial studies on soil nutrients in Argentinean soils were carried out at the end of the 19th century with a soil fertility book published in 1916. However, the application of soil analysis to assess soil fertility only started in the 1930s using published French and German techniques and standards. Soil scientists were astonished by the very high levels of organic matter, nitrogen, phosphorus and other nutrients they found in Pampas soils. Their findings validated an already popular belief by local residents that Pampas's soils were inherently rich in nutrients.

The direct consequence of these scientific results was the prediction that soil fertility would last for several years; e.g., potassium would last for more than 400 years, assuming that the soils could supply potassium to crops without problems. Some researchers applied the theories of "soil domestication" and the biological role of plants which coming from the Soviet Union in the 1930s. Such optimistic ideas eventually reached the political circles and gave the scientific basis of an excessive taxation of the agriculture production in Argentina applied from the 1940s. It had several negative effects on the industry, but in particular on the soil nutrient balance because farmers could not afford more sustainable practices.

These policies were among the factors that affected nutrient balances in the Pampas. Initially, the intensive agricultural evolution of the Pampas region was relatively similar to that of the North American prairies. Crop production was driven mainly by cereal crops that relied on natural soil fertility, with later management practices such as crop/pasture rotations and application of green manures. In the Pampas, animal manure was not used as a source of fertilizer because livestock grazed on large lots on a round-year basis. Despite these initial similarities, by the mid-20th century there was a large increase in fertilizer use in North America, while fertilizer use in Argentinean croplands remained virtually nonexistent. Commercial agriculture based on nutrient extraction was maintained for decades. The high taxes on fertilizers and extra taxes on crop production were initially part of a policy designed to transfer monetary resources from a successful agricultural economy to a weak industrial economy residing primarily in urban centers. It can be said in retrospect that the whole policy was based on the consumption of the extraordinary nutrient content of the Pampas soil, leaving out consideration of the problems this would cause for future generations. Incredibly, soil nutrient depletion was not foreseen by soil scientists of the time. To demonstrate that soils would remain fertile, most of them would rely on very complicated calculus and explanations, and, in extreme cases, anyone who disagreed with these scientists was accused of favoring foreign companies involved in the fertilizer trade.

By the early 1990s, the area covered by highly fertile soils had shrunk, and acute plant nutrient depletion was commonplace across the Pampas region. Native soil nitrogen and phosphorus levels could not sustain the demand of new, more productive wheat cultivars and maize hybrids. At the same time, the overtaxation of agriculture production was over and, as a consequence, fertilizer use in the Pampas region increased exponentially. Fertilizer use increased from just over zero to nearly 100% for the wheat and around 83% for the maize cultivated in this region. The nitrogen sources used are mainly urea and ammonia phosphates. Although nitrogen (N) use rates are higher in other world cultivated areas, the rates of N application are still low in Argentina and range from 20 to 80 kg N ha^{-1}. This is the reason why, in spite of nitrogen fertilizer use, there is still a negative balance between N inputs and outputs from Pampas's soils.

Even today, soil organic mineralization to supply nitrogen to crops and other nutrients exported by the Pampas crop harvest exceed fertilization inputs. It was estimated that for soybean, wheat, maize, and sunflower, which are the main crops of the region, fertilization restored only 28%, 42%, 13%, and <2 % of the original content of these nutrients, respectively. Additionally, it has been estimated that only 13% of the nitrogen, potassium, sulphur, and phosphorus were restored with fertilizer. For example, most native soils could have a total phosphorus content around 1,400 mg kg^{-1}, but present cultivated soils show value of 300 to 500 mg P kg^{-1}. For cultivated soils, the Bray & Kurtz extractable P concentrations are now usually low and very often around or below the threshold limit for soybean responses (10 to 12 mg P kg^{-1}), maize (15 to 17 mg P kg^{-1}), and wheat (18 to 20 mg P kg^{-1}).

Pampas cropping systems were also fertilized using nitrogen fixation from leguminous crops by rotation of a few years grass-alfalfa pastures followed by a number of years in crops. However, the amount of nitrogen fixed by the grass-alfalfa pastures and cycled to the crops was not enough and the systems averaged low grain yields. This quasi organic agriculture also contributed to degrading soils since the carbon returns to soil by agricultural residues were not enough to mach carbon lost by organic matter mineralization. Soil carbon content of areas with long agricultural history was reduced by 30% to 50 %, and in some cases up to 70%, as compared with native soils.

Although the rotation of pasture crops was depleting nutrients from Pampas's soils, it was reducing the balance at a low rate of decline. This rate of decline was accelerated significantly in the 1970s by the introduction of the soybean. Although this crop was well adapted for the weather of the region and had high yields that matched those of the United States, the low crop residue promoted negative soil carbon balances and accelerated soil erosion in sloped areas, creating problems for soil conservation.

Soybean was grown as a single annual summer crop (one crop per year) or as double crop after a winter crop (usually wheat). As a double crop, the yield was lower; however, farmers earned higher incomes because they could grow two crops per year. The wheat–soybean crop was also able to mitigate some of the erosion since the soybeans were drilled into the wheat residue (minimum tillage). Although the wheat–soybean is widely used today across the Pampas, barley–soybean and canola–soybean are also used as double cropping systems. The wheat–soybean–corn two-year rotation system is widely used as well. The introduction of a more profitable soybean alternative contributed to the reduction of the sown grazing pasture for livestock by 5 Mha.

PRESENT

The original traditional pasture (grazing livestock)–crop rotation was replaced with more economically viable crop rotation systems, such as double cropping systems. Livestock production has been displaced to marginal areas or concentrated in feedlots. These changes in agricultural production contributed to an accelerated negative increase in nutrient balances and had increased the role of the Pampas region as a world exporter of nutrients that were accumulated over millennia. A process of depletion that was believed would occur over several decades or a century was accelerated by these changes, and in actuality happened in less than a decade.

One positive outcome of the changes in agricultural production was the conversion from conventional tillage to no-till farming, which has resulted in better soil water conservation, nutrient cycling, time efficiency, reduction in the use of fossil fuels, and soil carbon sequestration. In contrast

Maize grown in the Pampas.

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with much of the published literature, no-till does not always contribute to a positive physical structure. In our Argentinean soils, where we have soils with a high content of fine silt (2 to 20 μm), such as those prevailing in the northern Pampas region (i.e., the so-called Rolling Pampa), many soils developed shallow compaction and topsoil hardening from years of continuous direct seeding. This compaction has reduced soil infiltration rates and contributed to runoff losses during periods of high precipitation.

A soil survey carried out in the late 1980s revealed that at least 60% of the Pampas region was affected by different forms of water erosion (e.g., laminar, rill, gully). After the extensive adoption of no-till farming, soil erosion losses were reduced significantly. However, other soil and water conservation practices, such as crop rotations, cover crops, terraces, and buffers among other practices, are needed to maximize conservation in areas with high soil compaction and/or with high slopes.

SUMMARY

The soils of the Pampas region have suffered different processes of degradation and erosion. Several of the causes of this degradation are commonly found throughout the world; other causes are more particular to the Pampas, such as established policies that affected the nutrient balance of the Pampas soils. At present, we face new challenges to maintain nutrient levels and soil productivity of this key world agroecosystem.

With continued global population growth, the Pampas region will be an important world resource for grain production. The inherent soil fertility of the region has made this region a major exporter of grains and nutrients until now; however, new nutrient fertility programs will be needed to ensure that the region yield productivity is maintained and/or maximized. Soil and water conservation is a critical component of ensuring the productivity of this world resource, particularly now that carbon sequestration can be used to potentially mitigate anthropogenic emissions of carbon. New policies concerning nutrient management and soil and water conservation will be needed to help maintain the Pampas region as a key world agroecosystem and to provide farmers with viable agroecosystems that maximize productivity and sustainability.

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