agriculture

Review

Conservation of Ecosystem Services in Argiudolls of Argentina

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Abstract: Mollisols are a fundamental component of global agricultural production. In the Argentine Pampas region, 65% of the Mollisols belong to Argiudoll great group. These soils have an agricultural aptitude, with limitations given mainly by varying thickness of the top horizon A as a result of the severity of water erosion depending on its site in the landscape layered on an argillic B horizon. Over the last three decades, Pampean agriculture has been widespread because of a modern technological matrix characterized by transgenic crops, and increasing use of fertilizers and pesticides. Large changes have taken place in crop sequence composition, toward the disappearance of pastures and the rapid expansion of soybean monoculture due to the upward trend of the international price of this commodity. This review contributes to an alertness regarding the significance of the soil degradation problem, in terms of decline in soil fertility and structural condition, decrease in size of soil aggregates, surface and subsurface compaction, decrease in organic carbon content, soil and water contamination, reduction of infiltration rate and structure stability, causing an increase in water losses through surface runoff and water erosion and lost ecosystem services. Additionally, a set of sustainable land management practices and legal aspects is shown.

Keywords: argiudolls; land degradation; soil conservation; management practices; ecosystem services; legal aspects

1. Argiudolls of the Pampean Region

Argiudolls are a Great group of Mollisols, which are key components in the provision of ecosystem services associated with global food production. These soils act as support for different anthropic activities and are involved in the regulation of water quality and quantity, nutrient recycling, carbon reserve and maintenance of biodiversity. They are found in semi-arid, sub-humid and humid areas, occupying 7% of the ice-free surface, usually under grassland vegetation. They are located at mid-latitudes, mainly in the Great Plains of the United States, in Mongolia and the Russian steppes, in Europe in South Australia, in southern Africa, in Brazil, and in the Pampean region of Argentina. In general, they are dark soils, rich in organic matter and bases, which have developed from loess and its distinctive characteristic is that they have argillic horizon—Bt (illuvial feature).

In Argentina, the area under the loess covers approximately 800,000 km^2, i.e., between 25% and 30% of the total area of the country [1,2], where udic water and thermal temperature regimes prevail. In the Pampean region, as a result of wind transport, the texture of these soils varies, with sandy loess in the west and clayey loess in the east [3]. The climate of the Pampean region is temperate–humid, with precipitations concentrated in spring and summer [4] and showing variations from east to west (1000 to 600 mm). The temperature increases from south to north, ranging from 15 to 17.5 °C [5]. In this region, about 65% of the Mollisols correspond to the Great group Argiudoll [6], these being the most representative and productive soils (Figure 1).

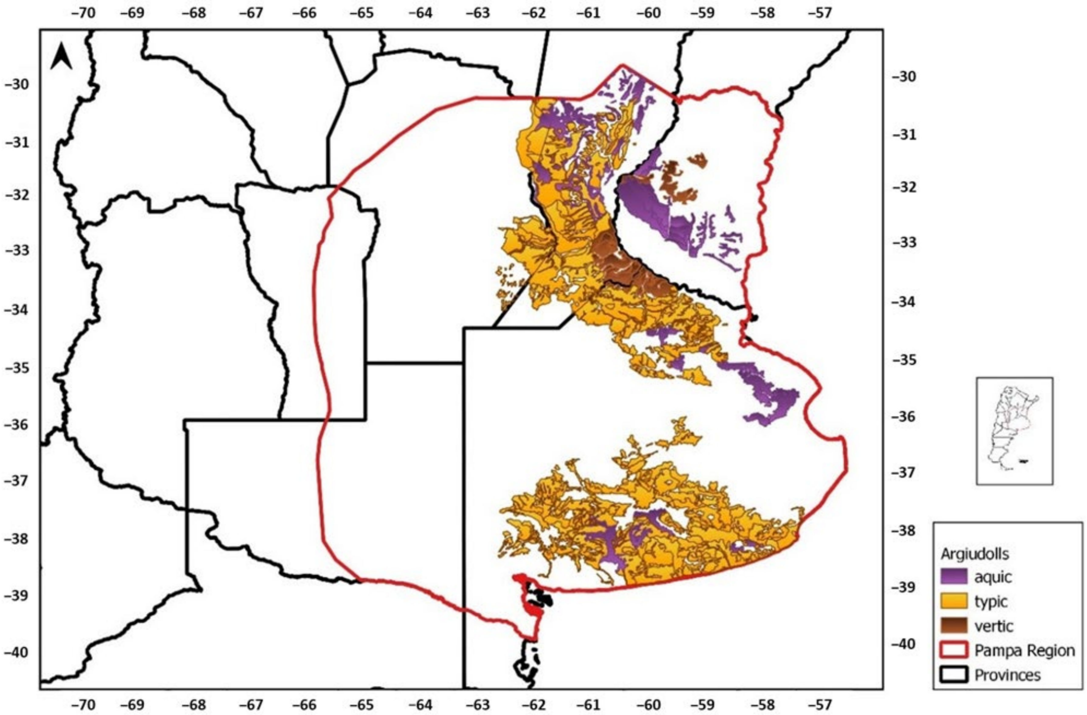

Figure 1. This is a Map of location of Argiudolls in the Pampean region.

Bonfils [7] indicated that the pedogenetic processes that define the large soil groups of the Pampean region are defined according to the alteration conditions, the state of the adsorbent complex, and the nature of the migrations of fine particles.

Different portions of the landscape of the Pampean region are occupied by different subgroups of Argiudolls, among which the most representative are Aquic, Typic, and Vertic Argiudolls [8]. Aquic Argiudolls are located in the upper parts of the landscape and are characterized by having deep profiles, sometimes with a somewhat thickened epipedon, followed by an argillic B horizon, with a thickness of 30 to 50 cm, which limits the percolation of water in the profile and predisposes to water erosion. Typic Argiudolls are the most widespread and productive soils in the region, being found in the provinces of Buenos Aires, Santa Fe, Entre Ríos and Córdoba. Their surface horizon commonly presents 3% of organic matter. In depth, their argillic horizon can contain between 30% and 50% of clay, with less amount in the west–southwest of the region and greater amount in the east–northeast. The profile of these soils can reach 120 cm deep, and may have calcium carbonate nodules in the BC and C horizons [8]. Finally, Vertic Argiudolls are located mostly in Entre Ríos province and have some characteristics of Vertisols (presence of cracks, cuneiform aggregates and slickensides in the argillic horizon), because they present a higher proportion of expandable clays [6].

Argiudolls are naturally fertile. Their agricultural and livestock aptitude is based on the properties of the soil surface layer, with a high content of soil organic carbon (SOC) and soil bases, neutral or close to neutral pH and soil structure favorable for root development. This horizon can have a proportion of fine silt of 50 to 67%, giving it very low expansion capacity and contraction and with resilience problems once it has lost its natural condition [9]. Under normal conditions, the surface horizon has a depth of approximately 8 to 25 cm, depending on the degree of erosion achieved. In addition, the in-depth presence of the argillic horizon provides physical characteristics that make it difficult for the roots to explore and absorb water and nutrients, thus being less favorable for crop growth than other Mollisols.

In short, the high content of silt in the surface horizon of Argiudolls, the presence of the argillic horizon and the length of the slopes (which can reach 1000 m) determine that one of the main limitations of these soils for agricultural production is the susceptibility to water erosion. In this sense, the soils in Argentina affected by both water and wind erosion occupy approximately 105 million ha, with water erosion being the main cause of land degradation in the last 25 years. Considering only the provinces of Buenos Aires, Santa Fe and Entre Ríos, about 14,000,000 ha are affected by slight and moderate erosion, whereas around 500,000 ha are affected by severe erosion [10]. For example, in the province of Entre Ríos, 57% of its area is susceptible to some degree of water erosion. This means that 4,500,000 ha can be eroded [11].

In the middle sector of a 70,000 ha basin located in the north of Buenos Aires province, Buján et al. [12] determined, using the 137Cs technique, that 50% of the Vertic Argiudolls conventionally agricultural way of use had moderate to severe erosion, a percentage that 20 years later increased to 68%, despite the implementation of direct sowing [13]. On the other hand, based on the modeling of runoff and sediment loss in a 10,040-ha basin in the town Santa María, in Entre Ríos province, a mandatory area of soil conservation where Aquic and Vertic Argiudolls predominate, Ramírez et al. [14] estimated that, despite having incorporated terraces to remove excess surface water in more than 30% of the area, the soils of the entire sub-basins had moderate to severe erosion [15]. Some examples of soil erosion in soils with argillic in other regions of the world have been reported [16–19].

2. Land Use Change in Recent Decades and Its Impact on Argiudolls

The expansion of agriculture in the Pampean region has occurred in three stages: one that lasted from 1960 to 1986, corresponding to a traditional extensive model characterized by a low-intensity production of resource use; another from 1986 to 2001, which was a transition period; and another one from 2001 until the present, which has been a period of intensive agricultural technology [20]. As a result of this transformation, between 1960 and 2005, the area for annual crops in the Argiudolls of the Pampean region increased from 37 to 70%. Casas [10] indicated that this increase was partly due to the incorporation of more fragile land into agricultural production, and to the fact that this land is more susceptible to water erosion and hydromorphic problems given its proximity to permanent watercourses. This, in turn, led to increased sediment production and water loss, thus deteriorating the water quality of streams [14,21,22].

Until the mid-1990s, the farming system prevailing in the Pampean region was conventional tillage, a system that led to the degradation of agricultural soils, losses in their thickness due to erosion, and a reduction in the carbon and nutrient stocks. This loss of organic material and physical deterioration of soils due to their use was alerted by numerous authors, including Michelena et al. [23], Senigagliesi and Ferrari [24], De Battista et al. [25], Chagas et al. [26] and Diaz-Zorita et al. [27], who further demonstrated that less soil removal favored the physical condition of Argiudolls. In addition, regardless of the prevailing tillage system, in a purely agricultural approach, as the years with agriculture increase, the organic carbon inputs into the soil are lower than the carbon dioxide emissions [28], especially after long fallow periods with low annual supply of harvest residue [29]. This behavior results in a progressive deterioration of the physical and chemical fertility of the soil [30,31], which is a situation that can only be counteracted by the incorporation of pastures [32].

The increase in grain production in the region has been due to the increase in yield per unit area, favored by the increasing use of pesticides and fertilizers, a fact that has intensified the capital invested in production. On the other hand, global increases in the demand for grains (mainly soybean) and their derivatives, as well as in their price, have promoted the increase in the area sown with this oilseed [33]. As a result, the Pampean agricultural systems have been simplified, specializing in the production of grain crops, currently dominated by oilseeds to the detriment of cereals. Thus, producers have unbalanced the crop rotation, decreasing the area with winter species (mainly wheat) and displacing pastures to marginal areas.

As a technical response to the problem of degradation of labored and eroded soils, the no-tillage (NT) farming system was promoted in the Pampean region. However, this responded mainly to economic reasons, due to the reduction in the use of fossil fuels and the operational simplicity of this farming system. From 1993 until the mid-2000s, NT expanded exponentially due to the incorporation of genetically modified soybean varieties and the reduction in the price of glyphosate at the expiration of its patent date.

2.1. Consequences on the Soil—The Role of Simplifying Rotations

NT was beneficial due to several factors, including the fact that it maintained the soil cover and led to lower water and soil losses due to erosion. In a review of several works developed in the Pampean region, Alvarez and Steinbach [34] determined that soils under NT had greater structural stability, greater infiltration rate, and higher water content, the latter mainly in critical periods for crops (planting and flowering). However, these authors also found that nitrate availability was lower, the bulk density in the first 20 cm of soils under NT was 4% higher, and that, in some cases, penetration resistance was 50% higher, than in soils under other tillage systems. Steinbach and Alvarez [35] also reported an increase of 2.76 Mg ha-1 of organic carbon under NT, relative to production systems under conventional tillage.

When analyzing the runoffs generated in an agricultural 300-ha microbasin in the northern Pampean region, we observed that in Vertic Argiudolls under NT, the curve number values were higher and the duration of the direct runoff was longer than that in soils under conventional system [36]. However, the flow rates observed in soils under NT were significantly lower.

Despite the benefits of NT, the combination with simplified crop sequences, particularly with the predominance of soybean monoculture, created the need to study new aspects of the physical degradation of cultivated soils, to ensure an evolution of the soil structure that did not constitute a limitation to its sustainability [37]. As a general rule, any monoculture is excluded as good agricultural practice, as it impacts on the long-term sustainability of the system. In particular, the soybean monoculture, or its high frequency in the rotation, generates negative balances of carbon and nutrients due to the high speed of stubble recycling because it has a low carbon:nitrogen (C:N) ratio, which contributes to soil degradation [38].

Results of long-term experiments with high soybean frequency confirmed the reductions in the C, N and phosphorus (P) contents in the soil [28,39–43]. In addition, studies have shown that crop sequences with high soybean frequency are inefficient in capturing other resources such as radiation and/or water, because the soil remains under long fallow periods [38]. These crop-free periods with low surface residue cover contribute to water losses due to runoff as well as to soil losses due to erosion [44,45].

One of the main soil characteristics that determine the quality of the structure of Argiudolls is the content of organic matter. In this regard, and taking into account Pieri's structural stability index [46], for the Argiudolls of the northern Pampean region to present a low risk of physical degradation, they should have percentages of surface organic matter between 4.5 and 6.7%, which are values that, in this region, only pristine soils have [47]. As a result, it has been found that, after 4 to 20 years under agriculture, these soils have losses of 20 to 60% in structural stability, losses of 10 to 44% in SOC, and increases of 3 to 40% in bulk density, compared to situations with minimal disturbance [48]. According to a survey by Sainz Rozas et al. [47], the surface organic matter content of soils under agriculture in the northern sector of the Pampean region ranges from 2 to 3%, a condition that did not change between 2011 and 2018, suggesting that a balance between soil carbon gains and losses has been reached [49].

Multiple aspects of the degradation of Argiudolls have been alerted by the regional scientific community [50]. Figure 2 presents the evolution of relevant scientific production in scientific journals for the period 2000–2020, whereas Figure 3 highlights the most important causes and consequences of land use.

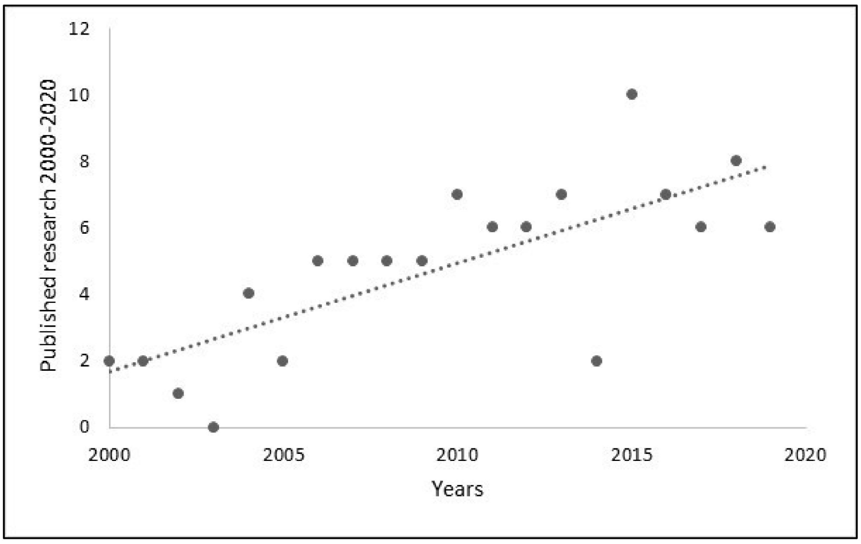

Figure 2. Number of published articles alerting about the causes and consequences of the use of Argiudolls in the Pampean region, based on the most relevant articles [period 2000–2020, R2 = 0.56].

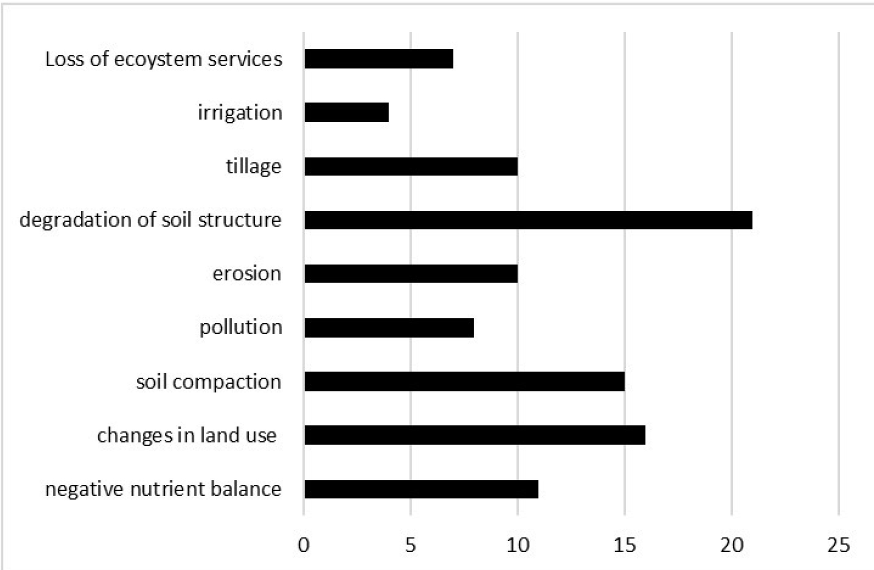

Figure 3. Number of studies pointing out the soil degradation problems reported by the scientific community in Argiudolls of the Pampean region under agricultural production in the period 2000–2020.

References by year of publication: Studdert and Echeverría [39], Wilson et al. [32], Alvarez [28], Ferreras et al. [51], Lossino et al. [52], Botta et al. [53], Díaz Sorita et al. [54], De la Vega et al. [55], Taboada et al. [56], Bonel et al. [57], Morrás and Bonel [58], Gaspari et al. [59], Sasal et al. [60], Castiglioni et al. [36], Micucci and Taboada [61], Ramírez et al. [62], Steinbach and Alvarez [35], Botta et al. [63], Pilatti et al. [64], Ghiberto et al. [65], Ferreras et al. [48], Cosentino et al. [66], Aparicio and Costa [67], Barbagelata and Melchiori [41], Gerster [68], Álvarez et al. [69], Cosentino and Chenu [70], Andriulo et al. [43], Salvagiotti et al. [42], Lavado and Tabodada [71], Álvarez and Steinbach [34], Álvarez et al. [9], Fabrizzi et al. [72], Imhoff et al. [73], Irizar [29], Castiglioni et al. [74], Soracco et al. [75], Caviglia and Andrade [38], Sasal et al. [44], Fernández et al. [76], Imhoff et al. [77], Carrizo et al. [78], Sainz Rozas et al. [47], Gabioud et al. [79], Novelli et al. [80], Chagas et al. [81], Viglizzo et al. [20], Roldán [82], Sasal [37], Wilson and Paz Ferreiro [83], Restovich et al. [84], Scotta and Gvozdenovich [85], Álvarez et al. [86], Aparicio et al. [87], Duval et al. [88], Caviglia et al. [89], Novelli et al. [90], Wilson et al. [91], Berhongaray et al. [92], Denoia et al. [93], Oszust et al. [94], Álvarez et al. [95], Carrizo et al. [96], Rodríguez et al. [97], Lupi et al. [98], Duval et al. [99], Panigatti [100], Carrizo [101], Kraemer [102], Wingeyer et al. [103], Sasal et al. [104], Ghiberto et al. [105], Ronco et al. [106], Castiglioni et al. [107], Álvarez and Álvarez [108], Maggi et al. [109], Wilson et al. [110], Ramírez et al. [14], Imhoff et al. [111], Okada et al. [112], Álvarez et al. [113], Deagustini et al. [114], Novelli et al. [115], Sasal et al. [116], Gregorutti and Caviglia [117], Fernández [118], Di Gerónimo et al. [119], Milesi Delaye et al. [120], Darder et al. [121], Rositano et al. [122], Castiglioni et al. [123], Castiglioni et al. [124], Waigand et al. [125], Vangeli [126], Caprile et al. [127], Sasal et al. [128], Sasal et al. [129], Castiglioni et al. [130], and Sainz Rozas et al. [49].

Figure 3 shows that the main degradation problems detected in these studies are: the degradation of the soil structure, changes in land use and management, soil compaction, negative nutrient balance, excessive tillage, erosion, pollution, irrigation degradation and loss of ecosystem services. On the other hand, associated with comprehensive approaches regarding agrosystems and loss of ecosystem services have increased.

2.2. *Runoff and Water Erosion in Argiudolls*

In the Argiudolls of the Pampean region, which have a high content of silt on their surface, plant cover plays a fundamental role in the infiltration–runoff processes. In microplots under simulated rain, De la Vega et al. [55] determined that the final infiltration rate of a soil under NT without plant cover decreased by 50%, and that the period until waterlogging was 50% shorter than that of plots with plant cover. Aspects such as the crop sequence implemented, the soil drying, the root and microorganism activity, and the quality and quantity of dry matter produced also have consequences on the infiltration process. In this sense, Darder [45] and Kraemer [102] determined under simulated rain, higher infiltration rate and lower soil loss in Argiudolls with more diversified crop sequences (especially in those with incorporation of cereals) than in those with soybean monoculture. They also observed that this response in turn depended on the amount of rainfall. In this sense and at slope scale, in an Aquic Argiudoll of Entre Ríos, we determined less accumulated runoff as the intensification in the crop sequence increased, although such behavior was only significant for rains of less than 70 mm [44]. When the surface of these soils is saturated due to the presence of a subsurface argillic horizon with low permeability, the equilibrium infiltration rate could be less than saturated hydraulic conductivity mentioned by Reynolds et al. [131] as a threshold [123]. In turn, especially in Argiudolls with greater shrinkage capacity such us those located in Entre Ríos province, drying cracks can form and cause infiltration rates that are as high as the rainfall intensity applied [44,60,124]. On the other hand, the water erosion processes generated in these soils also influence the quality of their surface structure. In Argiudolls of the north of the Pampean region, it has been verified that the increase in the degree of erosion decreases the aggregates stability [13,109]. This process also affects the relevance of the provision of ecosystem services, since the loss of the most fertile horizon of these soils generates lower yields [85,109,132] and increases in production costs [133], while a decrease in the infiltration rate leads to a displacement of pesticides and nutrients outside the fields, causing eutrophication and contamination of watercourses [128].

2.3. *Decreased Soil Fertility*

By the late 1980s, non-eroded soils had already lost 30% of the SOC [120] and 42% of the total P reserves of the arable layer [30], and the lack of replenishment of nutrients exported through crops led to the loss of the region's natural fertility with the time of land use.

Until the mid-1990s, the use of fertilizers in Argentina was low and although in the last twenty years it has increased, N, P, and sulfur balances in the Pampean region remain deficient, with their consumption exceeding about twice the amount of nutrients applied [71]. As a result, the northern

Pampean region presents very low to low P levels, which could not be supportable with crop production [20].

2.4. Decrease in the Size of Soil Aggregates

Agricultural use and management cause changes in the natural structure of the soil, with complex effects according to the soil origin, which, in the long term, can condition its productivity [134]. Amézketa [135] summarized the different mechanisms of soil disaggregation, with aggregate stability considered a sensitive indicator of soil recovery or degradation [136]. In this sense, the high percentage of silt in the surface texture of Argiudolls gives low stability to the aggregates due to their reduced cationic exchange capacity, low specific surface area, null plasticity and reduced affinity for other particle sizes [56,137].

In Argiudolls, SOC is considered one of the main stabilizing agents of soil aggregates [72,79], and SOC and clay interact forming complexes and micro-aggregates that protect the soil from degradation. The SOC storage can be increased by combining NT with the intensification in the crop sequence [29,90]. In addition, crop sequences that reduce fallow periods maximize the amount of SOC and N sequestered into the soil. Regarding this issue, Novelli et al. [90] found a close positive relationship between the crop intensification rate and SOC, associated with the time with live plant cover, which allows continuous activity of microorganisms and roots for extended periods. In contrast, an increase in the frequency of soybean cultivation leads to the reduction of SOC in macro-aggregates and to the loss of larger aggregates [90], independently of the production system used [138]. In short, in systems with a high rate of crop intensification, the more frequent return of plant residue favors the addition of aggregation agents, particularly transient and temporary [139], which can contribute to increasing the stability of aggregates and consequently the storage of SOC.

2.5. Soil Compaction

The Argiudolls of the Pampean region are characterized by their natural susceptibility to compaction and by presenting massive and homogeneous structures. In addition, soil degradation by compaction may be increased by the traffic of agricultural machinery with equipment of increasing size and weight. This is one of the main problems of physical degradation in the silty soils managed under NT. Such traffic, which increases mainly during the harvest stage and occurs in soils with higher soil water content than the one optimal for wheel traffic, is among the main causes of formation of a massive structure on the surface horizon of agricultural soils [140–147]. Soil compaction also alters other physical, chemical and biological properties of the soil [148–154].

In Argiudolls under NT, some studies have detected higher penetration resistance and bulk density values in the soil layer between 5 and 12 cm deep [155]. In the layer from 0 to 80 cm of an Argiudoll of Entre Ríos, Wilson et al. recorded soil penetration resistance in successive dates with decreasing soil water content [110]. These authors also found that the penetration resistance profiles showed a trend to a bimodal pattern of variation as a function of soil depth, with two maxima. The first of these maxima was located near the soil surface and the second below 40 cm depth. On the other hand, the standard deviations of soil penetration resistance showed a trend to increase with increasing soil dryness. The authors also noted that maximum soil resistance to penetration near the soil surface was located over the Bt horizon, but not within it. This pattern of penetration resistance near the soil surface suggests that the effects of platy structure are not negligible.

Regarding this issue, for an Argiudoll of Entre Ríos province, we determined values of 1.44 Mg m-3 of critical bulk density, using the least limiting water range [91]. On the other hand, Kraemer et al. [156] found that a higher proportion of crops per year increased the macroporosity of the Argiudoll studied, especially in pores greater than 1000 μm, these being mostly elongate. At the same time, although these researchers observed a strong trend in the horizontal orientation of elongate pores, these were prevalent in rotations with long periods of winter fallow.

In the north of the Pampean region, we evaluated the structure type organization of Argiudolls under NT, and highlighted the regional extent of a platy structure near the soil surface and studied its evolution and impact on runoff. These authors explained the proportion of platy structure in the A horizon by the number of consecutive years under NT and the intensification of cropping systems: the higher the number of years under NT, at least until 15 years, and the lower the intensification in the crop sequence, the higher the proportion of laminar structure [157]. This platy structure alters the drainage pattern, restricts the water entry into the soil and favors surface runoff according to its proportion in the profile of A horizon. Sasal et al. [158] also analyzed the origin of the platy structure and found that consecutive wet–dry periods and changes in soil volume of previously compacted structures by cracking led to platy structure formation [159].

2.6. Soil and Water Contamination

In Argentina, as a result of the increase in the use of pesticides and fertilizers in agricultural production and due to the increase in the physical degradation processes of the Argiudolls of the Pampean region, research work related to the contamination of water bodies with nutrients and pesticides has increased in recent years [21,104,126,127,160–163]. Recent studies in the Paraná-Paraguay River basin, for example, have detected glyphosate and its metabolite AMPA in water and bottom sediments [106], as well as endosulfan, chlorpyrifos and cypermethrin at concentrations higher than the guideline levels established for the protection of aquatic life [164,165].

In turn, in 300 sites located in different watercourses of Entre Ríos province, Sasal et al. [116] recorded glyphosate in 40% of the samples analyzed. In hydromorphic soils affected by the expansion of agriculture, Vangeli [126] determined greater presence of sediments and glyphosate in the runoff water, as a result of land use change. These results raise new questions about the effects of land use change on surface water quality, and put in evidence the loss of the potential capacity of Argiudolls to regulate lateral flows of water and of the substances transported.

The practices applied to minimize losses of pesticides and nutrients from agro-ecosystems developed in Argiudolls are not novel or unknown to the agricultural sector. Regarding this, Sasal et al. [104] and Seehaus et al. [166] showed that rains very close to P fertilization or spraying with herbicides favor agrochemical losses by runoff. It has also been shown that minimizing runoff reduces the contribution of nutrients and pesticides from agro-ecosystems to aquatic environments. Soil conservation practices, such as land systematization and NT, allow the speed and volume of the runoff to be controlled, constituting adequate tools to minimize water erosion and associated losses. In turn, uplands and middle slopes with continuous agriculture, it is necessary to implement intensified sequences, whereas, in lowlands, it is essential to preserve the vegetation of the riverside strips [167].

3. Soil Management Practices Aimed to Restore Ecosystem Services

Preventing and reversing soil degradation processes is a challenge that must be addressed with a holistic approach, based on land-use planning, especially in a context of global climate change [168]. This approach, designed to be developed on a scale larger than a field scale, requires analyzing the landscape as a whole. To address this problem, in 2015, the UN General Assembly adopted the 2030 Agenda for Sustainable Development. One of the goals of this Agenda is to promote the sustainable use of terrestrial ecosystems and the fight against desertification, urging to stop and reverse land degradation, to stop the loss of biodiversity, and to seek to achieve a world with neutral soil degradation by 2030.

Soil use and management practices should maintain the integrity of the agroecosystem and guarantee a continuous provision of services. The key to sustain the integrity of Argiudolls and to continue to generate local, national, and global benefits is an adequate use of the lands. To find out whether complex production systems are a reasonable alternative for this, a plan with a set of sustainable land management practices should include the following:

3.1. Land Systematization to Prevent Soil Loss Due to Water Erosion and Conservation of Ecosystem Services

Land systematization is an agronomic practice used to control the speed and volume of runoff, at the level of the landscape or watershed, through a system of terraces to remove excess surface water [169]. These drainage (or gradient) terraces are used in soils with low permeability and susceptible to erosion, where it is necessary to take the excess water through the terrace channel to a collecting channel that drains water from the field [170]. In addition to controlling soil loss from water erosion, the implementation of drainage terraces allows soybean and maize yields to be increased by 22% and 25%, respectively, compared to non-systematized fields [85,171]. Currently, the province of Entre Ríos has more than 400,000 systematized hectares, highlighting the key role of the implementation of the Provincial Law N° 8318 for Soil Conservation and Management [129].

In areas with slopes and risk of water erosion, the systematization of land at the basin level allows the conservation of biodiversity and soils by reservoir terraces [94,172]. A reservoir terrace consists of a terrace and/or collecting channel, which is allowed to be entirely covered by vegetation of native species (herbaceous, shrub and arboreal), not harmful to the production system. This allows the intensity of water erosion to be reduced. In addition, since these terraces are connected with patches of native forests, linear elements of landscape, and natural watercourses, they also play a fundamental role as biodiversity refuges and corridors.

3.2. Practices That Promote the Minimum Disturbance of the Soil by Tillage

Conservation agriculture practices, such as NT, attempt to control the adverse aspects of traditional agriculture. According to Reicosky and Saxton [173], conservation agriculture requires three principles or pillars for its implementation: minimal soil disturbance by labor, diversity of species in rotations, and continuous production of crop residues to maintain soil cover. Thus, one of the main benefits of conservation agriculture, in particular of NT, is the increase of surface soil organic matter and its positive impacts on many processes that determine soil quality [103].

NT comprises a series of agronomic practices that allow soil management with minimal disturbance of the soil composition, structure and biodiversity. As stated above, in general terms, residue cover results in improved water conservation in the soil profile, lower surface runoff, and reduced impact of agricultural machinery. In the Pampean region, NT has been imposed on the basis of its increased efficiency in the control of runoff and erosion, achieving a better use of rainfall for crops and lower soil losses. The soil cover achieved by this tillage system is one of the most effective means of dissipating the impact energy of rainfall. Its degree of efficiency depends on many factors such as the crop type, height, species sequence, plant density and amount of remaining residue, as well as on the soil properties. In this regard, our research group has found that, in Argiudolls, the amount of water infiltrated in runoff plots is more associated with the time of occupation of the crops than with the soil physical properties [44]. However, since the implementation of NT did not solve all the problems of physical degradation presented by the Argiudolls of the Pampean region, an increasing number of local studies have aimed to evaluate the soil behavior under NT after an increase in the diversification and/or intensification of the crop sequence and after applying different types of tools. For example, the use of subsoilers do not invert the layers, but they reduce the compaction of the deep layers and leave residues on the surface. In an Typic Argiudoll of the northern Pampean region, Elisei [174] found that the scarification of the soil under NT improved the soil physical properties, with a durability of this practice of at least two years.

3.3. Crop Rotations and Cover Crops

A rotation or crop sequence plan consists of planning the succession of crops over time in the same unit of land. Its aim is to optimize the use of environmental resources (solar radiation, water and nutrients), to ensure the preservation of the soil and other natural resources involved (water and air), and to maximize the stability of yields and economic benefit [38]. In this regard, several studies have shown that a higher proportion of cereals in the rotations in Argiudolls increases aggregate stability and SOC [113,175,176]. Studies have also shown that an intensified crop sequence improves the supply of crop residues and some soil properties, such as structure quality and SOC, compared with soils with more frequent soybean sequences [102,115,177]. In Argiudolls of the northern Pampean region, D'Acunto et al. [178] determined that rotations with greater diversity of crops had greater production of biomass and residue, as well as greater diversity and activity of the microbial community. In addition, a study carried out over five years in Entre Ríos province at field scale revealed that, in years with normal rainfall (1000 mm), soils with soybean monoculture showed four-fold higher runoff losses than those with rotation with corn and wheat and eight-fold higher than those with a pasture [179]. The minimization of runoff has a direct effect on the reduction in nutrient and pesticide losses towards surface watercourses.

Regarding cover crops, they are sown in the fallow period, usually during the winter, and are suppressed by chemical or mechanical methods well in advance so as not to affect the yield of the income crop. Although the name "cover" refers to cultivation as a soil protector against the erosive action of rains, they also generate other positive effects. In Argiudolls of Entre Ríos province, the implementation of cover crops has been found to provide important services such as a reduction of the soil loss and surface runoff, improving the structuring and maintenance and formation of organic matter [44,115]. Besides, the inclusion of some species as cover crops in the simplified cropping systems, which currently predominate in the Pampas region, improves water and N use efficiency, compared to the long alternative fallow periods between summer crops [84].

Giannini [180] indicated that the use of cover crops accompanied by moderate doses of mineral fertilization allowed the recycling of P from organic matter in the medium and long term. Romaniuk et al. [181] also found that only one cycle of cover crops allowed the contents of C, N and P to be increased in the particulate fraction of organic matter corresponding to the first centimeters of soil. In a meta-analysis of results obtained in the Pampean region, Alvarez et al. [113] determined that the introduction of cover crops increased structural stability, infiltration and SOC, and decreased penetration resistance.

3.4. Use of Organic and Inorganic Amendments

Currently, the need to find new sources of exogenous organic matter, such as that based on waste from intensive animal production, is complemented by the need to give a final destination to waste from confined animal production. In general, the addition of organic amendments can positively influence soil structure, increasing the formation and stability of aggregates [60,139,182], decreasing the bulk density [183] and improving the infiltration rate, the hydraulic conductivity [184] and the water retention capacity of the soil [185]. These changes in the physical soil properties also allow runoff to be decreased, reducing the loss of nutrients, and thus improving plant development [186].

In silty soils affected by continued agriculture, Gabioud et al. [187] showed that the addition of "poultry litter" as organic amendment and gypsum as inorganic amendment led to the short-term regeneration of the soil structure in the surface horizon of an Aquic Argiudoll under NT. The application of the two amendments had a complementary effect, since poultry litter increased the proportion of gamma structure and gypsum strengthened soil aggregates against water action. The authors concluded that if the changes induced by poultry litter persisted over time, the increased Γ structure could promote improvements in other processes, determining soil productivity through water infiltration, percolation rates and water distribution in the soil profile. On the other hand, Barbieri et al. [188] indicated that the addition of organic and inorganic amendments reduces soil compacted areas on the surface horizon of an Aquic Argiudoll under NT, and that the reapplication of poultry litter leads to profiles with lower penetration resistance and more homogeneous kriging maps of penetration resistance.

3.5. Legal Aspects Related to Soil and Ecosystem Services Conservation

Many efforts have been made to develop legal instruments to contribute to the soil conservation in the region. At the national level, Law N° 24,428 has not been repealed, but it is no longer financed [100]. Regarding this, Acuña [189] held that this National Law and other provincial laws in force under the National Constitution reformed in 1994 and the General Law N° 25,675 on the Environment lack tax, economic and financial incentives, budget allocations, and an appropriate degree of articulation of public–public operational–technological actions at the different levels of state aimed at their implementation.

In the Buenos Aires province, it is important to highlight the existence of a Rural Code, which regulates the conservation of the agricultural land of this province, declaring the maintenance and improvement of its productive capacity as an issue of public interest. In Law No. 11723/95 on the Protection, Conservation, Improvement and Restoration of Natural Resources and the Environment in General, there is a Chapter dedicated to soils, which establishes the principles that will govern the treatment and implementation of policies aimed at their protection and improvement. On the other hand, in Santa Fe, the province has had the Soil Conservation Law N° 10,552 since 1992. In addition, by Resolution 1069/17, the Ministry of Production established the Soil Observatory of Santa Fe, which consists of a panel of experts made up of representatives of different institutions, whose role is to advise on policies related to soil conservation [190].

In Entre Ríos province, based on the acknowledgement of the problem of water erosion, in 1989, the government passed the Provincial Law on Soil Conservation and Management N° 8318/89. This law of public interest aims to promote the conservational use and management of the soils of the province, which, due to their natural conditions and anthropic actions, show symptoms or susceptibility to degradation. This law also aims to promote the access to economic stimuli for all producers holding property title in the areas of conservation and management, and, in accordance with the conservation practices that are implemented, establishes a differential reduction in the value of the real estate tax in 4 to 10 years depending on the type of practice. In addition, in 2015, driven by the generation of information from the GEF PNUD ARG/10/G49-PNUMA 4B85 Project "Incentives for the conservation of ecosystem services of global importance", the incorporation of Article 12 bis to Law N° 8318, which considers a series of actions for the conservation of ecosystem services in an integral way, achieved half a sanction in the Chamber of Deputies of Entre Ríos province.

4. Summary

In Argiudolls, NT is a key management practice that allows reducing soil loss and promoting a higher content of surface organic matter, although it is not enough to solve the problems of physical degradation to which these soils are susceptible. With the aim to reach neutrality of land degradation in areas with Argiudolls, it is possible to use management practices that, integrated and complemented by NT, provide greater sustainability of production systems. In this way, the synergy between scientists and decision makers will allow the services provided by these soils to be maintained in the long term. In this sense, sustainable intensification and crop rotation promote biological action in these soils. These practices should be integrated with more structural ones at the landscape level, such as the systematization of land through the construction of terraces to evacuate water excess in a non-erosive way, and complemented by practices that incorporate linear elements of vegetation. The promotion of the conservation of ecosystem services in Argiudolls of Argentina will allow both the development of its economic potential and the care of the environment for the entire society.

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