Chapter

Why Are Moss Biocrusts Necessary for System Conservation in a Semiarid Region of Southern Argentina?

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Abstract

The importance of biological crusts in arid and semiarid ecosystems has been widely recognized in the last decades, but their function is still not fully known, much less so in our country (Argentina) and region, where they have often gone unnoticed. Biological crusts appear in sites with a low level of disturbance and have a fundamental role in maintaining the soil surface structure. In the Monte ecoregion of Rio Negro province, Argentina, this layer is dominated by moss, and it is present in diverse physiognomic-floristic types of vegetation, but it tends to disappear in sites disturbed by grazing and by severe fires, and at sites where clearing methods were used to remove the soil surface. The multiple benefits that these crusts can provide to ecosystems justify the need to intensify the knowledge of their structure and functioning, to understand the particular role that they fulfill and to be able to manage these systems by taking this component into account.

Keywords: disturbances, water balance, seed bank, seedling emergence

1. Introduction

The vegetation that characterizes the southern Monte ecoregion is a shrubby steppe, and, as in other drylands, it is scarce and arranged in islands of vascular plants with large interspaces between them, covered to a greater or lesser extent by a herbaceous layer. The third functional group that accompanies the shrubs and the herbaceous layer is that of the biological crusts, which is globally known as a diverse soil surface community of cyanobacteria, algae, fungi, lichens, and bryophytes [1]. Research on these biological crusts has received considerable attention, especially since Belnap and Lange´s publication [2], so that knowledge about them has grown exponentially throughout the world, highlighting their sensitivity to global change. However, in South America, there are still gaps in the framework of that knowledge [3].

It has been widely accepted that succession in biological crusts follows a general pattern, starting with cyanobacteria and algae and concluding with bryophytes at the later successional stages, probably due to their greater hygroscopicity, higher growth rates, relative height, and deeper rhizoids [4, 5]. However, recent studies have proposed that mosses can be present from the initial phases of succession if the conditions are favorable [2, 6].

Several studies in recent decades have shown that this component of dryland ecosystems [7] is often not taken into account but has many important functions in the sustainability of these systems, such as aggregation of soil particles (resulting in soil protection), seed retention and germination [8], water infiltration [9], reduction of wind and water erosion [10], as well as nitrogen fixation [11–13], and carbon sequestration [14]. In addition, if a disturbed site is given time to re-establish the crust, it would also improve the results in terms of the establishment of seedlings [1]. Its role is especially important to maintain the stability of the soil surface against the impact of raindrops in those soils which, due to their physical and chemical characteristics, tend to form vesicular surface crusts [15] and favor desertification processes in the face of successive wetting and drying cycles. All these attributes allow us to designate biocrusts as “ecosystem engineers.”

In general, the effect of disturbances has been studied on the two most visible guilds of the Monte ecoregion (grasses and shrubs), although a rational management of natural resources should consider all its components, taking account of their function within the system. The biological crust has a fundamental role not only in the conservation of the superficial structure of the soil and the possibilities of regeneration of the herbaceous cover, but also in its contribution to biodiversity. In a States and Transitions model that we proposed [16], we were able to establish that the original system in the place where we carry out our studies was formed by two states that integrated a single domain of attraction and had a high resilience. The reduction of the herbaceous and biological crust layers, and the changes in the superficial structure of the soil, generated a distance from this domain of attraction, leading the system to other very stable states of lower productivity, and would be responsible for the advance of the desertification process.

Biological crusts in the eastern Monte ecoregion are dominated by moss, and their main species are *Syntrichia prínceps* (De Not.) Mitt. and *Ceratodon purpureus* (Hedw.) (**Figure 1**) [17].

Assuming that the presence of biological crusts would be associated with the lack of disturbances which is verified in more stable systems, some authors are using the presence of biological crusts as an indicator of the condition or “health” of grasslands [18–20]. In the same sense, Song et al. [21] concluded that biological crusts act as natural regulators for vegetation patterns and thus promote ecosystem stability and sustainability.

Concerning climate change, perhaps the most worrying and great environmental problem today, studies by Rutherford et al. [22] utilizing climate manipulation treatments suggest that the elimination of key species of mosses and lichens from the biological crust community may have dramatic effects on the biogeochemical and hydrological functions in drylands.

Also, the reduction in biocrust cover due to warming will lessen the capacity of drylands to sequester atmospheric CO_2. This decrease may act synergistically with other warming-induced effects, altering C cycling in drylands, and reducing soil C stocks in the mid to long term [23], which is one of the most globally valued functions in ecosystems today. In accordance with this, Durán et al. [24] propose the use of the specialized microbiome of biocrusts to be applied in a new environment to counteract the negative effects of climate change.

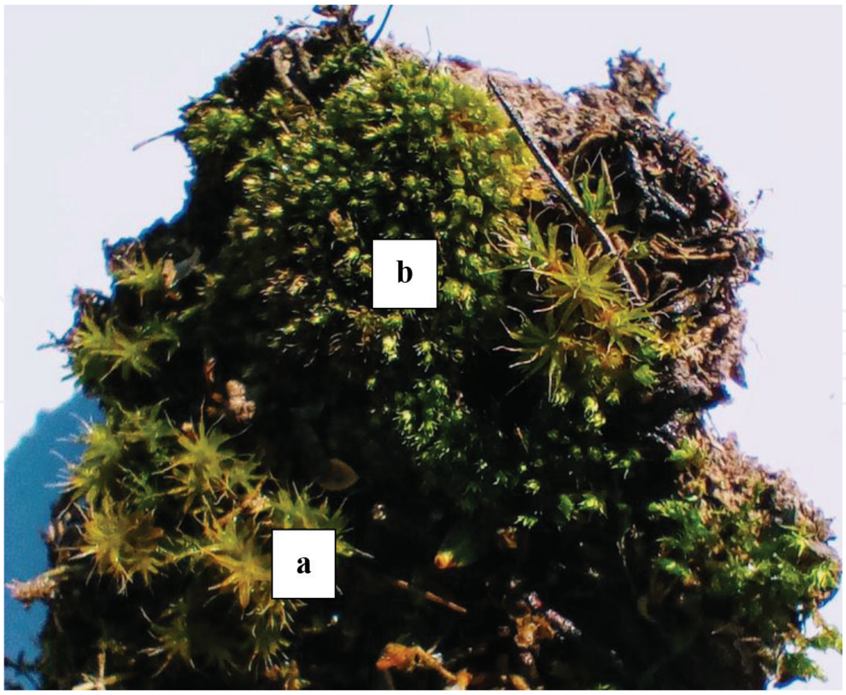

Figure 1.
Moss biocrust with Syntrichia prínceps (a) and Ceratodon purpureus (b) species.

Our concern in recent years has been trying to highlight the presence of moss in our ecosystem and to quantify some of its functions and how it is affected by the occurrence of disturbances at different scales.

2. Moss biocrusts functions

2.1 Soil protection

In the eastern Monte region, moss biocrusts cover a variety of soil surfaces, according to the physiognomic type of vegetation and the degree of disturbance affecting it, although these biocrusts are highly vulnerable to alterations by both natural and anthropogenic disturbances [25], and among these, domestic livestock trampling is recognized as the most widespread [26].

The trampling of grazing animals has a negative effect on arid and semiarid grasslands by causing fragmentation of the biological crust, and also, the loss of this crust and the herbaceous cover, contributing to an increase in bare soil, facilitating the processes of erosion, loss of nutrients, and the formation of vesicular crusts, which are difficult to reverse [27].

In addition, chaining used to remove the shrub layer increases the area that can be trampled by livestock, potentially generating an indirect negative effect on these crusts.

We studied the effect of some of those disturbances on the cover of moss biocrusts in relation to intact sites, and, as these organisms are of small size, it must be taken into account that microenvironments are often determining factors in their maintenance within those systems.

As described earlier, the vegetation of our region is grouped into islands with interspaces between them, which have different microenvironmental characteristics:

	Grazed	Ungrazed	p
Flat sites	19.90	46.89	<0.01
Mounds	32.13	38.98	ns
Total	26.49	43.87	<0.05

Table 1.
Mean cover of moss biocrust (%) in grazed and ungrazed areas, grouped according to their microtopographic location.

the islands constitute phytogenic mounds, where shrubs offer shade, protection, and nutrients to the vegetation growing underneath them, and the interspaces are flat sites more or less vegetated, with opposite environmental conditions (wind exposure, run-off, trampling access, and increased insolation). When we analyzed the differences in the cover of moss biocrust between both kind of sites under grazed and ungrazed conditions, we found a significant reduction in the flat sites between the shrubs, where trampling had an undeniable presence (**Table 1**). The lack of such difference in the mounds is strongly conditioned by the difficulty of access that shrubs impose on cattle, even though the whole field is being grazed.

The results of Yang et al. [14] showed that, in addition to the direct damage to the moss, there is a significant change in the environment that will affect it, because trampling disturbance increases carbon emissions from biocrust soils. These losses of CO_2 from biocrust soils after disturbance, in turn, may substantially reduce the biocrust contribution to the soil carbon budget.

We also found that, if a site was mechanically disturbed by chaining, in addition to being grazed, the cover was significantly reduced by about 33%, and, when we compared ungrazed and grazed conditions in a chained site, the reduction was of 36%, as we had found in another study [17].

In a previous trial where we compared the effect of clearing, fire and both disturbances occurring successively on the same site, there was a significant decrease in the moss cover with any of the disturbances (**Figure 2**), thus leaving more bare ground than in the control site [28] and confirming the general theory.

However, shrubs not only provide protection against trampling, but also they offer shady conditions which improve conditions for the development and survival of moss. On grazed sites, shading is due to the shrubs and other vascular plants that grow underneath them, but on ungrazed sites it is the grasses and herbs that form the intact herbaceous layer that mainly provides shading.

When we compared moss cover between sunny and shady sites in a field with small shrubs (as it had been cleared 3 years previously), we always found differences in favor of shaded sites, regardless of whether or not the environment was grazed (**Table 2**).

Although, when we compared the sunny and shady sites with each other, we did not find any significant differences, suggesting that the degree of sunlight was more important than the location of moss in the environment and which functional group provided the shade. However, if the shading is too intense, the moss biocrust would be affected because the relationship goes from facilitation to competition: according to Zhang et al. [29], vascular plant communities can affect biocrust development, composition, and function through canopy shading, although a dense canopy can deprive crusts of adequate light for photosynthesis.

To analyze the effect of mechanical removal, we carried out a trial where we compared the soil cover at a site with complete removal of the shrubs (clearing) and

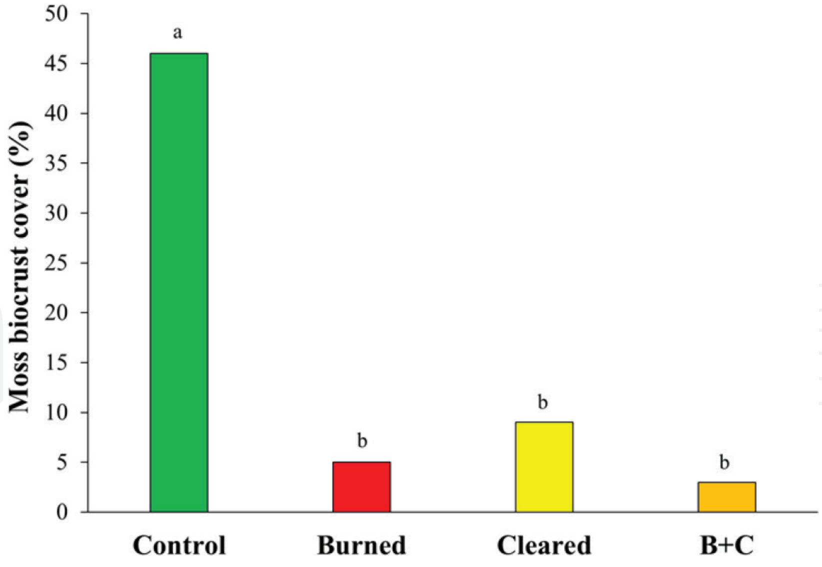

Figure 2.
Moss biocrust cover (%) in three disturbed sites (burned, cleared, and burned + cleared) and a control site. Lowercase letters indicate significant differences (p < 0.05).

		Ungrazed		Grazed	
Site		**ẋ ± SE**	***p***	**ẋ ± SE**	***p***
M	Sun	18.1 ± 9.8	0.05	21.2 ± 4.0	0.013
	Shadow	39.2 ± 5.4		42.4 ± 4.7	
F	Sun	28.3 ± 4.1	0.01	19.4 ± 3.1	0.025
	Shadow	53.1 ± 6.2		34.6 ± 6.3	

Table 2.
*Moss biocrust cover (%) in sunny or shady locations of mounds (M) and flat (F) sites, ungrazed or grazed in the same field, with the level of significance of the differences between them (**p**).*

a partial one (thinning) with an intact site (Monte), in a closed area and another area grazed for 3 years. Every year we found the same situation repeated: the intact site significantly outperformed the modified ones, and the thinned site outperformed the cleared one, showing a graduation of damage as the level of shrub removal (small-scale disturbance) increased. There were no differences between years ($p = 0.16$), or between grazed and ungrazed sites ($p = 0.078$) (**Figure 3**).

In addition to trampling and mechanical removal, another disturbance of great magnitude on the cover of moss biocrust is fire, although the damage will depend on the severity of the fire. *Ceratodon purpureus*, in particular, can resist high temperatures and apparently can resume its activity when humidity conditions allow, as we have noticed in the field. After a fire season in the region, Bran et al. [30] analyzed the effects of fire severity on the vegetation, classifying sites with a burn severity index (SI) established visually into categories from 0 (unburned control) to 5 (maximum severity) depending on the remaining standing biomass of the shrub layer. In unpublished data from that paper, Cecchi (*pers. com.*) found a strong subsequent reduction in moss cover in relation to the degree of severity of the fire (**Figure 4**). It can be seen that, from severity level 3 ("shrubs with most of their structure standing, branches of less than 0.6 cm in diameter conserved, leaves

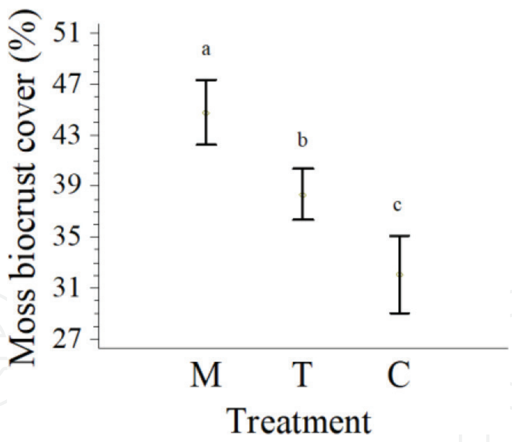

Figure 3.
Moss biocrust cover (%) in three vegetation situations, control (M), shrub clearing (C), and thinning (T). Lowercase letters indicate significant differences ($p < 0.01$).

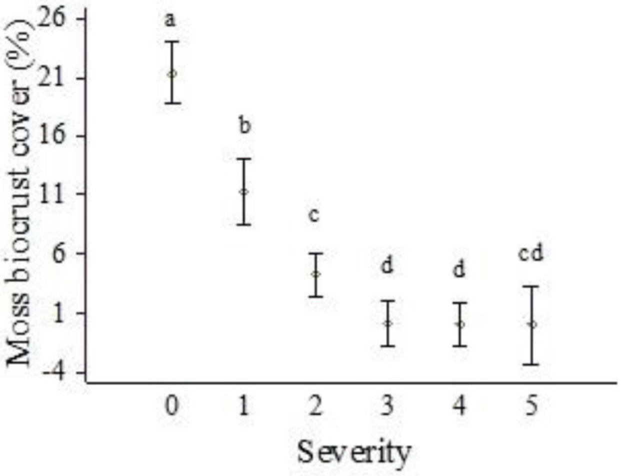

Figure 4.
Moss biocrust cover (%) in relation to increasing degree of burn severity. Lowercase letters indicate significant differences ($p < 0.05$). Source: Gustavo Cecchi.

totally destroyed by fire"), the damage would be the same and the moss coverage does not exceed 1%.

If the fire is severe, one of the results it produces is a redistribution of the sediments accumulated underneath the shrubs, homogenizing the soil surface, modifying the soil texture in the interspaces, and eliminating the sheltered sites provided by the shrubs and their nursing effect. This means that the moss biocrust will take some time to recover, and quantitative studies are still lacking in our region to be able to estimate how long that time could be. In this sense, Brianne et al. [31] performed a meta-analysis to gather information about the recovery of biocrust cover following fire at the global scale and highlighted the need to advance with that research across a broader geographic range.

Novel approaches for *ex situ* cultivation and inoculation are now being developed for using these communities in large-scale post-fire ecosystems restoration [32], thereby considering moss biocrust as a tool for accelerating soil restoration in semiarid ecosystems affected by wildfires [33].

2.2 Water balance

Mosses can use the surface moisture of the soil that appears in pulses in these systems and have rapid physiological responses [34], which would favor their primary productivity. In fact, they only need a short-wet time to recover their metabolic activity after a drought period and maybe this would allow them to be considered as "resurrection plants."

Positive influences of biological crusts on surface hydrological processes in semi-arid ecosystems have been documented by many authors [9, 35–37]. The roughness of moss biocrusts creates a larger surface for the detention of rainwater, so it contributes to increased infiltration in those sites where mosses are the main component of the biological crusts [5]. This can also reduce runoff and the risk of water erosion in sloping areas, since it decreases the kinetic energy of the water and therefore its erosive force [38].

Since the observations of St. Clair et al. [39], it has been known that the loss of moss biocrust of the soils surface due to disturbances can affect infiltration.

To evaluate water content in the field, we extracted superficial cores in sites with and without moss biocrust and weighed them following the gravimetric method, after removing moss present of the surface. We found significant differences in water storage between both the two kinds of surfaces (**Figure 5**).

Also, to evaluate the effect of the moss biocrust on the water storage capacity and on water evaporation more accurately, we extracted undisturbed soil cores from an exclosure in spring, either with or without moss biocrust, placed them in pots to transfer them to a greenhouse, and we repeated this trial in autumn [17]. Water storage capacity was significantly higher in the soil with moss biocrust than in the soil without mosses, for both dates ($p = 0.002$ and $p = 0.05$, respectively) (**Figure 6**).

In the first trial, we also calculated the daily loss of water by the difference in weight until no more evaporation occurred, and the water evaporation rate was lower with moss biocrust than without it. On that date, we also prepared the same number of samples extracting the moss layer (MB extracted), and we verified that the soil behaved in exactly the same way as that of the samples that preserved the moss

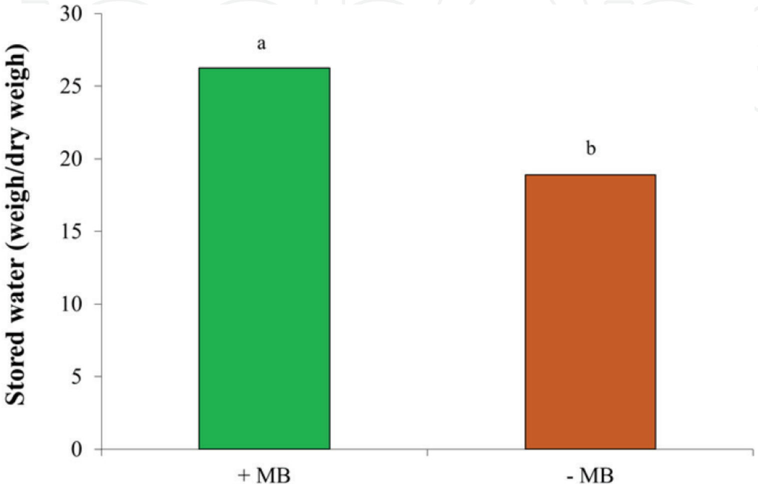

Figure 5.
Water content stored in samples with (+ MB) and without (– MB) moss biocrust. Lowercase letters indicate significant differences ($p < 0.01$).

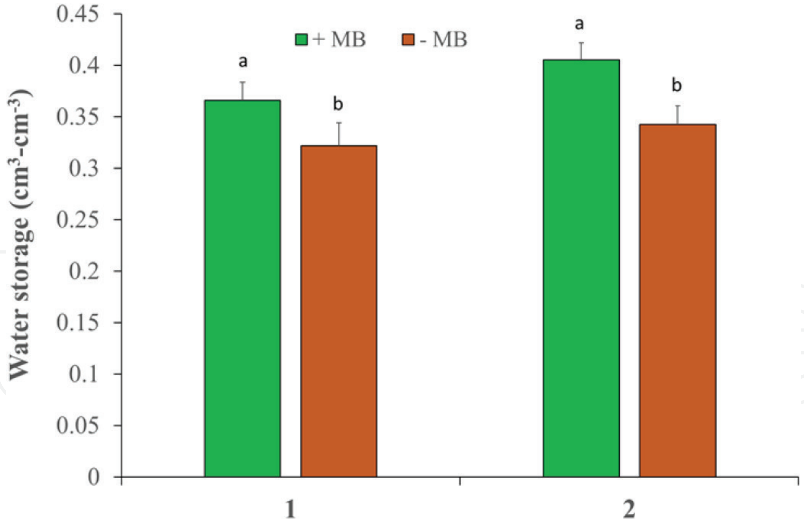

Figure 6.
Water storage (volume/volume) in samples with and without moss biocrust (+SE), for two sample dates (1: spring and 2: autumn). Lowercase letters indicate significant differences ($p < 0.01$).

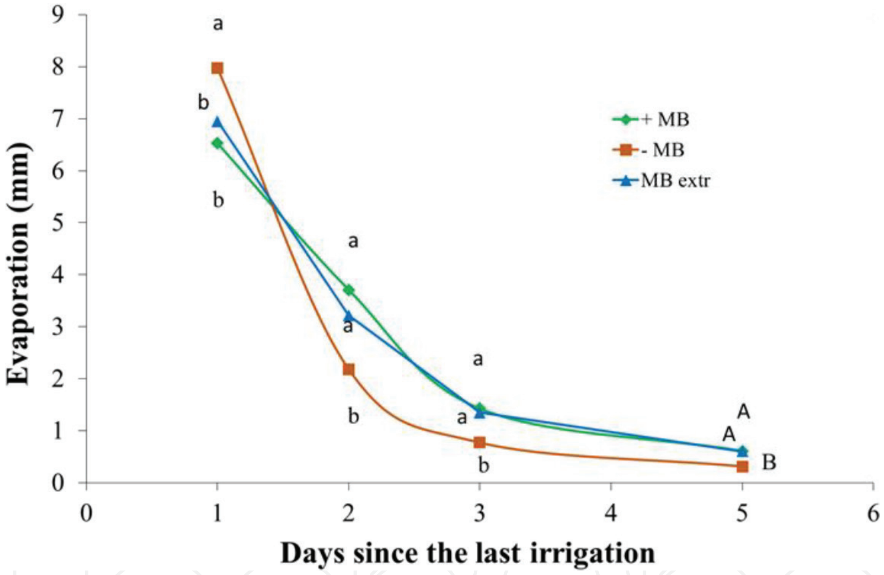

Figure 7.
Daily surface evaporation since the last irrigation for plots with (+MB), without (– MB) mosses biological crust, and with moss biocrust extracted (MB extr). Lowercase letters indicate significant differences ($p < 0.01$) and capital letters indicate differences at $p < 0.1$. Source: Gustavo Cecchi.

(**Figure 7**), showing that the water retention benefit provided by the mosses persisted initially, even when the mosses were no longer present.

Our results suggest that the sites with moss biocrusts have surface water storage conditions that could favor the germination and emergence of seedlings, maintaining the water balance as they have greater water availability and lower evaporation rates in the first centimeters of soil. This agrees with results found by Chamizo et al. [9], who concluded that biocrusts increase water input by increasing infiltration and soil moisture and reduce water output by reducing soil evaporation, thus eventually enhancing the water available to plants.

According to this observation, Bowker et al. [19] highlighted the importance of biological crusts development in arid landscapes, as they seem to be the most influential factor to reduce water erosion, and, also among the most manageable factor to achieve it through management practices.

2.3 Seed bank

It has often been seen that the introduction of herbivores in the Monte ecoregion has decreased the cover of grasses and their seed contribution, but very rarely has it been taken into account that these herbivores also reduced the cover of moss biocrusts, which would have provided suitable sites for seed germination, loading to the possibility of grassland regeneration. Some authors [39, 40] have already suggested that surfaces with biological crust constitute "safe sites" for the capture, germination, and establishment of seedlings, with greater humidity and more nutrients present, although it is not clear if all these processes are equally benefited. On the contrary, others (e.g. [38]) have observed that the cover of herbaceous species decreases with the increase in the abundance of biological crusts, and some even refer to them as weeds that compete with vascular plants [41].

In the Monte ecoregion, the dominant grasses are C3, and most are species of the tribe Stipeae. Two dominant perennial grasses of this tribe, *Nassella tenuis* (Phil.) Barkworth and *Piptochaetium napostaense* (Speg,) Hack, have a mechanism that allows their seeds to bury themselves in the ground during a rain, but, in order for the seeds to be able to be buried in that place, they must first be retained on the surface, awaiting the appropriate conditions. The surface roughness and the higher humidity of the biological crusts would provide the necessary conditions to retain these seeds and allow their anchorage.

To evaluate the effect of moss on the soil seed bank, we extracted soil samples with and without moss biocrust on the surface from the field with a hole puncher, and we removed the moss and the litter from them, then collected all the seeds of *Nassella tenuis* and *Piptochaetium napostaense* present in the samples by sieving and manual separation. The number of seeds buried in the first few centimeters of the soil was significantly higher for the samples with moss biocrusts than without, for both species evaluated (**Figure 8**).

In another field trial, we tested whether the moss biocrust acts as a seed trap, by laying a fixed number of intact propagules (seeds with sharp tips and twisted hydroactive awns) of *Nassella tenuis* on the surface of buried plastic rings, either with or without moss biocrust, after having manually removed all previous propagules [17]. We counted the seeds again 3 weeks later and found three times as many seeds in the samples with moss biocrust than without (**Figure 9**).

We repeated the field experiment of seed retention under greenhouse conditions supplying irrigation but with natural ventilation so that the seeds could potentially be moved by air currents inside it. Although this test was repeated twice, in spring and autumn, both times the samples with biological crust retained three times more seeds on the surface of the soil than the uncrusted plots ($p < 0.001$) (**Figure 10**), as had occurred in the field trial.

Our data contrast with those of Li et al. [42], who concluded that vascular plant seeds are not retained on the smooth moss-crust surfaces in windy environments, although our natural environments are very windy and, despite this, we found that the seeds were retained effectively, not only in the greenhouse trial. What remains to

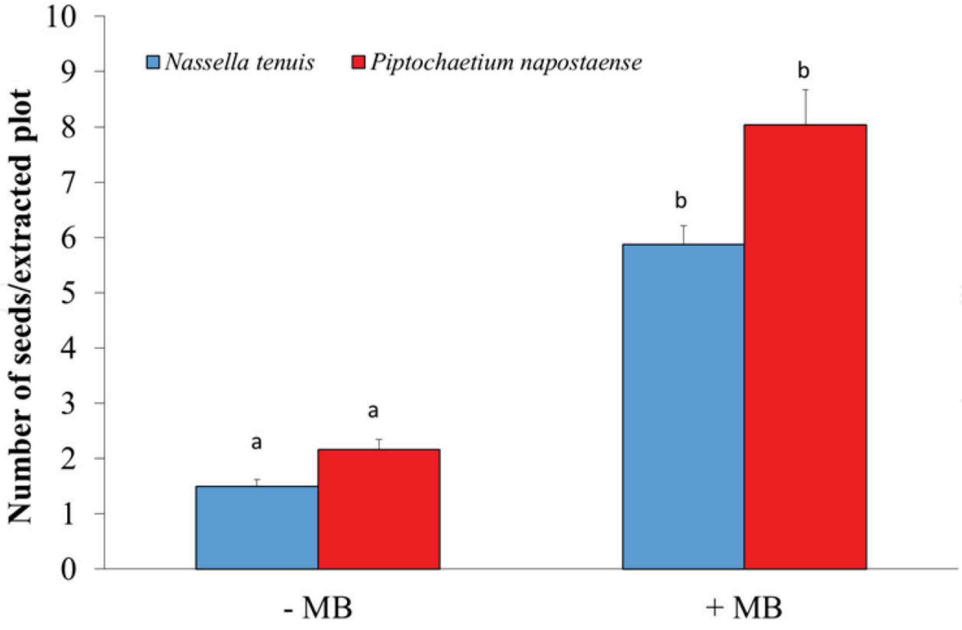

Figure 8.
Number of seeds per plot + SE of two grass species found in plots of 156 cm^3, with and without moss biocrust. Lowercase letters indicate significant differences (p < 0.0001).

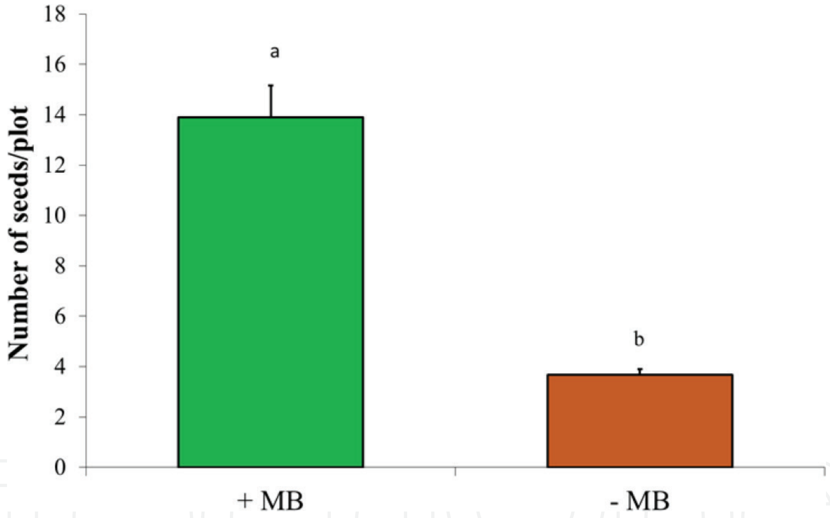

Figure 9.
Number of seeds of Nassella tenuis per plot of 45 cm^2 (+SE) with and without moss biocrust, retained after 3 weeks in the field. Lowercase letters indicate significant differences (p < 0.0001).

be tested is what happens with seeds of different sizes and shapes, since we have only analyzed what happens with dominant forage grass species.

2.4 Seedlings emergence, growth, and survival

If the seeds appear to be retained within the crust, what happens with their germination and the growth and survival of seedlings in that layer? There is no clear evidence about whether biological crust is a prerequisite for the development of higher plant cover or *vice versa*, or whether both processes occur simultaneously.

In a previous study [43], we found a greater number of seedlings in sites with moss biocrusts than without them, especially on flat surfaces between shrubs. This led us

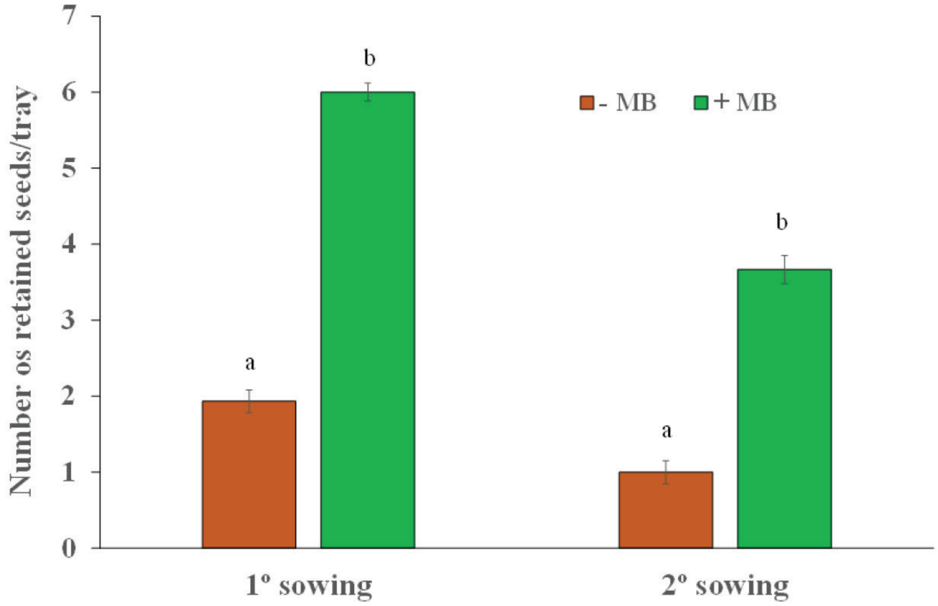

Figure 10.
Number of seeds (ẋ ± SE) of Nassella tenuis retained on the surface of metallic trays of 375 cm² with (+MB) and without (−MB) moss biocrust, for two sowing dates. Lowercase letters indicate significant differences ($p < 0.001$).

to evaluate the survival of grasses in relation to the presence of moss biocrusts, so we carried out a trial in two different conditions, one in the field and the other under greenhouse conditions, with pots extracted from the field.

In the field trial, we marked *Nassella tenuis* seedlings within small plots with and without moss coverage and counted the number of tillers and leaves appearing during 8 months throughout the spring and summer. We found no significant differences in those variables between the two kinds of sites over that period, as we had expected ($p > 0.1$), given that it is known that the dark colors of many biological crusts would produce a more rapid rise in soil surface temperature in spring [44] which would contribute to accelerating germination, seedling growth, and the phenology in general of the vascular plants associated with them.

In the greenhouse trial, we watered the extracted pots up to field capacity until the seedlings germinated and then we interrupted irrigation; after a drying period, we watered the pots again and compared seedling survival. The emergence percentage was very low and did not differ between the two treatments ($p > 0.1$), but, growth, measured as number of tillers (**Figure 11**) and leaf length of seedlings (**Figure 12**), was significantly higher in pots with moss biocrust. Furthermore, 78% of the seedlings with moss produced new tillers *vs*. 65% of those without moss. In addition, seedlings leaf growth rate was significantly higher ($p < 0.0001$) in plots with moss biocrust [17], although seedling survival was similar in both treatments ($p > 0.1$).

When we analyzed the relative growth rate (RGR) in relation to leaf length, we found very strong relationships between them ($p < 0.0001$), but, although the negative trends were similar for both treatments, the seedlings growing in pots with moss biocrusts only reduced their RGR with longer leaf lengths than those in the samples without moss (**Figure 13**).

These results indicate that sites with biological crusts have surface water storage conditions that would favor germination by providing greater water availability and lower evaporation rates in the first few centimeters of soil. Once the plants were

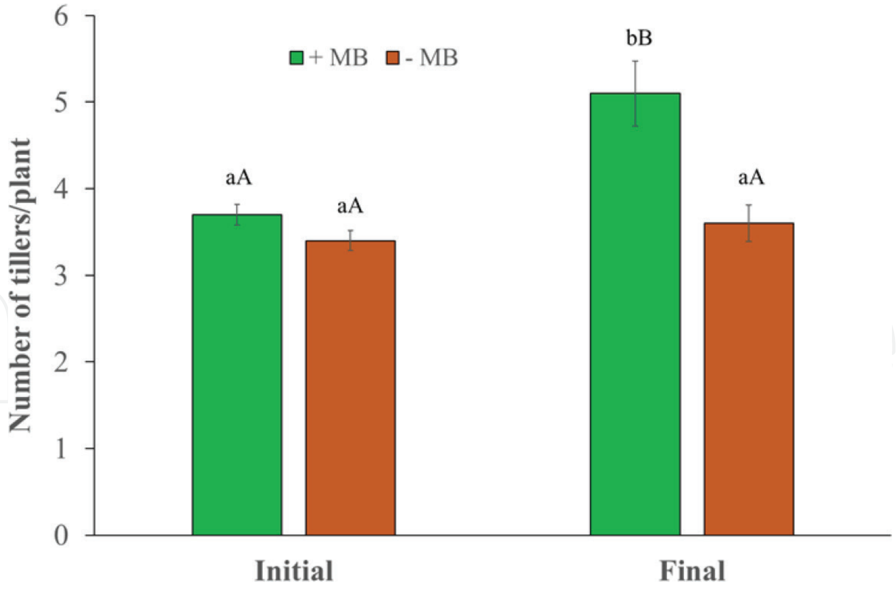

Figure 11.
Number of tillers (± SE), initial and final for plots with (+ MB) and without (− MB) moss biocrust. Lowercase letters indicate significant differences ($p < 0.05$) within the date and capital letters indicate significant differences ($p < 0.02$) between dates.

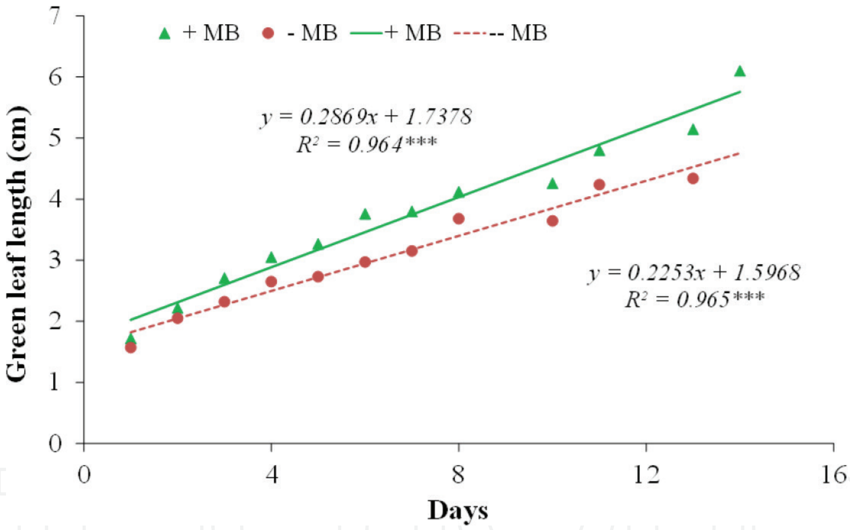

Figure 12.
Green leaf length of Nassella tenuis seedlings growing in pots with and without biological crusts in a greenhouse trial. Regression lines were highly significant ($p < 0.001$) and differ significantly between them ($p < 0.005$).

established, the pot trial suggested that plants growing on sites with biological crusts might have advantages in terms of increased growth rate; however, seedling survival did not differ between the two types of samples.

Trying to analyze plants survival in the field, we transplanted small plots with moss biocrust with and without seedlings of perennial grasses. We only watered them initially, at the time transplantation, then we left the pots subject to natural climatic conditions. A particularly dry period began after transplanting, so, a month after transplanting, we found that, although moss biocrust cover had prospered more in shady than in sunny sites (**Figure 14**), the patches generated by transplanting did not prosper homogeneously so as to allow measurements of seedling survival.

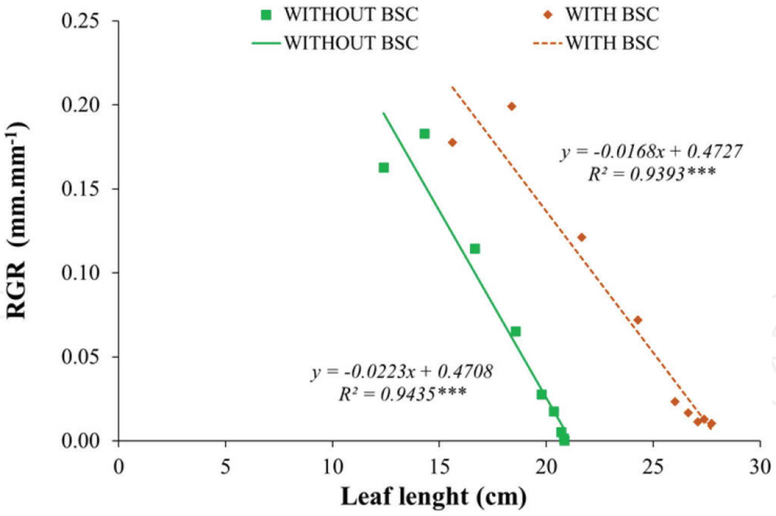

Figure 13.
Relative growth rate of Nassella tenuis seedlings with (+ MB) and without (− MB) moss biocrust in relation to leaf length. Regression lines were highly significant ($p < 0.001$). Source: Gustavo Cecchi.

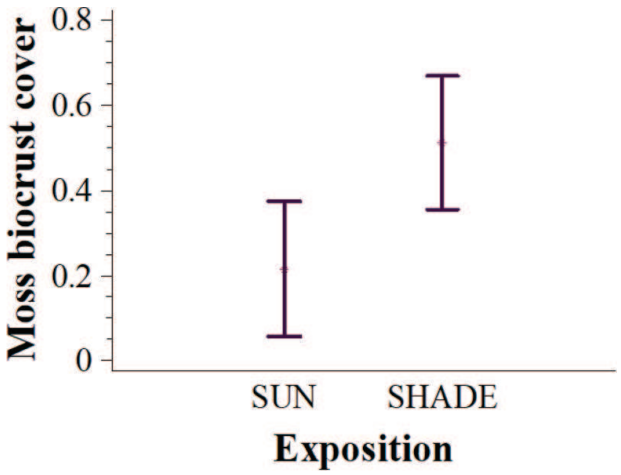

Figure 14.
Moss biocrust cover (arcsin percentage/100) of transplanted patches, in sunny and shady microsites of the field.

In general, we could only observe though not quantify that, as the survival of grasses and mosses was greater in the sites shaded by the shrubs than in the bare areas between them, the cover of moss biocrusts and the seedling density of the different species was not modified in the areas surrounding the transplanted patches.

This allowed us to visualize that, while biocrusts can be readily propagated under environmentally controlled conditions, rehabilitation in the field is complicated by environmental stresses which may be particularly acute in degraded, destabilized soils with harsh climatic conditions at the soil surface. However, it is a path that should be studied further, and certainly taking account of the most favorable period for transplanting in terms of weather conditions, and observing if these patches increase in soil coverage. In fact, today there are numerous efforts, by researchers and producers associated with them, trying to restore the crusts in drylands [45], and there is even a manual that synthesizes current information about biological soil crust restoration for resource managers making decisions on the ground (https://anitaantoninka.wixsite.com/biocrustrestoration).

3. Conclusions

In the eastern Monte ecoregion of Rio Negro province, in accordance with the results found by different researchers in other arid and semiarid regions of the world, the presence of moss biocrusts shows important functions related to the sustainability of the system, and this underlines the need to preserve them and even increase their coverage, in a way to contribute to the maintenance of ecosystem functions and mitigate the risks of climate change.

We have seen that disturbances of different scales, from livestock trampling to the removal of the shrub layer that may occur due to the action of man or the occurrence of wildfires, can affect moss biocrust cover. In the latter case, the damage will depend on the intensity of the fire. The use of an effective way to achieve moss biocrusts for ecosystems restoration should probably be studied further.

Regarding the use of water, this kind of crusts would improve infiltration, and therefore, the availability of water for the seedlings that may emerge there, in addition to the benefit that humidity provides to biocrusts themselves by allowing them to rapidly photosynthesize at the slightest wetting. The soils of our region are mostly clayey, with heavy textures, which favors their water retention capacity (in fact, the producers of the region refer to them as “bearing” soils), and this can be increased by the greater infiltration and less evaporation provided by the moss biocrusts.

On the other hand, the precipitation regime in our system is mainly autumn-winter-spring, which is different from other arid or semiarid ecosystems worldwide in which the main precipitation takes place in summer as torrential ones. The more extended period and the lesser rainfall intensity can contribute to water retention by these biocrusts, and this, added to the predominant soil’s types mentioned, was reflected in the prolongation of the benefit that they contributed in terms of the lower evaporation that we found in pots with moss biocrust already extracted. These characteristics are also important when considering the reduction of water erosion risks in the system.

The greater humidity that moss biocrusts can conserve would also influence their possibilities of retaining seeds, and offering a favorable first environment for the emergence of seedlings and their initial growth. Perhaps, this humidity is the factor which reduces the risk of the seeds being blown away by the action of strong winds. Although we found beneficial results regarding seed retention, perhaps the benefit depends on the size and shape of the seeds that can fall within the biocrusts, and it would be necessary to determine if, at some point, the facilitation provided by moss biocrusts could be transformed into competition.

Apart from the researches previously mentioned that need to be deepened, our “black holes,” in terms of regional information, are related to the contribution of moss biocrusts to nitrogen fixation and carbon sequestration, which should constitute future lines of research.

But there is no doubt that moss biocrusts should be taken into account when considering management practices for these systems, and the idea that their presence is a symptom of the “health” of these grasslands should be incorporated by both the researchers and producers.

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We carried out many of these trials with my husband, Gustavo Cecchi, who passed away long before seeing them written and published, although some of the hypotheses belonged to him.

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