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Partial Grazing Exclusion as Strategy to Reduce Land Degradation in the Traditional Brazilian Faxinal System: Field Data and Farmers' Perceptions

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Abstract: Land degradation is becoming a serious concern for the sustainability of traditional agrosilvopastoral systems such as the Brazilian faxinal. The IAP (Environmental Institute of the Federal State of Paraná) is favoring the partial exclusion to grazing for 10 years as strategy both to recover degraded lands and to reduce negative effects. Nevertheless, this strategy is being followed by a reduced number of owners (*faxinalenses*) and little is known about the effectiveness of these measures due to either lack of field data and knowledge on faxinalenses' perceptions. We have identified one out of few farms that have followed this official strategy and, within the same farm, we have compared values of some soil properties (bulk density, porosity, water holding capacity, penetration resistance, soil organic matter and root density) from an excluded area to grazing for 10 years, with some areas that represent a gradient of grazing intensity (natural forest, secondary forest, degraded forest, grassland and a degraded area by pigs). In addition, we have interviewed some faxinalenses (one faxinal farm is owned by several farmers) in order to better understand how the risk of land degradation is perceived by them and their opinions about the usefulness of partial grazing exclusion as a strategy to improve the management of their farms. The results have shown that soil quality increases considerably as a consequence of grazing exclusion, in spite of land has been used for cropping *yerba* mate during the exclusion time, but faxinalenses are not mindful of these benefits and they are no longer interested in excluding other areas of their farms. They think this strategy is simply an obligation imposed by the environmental authority.

Keywords: agrosilvopastoral land use; sustainable agriculture; soil quality

1. Introduction

The faxinal is a traditional agrosilvopastoral system performed in some areas of the State of Paraná (Southern Brazil) based on the sharing of communal lands by private owners (under strict rules agreed by them) known as *faxinalenses* within a context of subsistence farming, i.e., involving family members as main labor force [1]. It is actually a consequence of the progressive clearing of native *Araucaria angustifolia* forests since the European colonization (Spanish and Portuguese until the 18th century, and mostly Ukrainian and Polish in the 19th and 20th centuries) by low-impact (extensive) grazing and wood extraction [2]. They are areas reserved for communal grazing by privately-owned livestock:

cattle, horses, goats and pigs. They can be treeless grasslands and (native or secondary) forests that vary in tree density and they are accompanied by some crops (e.g., *yerba mate*) for self-consumption and sell in short-chain markets (areas reserved for private cropping) [3].

Nowadays, there are more than 200 faxinal farms in the State of Paraná representing the economic support for about 40,000 people and one of the most valuable aspects of the cultural legacy linked to the traditional way of living in rural areas [4]. Unfortunately, less than 25% of them maintain the values of their original land management (privately-owned livestock grazing in large unfenced communal lands), commonly considered as sustainable [5]. This actually is accompanied by serious environmental problems caused by recent changes in land management as a consequence of the current socioeconomic context (like mechanization, commercial crops, land abandonment, increasing in the number of animals and introduction of new pasture species) [3]. Some problems have already been detected both in faxinals and comparable land systems: soil compaction [6], changes in soil properties [7], reduction in vegetation cover [8], lack of tree regeneration [5], soil erosion [9], decrease in water infiltration [10], water pollution [11] and silting of water bodies [12], among others.

Faxinals are currently experiencing significant changes in land management. It is resulting in land abandonment in some farms and an increase in pressure on land in other ones [3]. According to the opinion of many faxinalenses (personal communications) among the drivers of these land degradation processes is the existing unbalance between the availability of pasture and the number of animals in those farms that have not yet been abandoned. Many traditional practices, such as rotational grazing and natural fertilization, are also being progressively abandoned [13]. In addition, some faxinalenses have decided not following any more the rules of land management, previously agreed by the community, by fencing some parts of the communal areas for their own animals. It has supposed a remarkable internal fragmentation of the landscape and the loss of the cultural essence of this endangered land system [14].

The environmental authority (IAP, Environmental Institute of the Federal State of Paraná) has proposed and supported the strategy of excluding some areas to grazing (size <1 ha) through tax exemptions, following the guidelines of the Federal Decree no. 6040 (7 February 2007) on National Policy for Sustainable Development of Traditional Peoples and Communities, in order to increase soil quality and pasture production [15]. This specific program began in the Faxinal Paraná Anta Gorda (our study area) in 2008, although it has been followed by a reduced number of faxinalenses. In fact, some of them have used these excluded areas for planting trees for timber (pines and eucalyptus) and native *yerba mate* trees since they have a positive impact on the recovery of degraded soils, maintaining the profitability of their farms at the same time [16]. The scarcity of field data and the lack of a proper assessment of this kind of initiatives from different perspectives (scientists and faxinalenses, environmental and economic, etc.) make many faxinalenses doubt or refuse its application in spite of they are mindful of the environmental problems that they must face.

This program applied in some regulated faxinals was unfortunately suspended by the IAP (Instituto Ambiental de Paraná) due to the unsuccessful number of faxinalenses which followed it (personal communication). Nowadays, the IAP manages most of its payments for environmental services through the guidelines published in the public call no. 001/2018 (*Seleção para pagamento por services ambientais às reservas particulares do patrimônio natural no Estado do Paraná*). So, there is no relevant information useful for assessing the effectiveness of this specific program. We have assumed land management in terms of animal stocking rates can be highly variable comparing different farms and even fenced areas within a single farm [17]. So, we have tried to agree common features to help to identify areas presumably affected by different grazing intensities. We have considered those with a high surface occupied by bare soil as degraded areas and we have assumed tree density is progressively reduced (medium and long term) when grazing intensity increases.

This work should provide relevant information regarding the land management and sustainability of faxinal systems, since there is still an open discussion about the fragmentation of faxinal farms, i.e., a debate between some faxinalenses that agree communal grazing lands should not be fenced

under any circumstance and those who consider the individualization of grazing as the best option. Furthermore, some uncertainties still remain about the convenience of excluding areas to grazing due to the lack of knowledge (few study cases) about risk perception (land degradation) of local faxinalenses, who must be key actors in the process of making fair and responsible decisions.

2. Materials and Methods

2.1. Study Area

The study was carried out in the farm named *Faxinal Paraná Anta Gorda* located in the municipality of Prudentópolis (Paraná, Brazil), where 18 of these faxinal farms are still active (Figure 1). This farm has a size of 277 ha used as communal land for livestock grazing (some areas have been already fenced for private use). In total, 36.4% of its surface is treeless grasslands, 34.7% is secondary forest, 16.1% is mature forest, and 11.4% is degraded forest. The remaining 0.7% is occupied by buildings (like houses and paddocks), orchards and roads. About 240 people (64 families) share these pieces of land in which extensive livestock husbandry is accompanied by subsistence crops, such as corn, bean, and rice. Nowadays, there are also people that they have bought faxinal rights for recreational purposes (they are known as the new owners).

Figure 1. Geographical location of the farm *Faxinal Paraná Anta Gorda*.

Regarding livestock, this farm is grazed by 90 cows, 60 horses, 250 goats and 1500 pigs that feed mostly pastures, fruits and roots in the communal land because feeding supplies are expensive. From a physical point of view, this area is formed by sedimentary and igneous rocks (Tertiary) and dominated by a variety of tropical humid climates (Cfb, Köppen classification), with cold winters and an average annual rainfall above 2000 mm. Its soils are mostly (degraded) epileptic Cambisols (WRB Classification) and Gleysols (WRB Classification) in the areas near water courses (permanent streams). The native vegetation in Prudentópolis is a mixed ombrophilous forest of *Araucaria angustifolia.*

Some small pieces of land (size <1 ha) that were unfenced treeless grasslands usually grazed by pigs, cattle and horses (forests and small agricultural lands were not included in this IAP program) were excluded to grazing for 10 years according to the guidelines proposed by the IAP program.

In these excluded areas, the no-tillage planting of *yerba mate* trees was allowed from the moment the exclusion started. During these 10 years (2008–2017) the unique activity authorized was weeding control manually and/or by using herbicides (glyphosate), since natural and chemical fertilizers were not used. The farmers took advantage of this exclusion to plant yerba mate trees, and during the 10 years they kept animals away.

2.2. Experimental Design

The study was focused, methodologically speaking, both on the determination of some soil parameters by collecting samples (for the most of them) in field and on personal interviews with some faxinalenses discussing field data, land management, problems, risks and mitigation strategies that can guarantee the sustainability of the system. In addition, we have asked for faxinalenses perception on this particular initiative by IAP of grazing exclusion. As sampling plots, we have selected a 10-yearexcluded area for grazing (several pieces of land smaller than 1 ha in size), a degraded area due to the concentration of pigs (nearby buildings), grassland (regular grazing), a degraded part of the forest (low tree density), secondary forest (medium-height trees and grasses), and native forest (fruits fed by pigs) that could be considered as control plot (Figure 2).
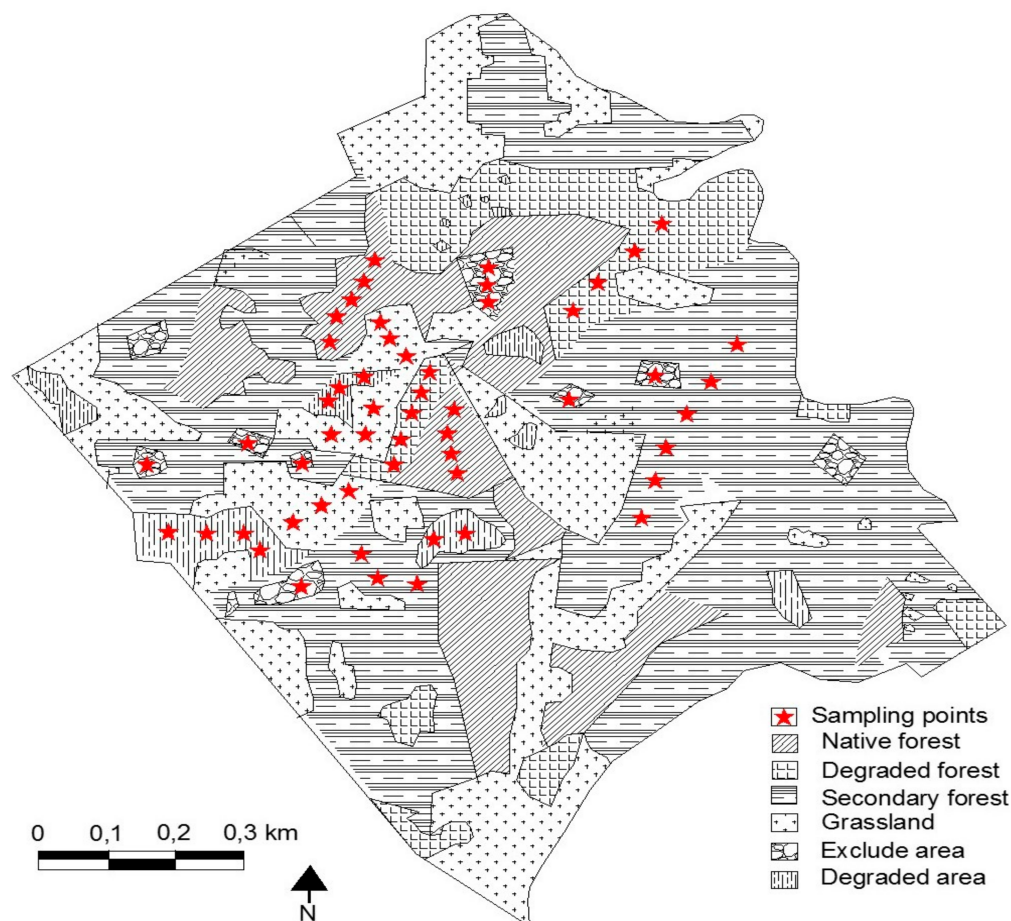

Figure 2. Sampling plots of the farm *Faxinal Paraná Anta Gorda*.

Regarding the selection of soil quality parameters, we have selected water holding capacity, penetration resistance, porosity, bulk density, root density and soil organic matter as indicators of soil quality. Soil samples were collected randomly in sampling points (*n* = 84) proportional to the surface of each plot, within representative areas, with a distance of separation between them of at least 10 m. On each point, soil penetration resistance was measured until a depth of 40 cm (maximum depth

reached by the penetrometer) and the rest of parameters were quantified by depth intervals of 0–5, 5–10, 10–20, 20–30 and 30–40 cm according to previous studies. Soil organic matter and root density were only assessed in 3 random samples collected in every plot, since their analyses involve a remarkable economic cost.

The environmental authority (IAP) proposed the exclusion of some small areas (<1 ha) to grazing in order to both recover soil quality and native vegetation as well as to promote the cultivation of *yerba mate* aiming at provide some inputs as compensation. This program was voluntary, and only 3 out of 54 farms followed it. In fact, these 3 faxinalenses were those selected to be interviewed. Due to the unsuccessful results, the IAP decided not to continue with this program and these 3 faxinalenses have begun to open these previously fenced areas. Table 1 shows the main characteristics of these three interviewees. The key points initially used as guide for the interviews were the following: (I) characteristics of the property and its land management, (II) perception on general environmental problems, (III) land degradation processes in the faxinal Paraná Anta Gorda, (IV) forecast on the survivorship of the faxinal system, and (V) ideas to improve soil conditions. Nevertheless, the camaraderie formed between the interviewer (V. Antoneli) and the interviewees meant that many other topics were addressed during the interviews.

Table 1. The main characteristics of the three interviewees.

No.	Sex	Age	Education	Marital Status	Descendants	Property Size	Pigs	Cows	Goats	Horses
1	Male	56	Primary school	Married	6	6 ha	45	10	25	0
2	Male	62	Primary school	Married	5	10 ha	68	6	12	2
3	Male	66	Primary school	Single	0	5 ha	38	6	12	2

2.3. Soil Sampling and Analysis

Standard methods and tools were used in the determination of every parameter. Soil penetration resistance was quantified by using an impact penetrometer that returns a value (expressed in MPa) at each 5 cm of depth. Water holding capacity was assumed to be the volumetric water content at field capacity measured in laboratory after 24 h at 105 °C. Bulk density was measured by soil rings of 100 m^3 of volume (3 replicates by every sampling point and depth). Porosity was determined from the difference between the values of the real (particles) and bulk (soil) densities. The method of the volumetric balloon was used to quantify real particle density (by using ethylic alcohol). Soil organic matter was quantified by wet combustion (Walkley and Black method) and root density (expressed in g cm^{-3}) was calculated in a sample of 1000 cm^3 (10 × 10 × 10 cm) after separation and weighing in laboratory. All these methods have been proposed and validated by EMBRAPA (*Empresa Brasileira de Pesquisa Agropecuária*, Brazilian Agricultural Research Company) [18].

2.4. Data Analysis

Some basic descriptive statistics parameters, such as mean value and standard deviation, were used to characterize each plot. The comparison between groups (plots with different grazing intensity) was made by the Tukey post-hoc method using as signification reference the level of 5%. The statistical procedure was made using the software package Statistica v. 6.0.

3. Results

3.1. Soil Penetration Resistance

The highest values (>4 MPa) of soil penetration resistance were recorded both in the degraded area (nearly buildings) and in the grassland, i.e., in those parts of the farms in which animals graze for more time (Figure 3). These high values were observed until a depth of 20 cm, i.e., the soil layer in which herbaceous roots perform their crucial activities. Contrariwise, the lowest values were recorded both in the excluded area and in the forest. Therefore, it is important to state that an excluded area can

reach values comparable to forest areas after 10 years of exclusion. Secondary and degraded forest showed intermediate values, confirming a gradient of degradation caused by grazing pressure.
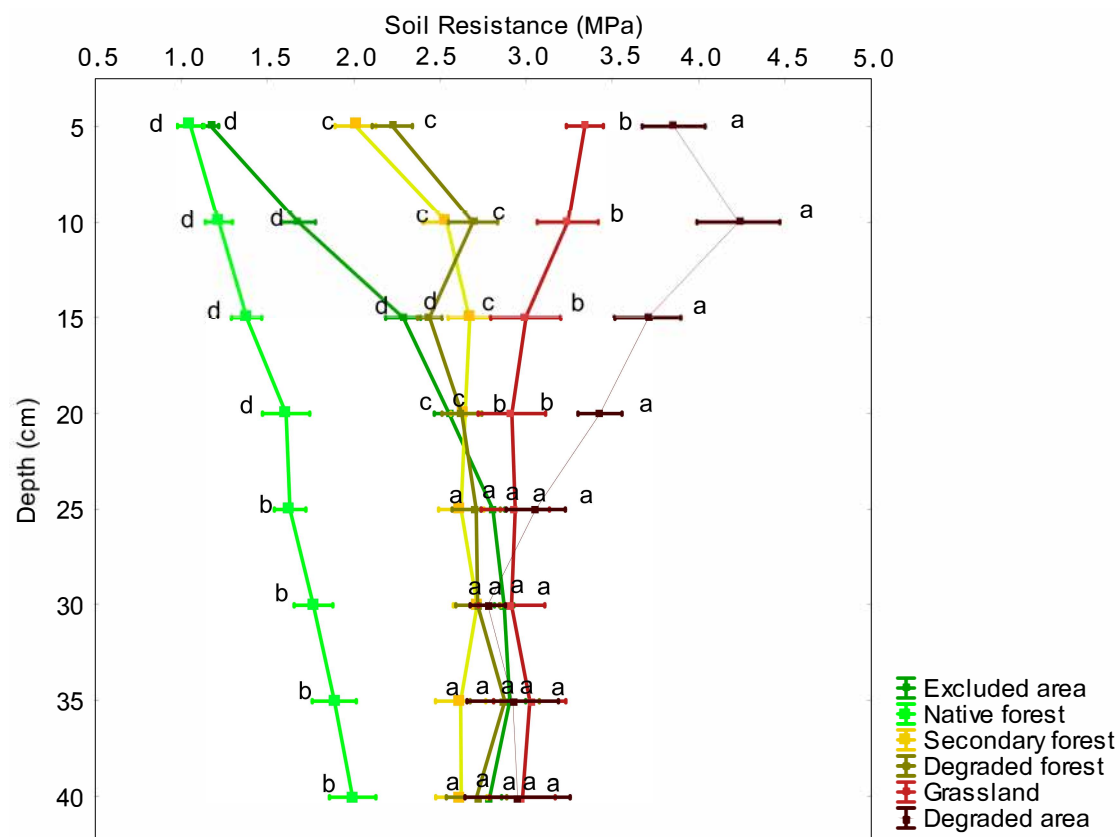

Figure 3. Soil penetration resistance of every plot. Letters mean statiscally homogenous groups.

The other remarkable finding is that the excluded area showed significantly lower values even in the deepest layers (40 cm) reaching a maximum value of penetration resistance below 2 MPa. The other plots showed values of compaction (>2 MPa) from 25 cm in depth. This finding could be interpreted as an indication of excluded area which can be useful for seeding and planting species with a deep rooting system (like perennial pastures and trees). In addition, it can be also interpreted that exclusion can be a good strategy to recover areas for grazing and even for commercial crops.

3.2. Water Holding Capacity

The volumetric soil water content at field capacity for every plot is shown in the Figure 4. The maximum values were recorded in the native forest (5 cm depth: 44.5%, 10 cm depth: 43.8%). The lowest values were recorded both in the grassland and the degraded area (statistically homogenous groups). The excluded area showed a mean value relatively comparable to those found both in the secondary and degraded forest and lower than in the native forest. Nevertheless, it has reached more than 50% at 5 cm depth level.
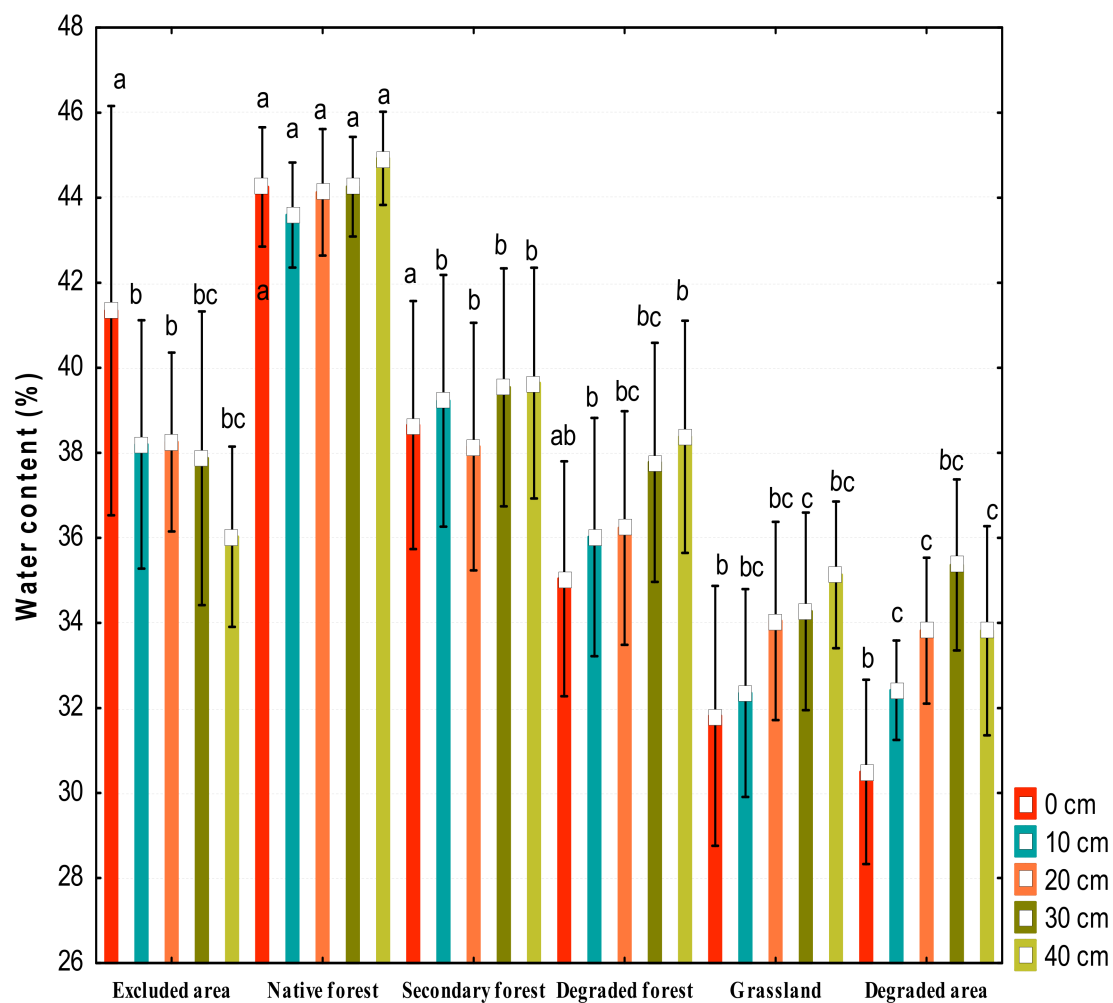
Figure 4. Soil water content measured at field capacity. Letters mean significant homogenous groups.

3.3. Bulk Density

The mean values of bulk density by plot ranged from $1.14 \, \mathrm{g \, cm^{-3}}$ in the native forest (reference area) to $1.39 \, \mathrm{g \, cm^{-3}}$ in the degraded land by pigs (Table 2). Nonetheless, a significant variability has also been observed within each plot induced by sampling depth. The native forest, for instance, varied between 1.03 and $1.09 \, \mathrm{g \, cm^{-3}}$ in the top 10 cm. The excluded areas showed a mean value of $1.20 \, \mathrm{g \, cm^{-3}}$, lower than in every grazed plot, although with a much higher variability. Particularly interesting has been the difference observed between the intervals of 0–5 cm ($1.05 \, \mathrm{g \, cm^{-3}}$) and 5–10 cm depth ($1.20 \, \mathrm{g \, cm^{-3}}$). Regarding soil porosity, the exclusion of grazing improved soil conditions in the excluded area until 20 cm in depth.

Table 2. Mean values of bulk density ($\mathrm{g \, cm^{-3}}$) by plot.

Plot	No. of Samples	0 cm	10 cm	20 cm	30 cm	40 cm
Excluded area	15	1.05c	1.20b	1.20b	1.26ab	1.31a
Native forest	15	1.03b	1.09ab	1.15a	1.20a	1.22a
Secondary forest	15	1.22a	1.28ab	1.30ab	1.31a	1.35a
Degraded forest	15	1.25a	1.29a	1.29a	1.30a	1.32a
Grassland	15	1.34a	1.32a	1.29a	1.30a	1.31a
Degraded land	15	1.39a	1.34a	1.36a	1.43a	1.42a

Note: The letters mean statistically homogenous groups (Tukey post-hoc comparison).

3.4. Soil Organic Matter

Significant differences of soil organic matter content at different depths were observed between plots, particularly between these areas in which trees are present and those without trees (Table 3). No significant differences were observed between the excluded area and the grassland in any depth interval. The lowest values were also recorded in the degraded areas by fattening pigs.

Table 3. Mean values of soil organic matter (g kg^{-1}).

Plot	No. of Samples	0–10 cm	10–20 cm	20–30 cm	30–40 cm
Excluded area	3	34.5a	27.0a	23.8b	-
Native forest	3	49.2a	43.8a	42.3a	-
Secondary forest	3	40.2a	36.0a	33.6a	-
Degraded forest	3	38.9a	36.6a	31.0a	-
Grassland	3	32.0a	26.7ab	21.3b	-
Degraded land	3	19.1a	21.7a	20.1a	-

Note: The letters mean statistically homogenous groups (Tukey post-hoc comparison).

3.5. Root Density

Table 4 shows the mean values of root density by every plot at three different depth intervals. As it was expected, the highest values have been observed in the top 10 cm, i.e., the rooting layer of several pasture species. The excluded area showed relatively low values in comparison to grassland and native and secondary forests. The degraded forest showed similar values in comparison to the excluding plot at every depth interval.

Table 4. Mean values of root density (g dm^{-3}).

Plot	No. of Samples	0–10 cm	10–20 cm	20–30 cm	30–40 cm
Excluded area	3	2.13a	0.37b	0.22c	-
Native forest	3	5.51a	2.48b	2.17c	-
Secondary forest	3	3.14a	1.23c	1.72b	-
Degraded forest	3	2.01a	0.47b	0.30b	-
Grassland	3	3.49a	0.51b	0.30a	-
Degraded land	3	0.00b	0.00a	0.00d	-

Note: The letters mean statistically homogenous groups (Tukey post-hoc comparison).

3.6. Faxinalenses' Interviews

Figure 5 shows a conceptual diagram that summarizes the questions made and the information provided by the faxinalenses that were interviewed.

The reason given by the interviewees for the low number of applicants is the lack of support of the environmental authority in terms of money, extension and publicity, among other reasons. They do not perceive land degradation as a serious concern both for the economy and the environment at their farm's scale. They think faxinal will disappear because many faxinalenses are fencing some pieces of land for private purposes and they disagree with the fact of sharing communal land for grazing. The faxinalenses interested in the abandonment of the traditional management are those that own machinery (e.g., tractors) for agriculture.

There are some faxinalenses that believe their land would be more productive if the traditional management turned into commercial crops and others who need the communal land for their livestock for self-consumption in order to guarantee the survivorship of their families. The limiting factor for them is the reduced size of their farms. It prevents a higher profitability and, consequently, they cannot invest in machinery and other inputs.

The interviewees have proposed to the environmental authority a rigorous control of the number of animals, i.e., their stocking rates, as a solution to prevent land degradation. This lack of regulation is the source of the undesired problems already detected in spite of faxinalenses' refusal to admit their importance. It is aggravated by the lack of young people working in the faxinal farms. They prefer to live in big cities such as Curitiba (1.7 million people) and São Paulo (12 million people), or at least in smaller cities such as Prudentópolis (50,000 people), Irati (56,000 people) or Londrina (500,000 people), but not in rural communities.

Regarding strategies to preserve the traditional character of faxinal farms the interviewees agree it is necessary the participation of the authorities via subsidies because they think at least the management of the smallest farms (i.e., the core of the system) is not profitable. The municipality of Prudentópolis provides some financial support to farmers for environmental conservation but the problem, according to the interviewees, is that support is provided in the form of material and with the proposal of maintenance of agricultural infrastructures. They propose this budget arrives directly to the faxinalenses' bank account as compensation for keeping ecological services that are keys for the municipality.

In addition, there are laws for the protection of faxinals but they are not being respected. The faxinals are being sold at low prices due to low economic profitability and they are being bought by people who live in urban centers. The new owners are more worried about the conversion into commercial farming and recreation. In addition, their arrival creates other problems that are putting the sustainability of this centennial system at risk.
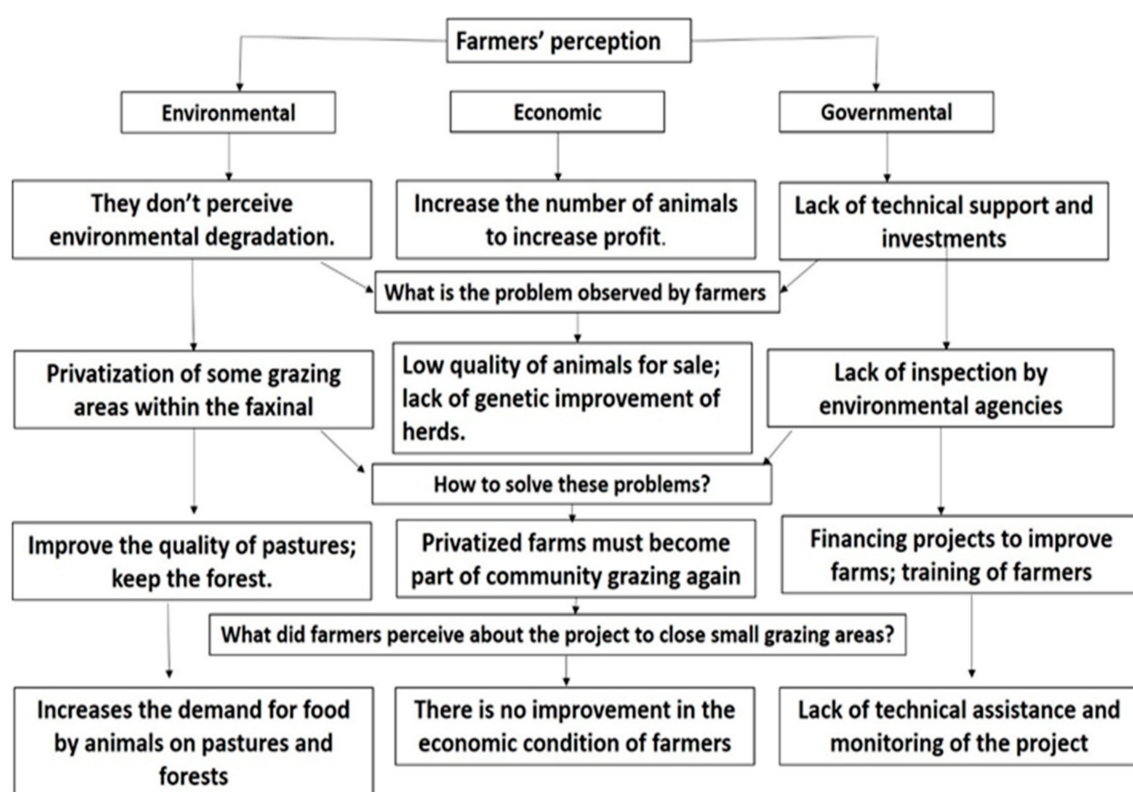

Figure 5. Conceptual diagram that summarizes the information provided by the interviewees.

4. Discussion

Regardless the opinion of faxinalenses, i.e., only interpreting field data, faxinal farms are currently facing serious problems of degradation—represented by the relative low values of soil penetration resistance recorded in the excluded area and native forest. In other words, grazing (with the current management) seems to be the main source of these problems. In this regard, penetration resistance

is an excellent indicator of soil quality, since it is highly influenced by the root density, among other parameters [6]; the absence or scarcity of roots leads to problems of soil compaction and a reduction in soil fertility. So, our findings are in agreement with similar works made in Brazil [19].

It seems that there is a cycling process that is difficult to understand and to explain. The IAP has proposed the grazing exclusion for environmental purposes. The faxinalenses have taken advantage of this exclusion to reforest with native *yerba mate* trees. The recovery of soil properties has therefore to do with the well-known natural cycles of grazing exclusion at the short term plus the presumably positive of effect of *yerba mate* trees (like absorption of nutrients and litter deposition).

Field data have confirmed that soil quality improves considerably after 10 years of grazing exclusion. According to Carvalho et al. [20], this improvement takes place as soil compaction is reduced because the active process of growth of herbs and grasses (root and shoot elongations) is not interrupted by grazing. In addition, plants provide soil organic matter and, consequently, the soil structure improves and more water and nutrients can be stored, so starting a positive environmental cycle in which land degradation is avoided.

Other important disturbance caused by grazing is the removal of litter, naturally accumulated on the soil surface [21]. Litter is a good nature-based solution to retain soil water due to its capacity to reduce evaporation, among other advantages [22]. This has been confirmed in the high values observed in the native forest, even at 10 cm in depth. The excluded area showed values of soil water 77% higher than in the grassland. It can be an effect of the recovery of vegetation through the reduction in evaporation and an increase in the capacity of infiltration; i.e., less water is released to the air and more is stored in the soil [23].

Grazing exclusion adds another positive effect from an environmental point of view: the reduction in land surface covered by animal paths. They are the effect of an increase in soil compaction, resulting in reduction of infiltration capacity and a serious soil loss by runoff after severe rainfall events [24]. This has already reported by many authors in similar environments [25], and this is the reason that grazing exclusion seems to be important to restore grazing lands. Soil compaction is usually assessed by the values of bulk density that increase as soil porosity decreases. According to Menezes [26], in a work carried out under comparable conditions, animal trampling causes soil compaction in the same magnitude than heavy machinery. This is commonly known and has already been reported by Greenwood and McKenzie [27] in other land systems.

The reduction in tree density can be also considered as a potential degrader of soil quality. In this case, grazed forests and grassland showed similar mean values of bulk density (range: 1.29–1.31 g cm^{-3}). This could indicate that grazing is the activity which most affects soil quality. Nevertheless, according to Pulido et al. [28] the effects of grazing are particularly visible in the top 10 cm. In this layer, some differences linked to bulk density have been observed. Cardoso et al. [29] found values much higher in similar environments after 3 and 19 years of continuous grazing. In our case, we can confirm soil compaction is significantly reduced at least after 10 years of exclusion.

The effect of tree is particularly remarkable in the mean values of soil organic matter, especially in the top 10 cm. This information provides a very interesting reflection, the exclusion of grazing improves physical quality of soil at the short term, but the plantation of trees is necessary because tree litter is the main source of soil organic matter. Contrariwise, Pulido et al. [21] found similar values in grazed areas between grasslands and woody rangelands, but it can be explained by the low tree density of holm oaks in the Spanish dehesas. This fact can be led by a better spatially distributed rooting system of grasses in soil profile in comparison to trees and shrubs—at least at the surface level in ecosystems dominated by water scarcity and shallow soils.

The values of root density found here are in accordance to that abovementioned. In this case, the reason behind these high values of root density in faxinal grassland is the root structure of the dominant grasses (*Brachiaria brizantha* and *Axonopus compressus*). These species are particularly important for avoiding soil erosion but it is not well-accepted by farmers, due to their low pasture quality/productivity [3].

The success of grazing exclusion has been supported in other ecosystems [30]. In this particular case study, the problem looks to be more focused, on one hand, on the conflict between farmers—big vs. small landowners; new owners vs. traditional owners—and, on the other hand, in the mutual disinterest between authorities and farmers. The first ones implement projects without pre-having consensus of the local farmers and without a program of support or monitoring, and the farmers do not believe a priori in the positive effects of the projects proposed by the authorities. Finally, these kind of projects should be interpreted as mechanisms to improve soil quality and consequently human health [31], and not as an imposition of the authorities.

The present paper presents a first attempt to study partial grazing exclusion as a strategy to reduce land degradation in the traditional Brazilian faxinal system. A more systematic study to investigate the partial grazing exclusion strategy may be needed to quantify the results of the present work.

5. Conclusions

Partial grazing exclusion seems to be an effective initiative to ameliorate the negative effects of the current land management of traditional faxinal farms, particularly in the top 20 cm of soil layers. Nevertheless, the plantation of trees also seems to be necessary in order to enhance the content of soil organic matter. The excluded areas improved considerably in terms of their physical conditions after 10 years of fragmentation. In spite of this improvement evidenced by our findings, faxinalenses believe that this kind of initiative does not make any sense, due to both the small size (<1 ha) suggested and the lack of economic support by the environmental authority. In fact, only 3 out of 54 faxinalenses have followed this program. In addition, farmers are not really worried about land degradation. They are more concerned about the survivorship of this land system because the current tendency is the abandonment of the communal grazing land by fencing for private use. Finally, it is confirmed that this IAP program is useful for recovering soil quality, but new initiatives agreed upon by the owners are much needed.

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