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Accelerating Capoeira Regeneration on Degraded Pastures in the Northeastern Amazon by the Use of Pigs or Cattle

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Abstract: In the humid tropics of Latin America, considerable proportions of agro-scapes are covered with degraded pastures that were taken over by dense weedy shrub canopies hampering further forest succession. While tree seeds are still constantly dispersed by bats and birds, these often do not reach the soil but got stuck in the dense shrubby vegetation. While manual up-rooting of weedy shrubs or tree replantation is too expensive, we tested if burrowing pigs or trampling cattle can enhance proportions of bare soils for fallow restoration. These hypotheses were tested in on-farm experiments at Igarapé-Açu, northeastern Pará. Soil-opening effects of ten pigs (40 days + nights) and ten oxen (40 overnight stays), respectively, were tested against manual clearing and control on three plots per treatment, respectively. Ground cover percentages of bare soil, weedy shrubs, grasses, and tree species were visually determined in 40 plots/treatment before and directly after treatments, and half a year later (n = 480 samples). Both animal treatments could not really match manual clearing (62%) but pigs reached above 36% bare ground cover, while cattle just 20%. As pigs are almost omnipresent on Amazonian smallholdings and even give a modest economic refund, the use of pigs is recommended to smallholders who want to break up the lush weed layers for the benefit of forest restoration.

Keywords: secondary vegetation; forest fallow; animal impact; smallholder agriculture; pasture ecology; tropical pastures; juquira; pasture degradation; *Borreria verticillata*; *Myrciaria tenella*

1. Introduction

In many humid tropical Central and South American regions, cattle pastures are ecologically not sustainable but enter into notorious degradation processes, leading to unproductive pastures after only 7–10 years of use [1–3]. Pasture degradation is thereby a complex agro-ecological process that is often early induced, e.g., by poor pasture establishment, and later by neglected controls and management activities, missing investments, or simply by mismanagement. Decreasing soil fertility, bush-encroachment, water deficiency, insect pests, and infection of fungi are the main ecological consequences of these shortcomings. In addition, technical aspects, such as inadequate forage grasses, overgrazing, inadequate fertilization, and underutilization of legumes, are responsible for early unproductiveness of pastures. Additionally, unfavorable socio-economic conditions like poor technical support, low return yields, inadequate development policies, and unsecure property rights lead to unsustainable cattle husbandry in these regions [2,3]. In the end, depleted soils, decreasing forage grass restoration and reiterating fencing costs force smallholders to abandon their pastures because further investment is not profitable anymore, even in short terms [3–6].

However, degraded pasturelands are difficult to turn into another land use, be it for another agronomic purpose or for forest use [3,7–9]. As manual restoration activities are generally too laborious, economically risky, and expensive [10,11], smallholders often simply abandon these degraded plots, trusting in the substantial biomass accumulation of the lush forest fallows in the humid tropics [7,12,13]. This secondary vegetation might develop into valuable forest fallows again [7,8,12–15]. After a few years, they will also be an effective tool to get rid of noxious agricultural weeds, which get shaded out by forest fallows [16]. Naturally, the dispersion of seeds by animals like bats, birds, and/or rodents is responsible for forest restoration [14,17–23]. However, this natural process can be quite slow, even in the tropics, especially when lofty isolated trees get uprooted and the next forest patches are far away. These plots in fragmented forest landscapes often need 25 years at most and up to 40 years to produce a useful amount of biomass for a subsequent cropping phase and to insure a complete suppression of shrubby weeds [4,7,23–26].

Besides time since abandonment, the overall pattern of forest restoration on degraded pastures is mainly related to the intensity of land-use history and decreasing distance to the next large forest patches [7,17,23,27]. Restoration happens due to slow secondary forest regeneration and its respective above-ground biomass accumulation, especially by spontaneously growing legumes that partly fix atmospheric N in the soils (Table 1a). Thus, natural vegetation succession should be artificially accelerated or even bypassed by farming activities, for instance by planting tree species or multi-purpose legumes [6,28–32]. First experimental trials in that direction showed promising results by using woody legumes that showed remarkable establishment rates even under unfertilized conditions [11,17,33–35]. However, one main drawback of this strategy is that legume planting includes high-input activities and are expensive [10,11,33,36]. Another problem is that plantation of exotic legumes would not restore the high biodiversity of the natural secondary vegetation with its diverse ecological adaptations and regional important ecological services [37,38]. Thus, there is still a need for cheap low-input technologies on smallholdings to bring degraded pastures back into the phytodiverse fallow-based smallholder production systems.

Table 1. Lists of characteristic spontaneous native legume species (a), capoeira tree species (b), and juquira (c), ordered by its frequency on pastures in the northeastern Amazon, in its respective group.

Species Name	Plant (Sub) Family	Life-Form
a) Spontaneous Legume Species		
Zornia latifolia Sm.	Papilionoideae	herb
Mimosa pudica L.	Mimosoideae	herb
Stylosanthes gracilis Kunth	Papilionoideae	shrub
Senna chrysocarpa (Desv.) H.S. Irwin & Barneby	Caesalpinioideae	shrub
Mimosa quadrivalvis L.	Mimosoideae	herb
Machaerium madeirense Pittier	Papilionoideae	liana
Machaerium froesii Rudd	Papilionoideae	liana
Desmodium barbatum (L.) Benth.	Papilionoideae	herb
Desmodium canum (J.F. Gmel.) Schinz & Thell.	Papilionoideae	herb
Bauhinia guianensis Aubl.	Caesalpinioideae	liana
b) Capoeira		
Vismia guianensis (Aubl.) Choisy	Clusiaceae	tree
Lacistema pubescens Mart.	Lacistemataceae	tree
Myrcia sylvatica (G. Mey.) DC.	Myrtaceae	shrub
Myrcia deflexa (Poir.) DC.	Myrtaceae	shrub
Myrcia bracteata (Rich.) DC.	Myrtaceae	shrub
Banara guianensis Aubl.	Connaraceae	tree
Lecythis lurida (Miers) S.A. Mori	Lecythidaceae	tree
Abarema cochleata (Willd.) Barneby & J.W. Grimes	Mimosoideae	tree

Table 1. *Cont.*

Species Name	Plant (Sub) Family	Life-Form
c) Juquira		
Borreria verticillata (L.) G. Mey.	Rubiaceae	shrub
Myrciaria tenella (DC.) O. Berg	Myrtaceae	shrub
Borreria latifolia (Aubl.) K. Schum.	Rubiaceae	shrub
Stachytarpheta cayennensis (Rich.) M. Vahl	Verbenaceae	shrub
Paspalum maritimum Trin.	Poaceae	herb
Paspalum conjugatum P.J. Bergius	Poaceae	herb
Panicum pilosum Sw.	Poaceae	herb
Scleria pterota C. Presl	Cyperaceae	herb
Rourea ligulata Baker	Connaraceae	liana
Rolandra argentea Rottb.	Asteraceae	shrub
Rollinia exsucca (DC. ex Dunal) A. DC.	Annonaceae	tree
Hyptis atrorubens Poit.	Lamiaceae	herb
Imperata brasiliensis Trin.	Poaceae	herb
Emilia sonchifolia (L.) DC.	Asteraceae	herb
Ipomoea asarifolia (Desr.) Roem. & Schult.	Verbenaceae	liana
Borreria suaveolens G. Mey.	Rubiaceae	shrub
Andropogon bicornis L.	Poaceae	herb
Andropogon leucostachyus Kunth	Poaceae	herb

Therefore, the objective of this study is to restore the traditional forest fallow as the key agro-ecological basis for smallholder agriculture in the Amazon and perhaps the remainder of the humid Neotropics with low-input methods [12,13,39]. Traditionally, the whole sustainability of traditional smallholder agriculture in the Amazon fundamentally depends on this secondary forest, nationally called "capoeira" in Brazil. Its agricultural value is due to its dense woody regrowth of fast-growing secondary forest trees, herbaceous and woody lianas, shrubs, perennials, and herbs [12,33,37,40]. The prolific and mega-phytodiverse vegetation can accumulate up to 30 t/ha dry matter above-ground biomass in just four years and is traditionally slashed and burned or mulched for a subsequent cropping phase [40–43]. Thereby, the capoeira provides important habitat function for the indigenous flora and fauna and fulfills important ecological services in rural Amazonian regions [37,42,44]. Some of the most frequent capoeira species from the Bragantina region [12,37,45,46] are listed in Table 1b.

Traditionally, pastures without the possibility of re-sprouting capoeiras are defined as "biologically degraded pastures" [3,45]. They are ecologically characterized by chemically and physically depleted soils with low nutrient supply (especially in P and N), low cation exchange capacities, and high soil compaction [4,7,14,25]. The capoeira is almost completely uprooted and rather unpalatable native grasses, perennial herbs, herbaceous lianas, and shrubs that do not reach the biomass production of capoeira species are invading the areas [3,47,48]. This agricultural weed vegetation formation is locally called "juquira" in the Bragantina region. The most important juquira species (weedy shrubs) on pastures in the northeastern Amazon are *Borreria verticillata* (L.) G. Mey. (Rubiaceae) and *Myrciaria tenella* (DC.) O. Berg (Myrtaceae) but also contain other taxa (Table 1c). Unfortunately, biologically degraded pastures are not easily identifiable by remote sensing (patchy distribution; a similar spectral signature as intact pastures), but first attempts suggest that 8.6% (41,572 ha) of Bragantinian agro-scapes are covered with these weedy shrubs [49]. On these biologically degraded pastures, the main problem is often that arriving tree seeds never reach the ground for germination but are entrapped in the dense shrubby vegetation and thick litter layers [7,14,19–23,25,29,50–53].

However, experiences from other neotropical regions, e.g., on montane pastures in Colombia [54], showed that a new short-time overgrazing of cattle create small weed gaps and thereby facilitate seed establishment of capoeira trees. This low-input option can be intensified by keeping cattle overnight or by using other domestic animal species like goats, sheep, or pigs. Domestic pigs, for instance, are well known to open soils by their intensive burrowing activities, also in the humid tropics [55–57].

In Pará, there are almost 560,000 pigs that are distributed on 153,273 smallholdings. A typical example of the rural landscape is the municipality of Igarapé-Açu where 689 pigs on 103 farms during the livestock census 2006 and 2014 were registered [58]. These numbers elucidate that pigs are commonly present on smallholdings and are an integral part within the northeastern Amazonian smallholder production systems. Thus, ecological services of these omnipresent pigs can be theoretically used on farms, for instance for the benefit of fallow restoration.

Thus, we assume that the ecological services of domestic animals (cattle, pigs) can substitute expensive manual hoeing by farmers to accelerate capoeira restoration. In more detail, we hypothesize that pigs and cattle increase the portion of bare soil on the plots to the same extent as manual clearing by day laborers. Furthermore, besides predicting that pigs are more efficient soil-breakers than cattle, we also hypothesize that they reduce soil cover of grasses and the shrub-layers, and especially that of *B. verticillata* and *M. tenella*. Even more, we feared that pig effects could be so strong that the animals would even damage and/or remove the desired tree saplings and would reduce their ground cover percentages. In terms of soil bulk density, we hypothesize that cattle increase soil compaction by trampling and values are also higher than control, while pigs and manual clearing will loosen the upper soil layers and values will be lower than control.

2. Materials and Methods

2.1. Study Area and Experimental Design

To test these hypotheses, cattle (*trt1*) and pig treatments (*trt2*) were tested against manual clearing (*trt3*) and control (*trt4*; Figures 1 and 2). The experiment was replicated on three different smallholder farms (blocks) in the center of the Bragantina region, at Igarapé-Açu (1°03′ S and 47°30′ W), northeastern Pará, northern Brazil (n = 3 farms; n = 12 plots; n = 480 subplots). The region belongs to the per-humid warm low-land tropics, with a mean annual temperature between 21.0–22.3 °C and rainfall between 2000–2847 mm/year [12,37]. The rainy season lasts from January until June, while the dry season from July until December. The driest months October and November have less than 50 mm, respectively [37]. During the experimental time (August 2007 until May 2008), typical temperatures and rainfall patterns were observed. However, November, not October as usual, was the driest month in 2007 with just 2.6 mm rainfall. Therefore, December received more than the double amount of rainfall than the mean (231 mm instead of 110), and April 565 mm instead of 400 mm (mean), while the other months of the rainy season showed values minimally below the annual mean [59,60]. Typical soils of the region are poor Oxisols, Ultisols, and Entisols, characterized by a mean pH of 4.5, low nutrient fertility, especially in P and N, and a low cation exchange capacity [12,41,42,61].

Between August 2007 and May 2008, on each block (replication farm), 2 ha big plots of relatively homogenous biologically degraded pastures were selected and subdivided into four 0.5 ha (50 × 100 m) plots for treatment establishment. All plots had the similar land use history, typical for the Bragantinian rural region: after slashing-and-burning 4–10 years old capoeiras, crops like maize or beans had been cultivated for one or one-and-a-half years. Thereafter, traditional mixed *Brachiaria*-pastures were established which were then yearly slashed back from infesting juquira. As this was done for the last 8–10 years, forage grasses and capoeira trees were also increasingly eliminated by slashing and burning, so that mainly the robust juquira vegetation remained on the plots. Consequently, our selected plots were mainly dominated by *B. verticillata* and *M. tenella* shrub cover (Figure 1d). All treatments were fenced with five strands of barbwires, just *trt2* receiving three strands more at the bottom to secure pigs on the plots. Animals were supplied with water and fodder ad libitum (pig fodder up to 7 kg/day plus kitchen scraps of the respective smallholding; around 0.5 kg/day for piglets). Palm-roofed shelters for pigs were located in one corner of the respective plots.

(**a**)

(**b**)

(**c**)

(**d**)

Figure 1. Illustration of the four treatments: (**a**) mixed-bred cattle (upper left photo); (**b**) domesticated pigs (upper right; in front of the pig there is a *B. verticillata* weed); (**c**) manual soil opening (lower left) with hoes and tolerated capoeira trees in front of the day laborers; (**d**) control (lower right) = biologically degraded pastures, with just typical shrub vegetation of *B. verticillata* and *M. tenella*. In the right background, an example of a capoeira can be seen.

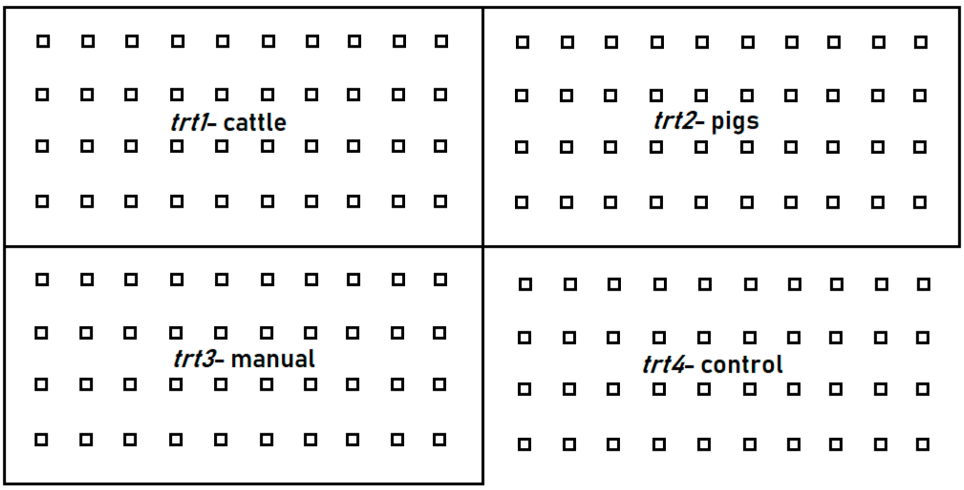

Figure 2. Design of the experimental plot with the four treatments (*trt* = subplots) of which three were fenced + control (unfenced). This design was repeated on three different smallholder farms in the Bragantina region. Within the subplots, there were four rows of ten sampling plots that were investigated at three different times (n = 480).

For *trt1*, ten mixed-bred cattle, including phenotypic characteristics of *Holstein-Friesian*, *Nelore*, and *Gir* breed (Figure 1a), with a mean body mass of around 400 kg, were put for 40 nights on the subplot in November 2007, between 6:00 p.m. until 8:00 a.m. Each block had its own herd of cattle and stocking rates were at 20 animals/ha (800 kg/ha) for the nighttime. The intention was that, during the early morning hours and also during the resting evening hours, cattle would roam through the degraded pasture to graze the remaining forage grasses and provoke a breaking-up of the juquira layers. During the days, animals grazed outside the experiment on distant pastures.

Trt2 received a pig family of domesticated pigs of the local Landrace breed of Pará, characterized by black skin spots (Figure 1b), for 40 days and nights. Three different pig families were put on the respective block in November 2007, December 2007, and January 2008. The pig family consisted of 11.7 animals (mean), with 2–3 adults, 3–4 piglets, and 5–6 baby piglets. Pigs were not withdrawn from plots in the daytime like cattle, as this was inoperable for farmers. Cattle could not stay on the degraded pasture plots during the daytime, as there were not sufficient forage grasses for animal alimentation. *Trt3* was manually cleared by day laborers with the help of hoes (Figure 1c). Workers were advised to open the soil and uproot the weedy shrubs but neither to eradicate young capoeira saplings, nor lofty isolated seed trees (Figure 1c) nor the spontaneous herbaceous legume layer. Litter remained on the plots. The number of workers and hours/ha are indicated in the result chapter. *Trt4* was control and was not altered. Plots were not fenced, as accidentally roaming cattle or wild herbivores belong to this traditional smallholder treatment. However, wild herbivores are extremely rare in the region.

2.2. Vegetation Sampling

The following six parameters were raised by estimating ground cover percentages of (a) bare soil, (b) *B. verticillata*, (c) *M. tenella*, (d) grasses- including remaining *Brachiaria* forage grasses but also all native spontaneously growing grasses (Table 1c), (e) native herbaceous legumes (cf. Table 1a), and (f) shrubs—all other weedy shrubs, lianas, and herbs, excluding *B. verticillata*, *M. tenella*, grasses, and herbaceous legumes. All variables were sampled at three times: *time1* = before treatment from August until October 2007, *time2* = directly after treatment effects in February–March 2008, and *time3* = half a year after last treatment impact, in September–October 2008. Additionally, the number of tree individuals was counted, the mean of the heights of the five highest capoeira trees were calculated, and the ground cover percentage of native herbaceous legumes were estimated at *time1* and *time2*. These variables were used as an indicator for possible animal damages on the young capoeira during treatments. Due to the high heterogeneity of the juquira and capoeira portions on degraded pastures in general, an extraordinary high number of 40 sampling subplots, i.e., four random transects of ten single 6.25 m^2 sampling plots (2.5 × 2.5 m), with at least 5 m distance from fences and each other, were sampled for each parameter (Figure 2). Ground cover of bare soil and vegetation were visually estimated and categorized into eighth classes: 0.1–12.5%; 12.6–25%; 25.1–37.5%; 37.6–50%; 50.1–62.5%; 62.6–75%; 75.1–87.5%; 87.6–100%). Each class received a percent value for further calculation (the mean of the class): *class1* = 6.25%; *class2* = 18.75; *class3* = 31.25; *class4* = 43.75; *class5* = 56.25; *class6* = 68.75, *class7* = 81.25; *class8* = 93.75. To have a rough proxy for seed survival success (cf. 52), the number of capoeira saplings (<15 cm height) were also counted within the sampling plots at *time2*.

2.3. Soil Compaction

We measured soil compaction effects of the four treatments by using the hand penetrometer to 1 m (Eijkelkamp, Giesbeek, the Netherlands). In each corner of the 12 subplots, the penetrometer was pushed three times into the soil within a 30-cm diameter circle. To avoid experimental border effects, we kept a distance of at least 10 m from fences, and measured during *time1* and *time3* on all treatments. As we expected just significant animal effects within the upper soil layers, data of 2.5, 5, 10, 15, 20, and 40 cm depths were read out from paper sheets (n = 893). As thicker tree roots were still quite common on the plots, values of ≥5 MPa were removed from statistical analyses. Density data were analyzed for means, standard errors, and significant differences at $p < 0.05$. For each other parameter, the mean values plus standard deviation were calculated and differences were calculated for significance ($p < 0.05$) by conducting ANOVAs between treatments and times, using the "aov-procedure" of the interactive statistics platform "R" [62]. The following fixed linear model was used to represent the variation of differences:

$$Y_{tfi} = \mu + at_t + b_f + c_i + ab_{tf} + ac_{ti} + d_{tfi},$$

where Y_{tfi} = cover of bare soil, shrubs, *B. verticillata*, *M. tenella*, grasses, capoeira, legumes, number of trees, and tree heights:

μ = overall mean,
a_t = effect of treatment (i = *trt1*, *trt2*, *trt3*, *trt4*),
b_f = block effect (j = *farm1*, *farm2*, *farm3*),
c_i = effect of time (k = *time1*, *time2*, *time3*),
ab_{tf} = interaction of treatment and block effect,
ac_{ti} = interaction of treatment and time effect,
d_{tfi} = residual deviation.

For the variables "legumes", "number of trees", and "tree heights", data were determined just for *time1* and *time2*.

2.4. Economic Costs and Benefits

It was originally not intended to completely compare economical features of all treatments in this study. However, to show a rough proxy of the slight economic gains of pig production, these animals were weighed before and after treatment, calculating also total weights/0.5 ha. Values were then multiplied by 2.5 R$ (BRL), the actual pig price per kg in October 2007, additionally multiplied by 2 to reach gains per hectare, and multiplied by 0.5 to get the economic gains in US$ (USD). The currency exchange rate was taken on 30th of August 2007 [63]. Pigs needed three more strands of barbwires to be held on degraded pastures, which needed two men for 30 minutes more than for the other treatments. These additional fencing costs were calculated with 0.94 US$ for each block (15 R$/8 working hours = 0.94 R$ for half-an-hour, multiplied by two day laborers) and then subtracted from the economic gains of each block. Costs for manual clearing were calculated by counting the needed working days multiplied by 15 R$ daily wage and the number of day laborers for the respective farm in US$. It was not useful to surveil cattle weight gains, as these animals spend the daytime on non-standardized different pastures and because cattle gains were not of interest in this ecological experiment.

3. Results

The results of the ground cover changes of the most important parameters under treatments are shown in Figure 3. Comparing the four treatments of the bare soil values (Figure 3a) against each other at *time2* showed that all treatments had significant different values ($p < 0.0001$). As expected, day laborers achieved the highest clearing rates. However, as young target trees should be spared from clearing and not all inhibiting shrubs could have been completely eliminated in practice, values reached not more than 62.4%. Pigs reached a remarkably high value of 36.3% at *time2*. However, they could not match the *trt3*-values ($p < 0.0001$), meaning that our first hypothesis is rejected. Surprisingly, the soil opening effect of *trt3* did not last for long, but values dropped back to below 20% at *time3* and similar to that of *trt1* ($p = 0.611$). However, *trt3* at *time3* was also significantly different from the value of *time1* ($p = 0.0003$). In line with the bare soil parameter, some shrub-values decreased significantly, i.e., by *trt3* and *trt2* (Figure 3b). *Trt2* did not eradicate the shrubs to the expected extent and reached just values equal to *trt1* (p = 0.0692). However, while *trt1* impact did not get significantly different between *time1* and *time2* (p = 0.2), this was the case for *trt2* (p < 0.0001). Regarding the values of the *B. verticillata*-cover (Figure 3c), almost all values became significantly different between *time1* and *time2* (p < 0.0001). Just the values of *trt4* remained statistically the same during the three times (all p > 0.26). In addition, *trt2* stayed at the same level between *time2* and *time3* (p = 0.261). Besides *trt3*, there were no significant treatment effects observed on robust *M. tenella*-shrubs (Figure 3d). *Trt1* and *trt2* showed the same disappointing results and were significantly higher than that of *trt3*. Besides *trt4*, which stayed at the same level from *time1* until *time3*, all grass treatments (Figure 3e) became significantly different at *time2*, albeit *trt1* and *trt4* that were quite similar (p = 0.0271). However, all grass cover values of the three treatments recuperated fast, and *trt1*-*trt3* between *time2* and *time3* were all significantly different (*trt1*: p = 0.000129), so that all values became significantly higher than *trt4* at *time3*. There were some observations of grass sods, turned by pigs, starting to spread roots again. Unfortunately, pigs dug up some valuable young target capoeira trees while burrowing up the plots, as *trt2*-values of the capoeira-data (Figure 3f) decreased from 42.9% to 34.1%. Thus, *trt2* was the only treatment that had an almost significant impact on the capoeira (p = 0.000909). However, this seems to be just a side effect, as pigs did not intentionally destroy the target species but searched also the forested parts of the plots, after a few days.

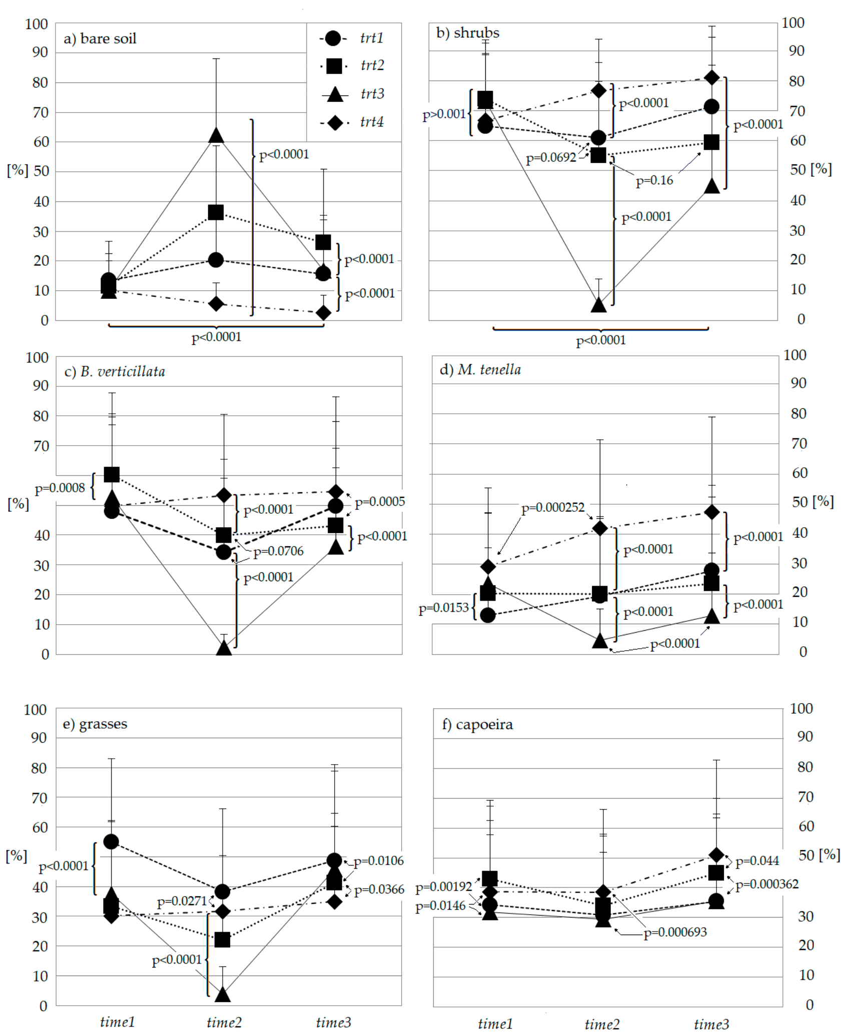

Figure 3. (**a**–**f**). Ground cover changes of bare soil, shrubs, *B. verticillata*, *M. tenella*, grasses, and capoeira trees of *trt1* until *trt4*, from *time1* to *time3* plus standard errors (n = 8640).

As it is predictable that this disturbance effect gets stronger the longer the animals stay on the plots, the animals should be withdrawn from the plots when the juquira is almost uprooted because there seems to be no other practical solution to keep the pigs from young desirable capoeira trees. However, young trees recuperated fast after impact on *trt2* and reached the level of *time1* (44.9%; $p = 0.451$). Day laborers paid enough attention to sparing young target trees, which was not always an easy task, as *B. verticillata* and/or *M. tenella* weedy shrubs sometimes grew together with capoeira trees at the same location.

At *time1*, on all treatments, the same number of tree individuals per 6.25 m^2 has been counted, except for *trt3*, which was significantly lower than *trt2* (Table 2). *Trt4* surprisingly decreased its values to 42%, probably due to the naturally closing shrub layers. The number of capoeira saplings was significantly lower on *trt4*, while all other numbers of saplings stayed at the same level ($p > 0.05$). Around 80% of the observed saplings of all treatments were of *Vismia guianensis* (Aubl.) Choisy (Clusiaceae) and around 5% of *Lacistema pubescens* Mart. (Lacistemataceae). Ground covers of herbaceous legumes were quite heterogeneous, indicated by the different values of the *time1*-values and high standard deviations (Table 3). However, after treatments, all legume values showed the same ground cover around 14.5% except for *trt3*, which showed almost the double amount (29.2%), as day laborers should spare legumes. On *trt4*, legume cover decreased significantly which might be due to out shading effects of the growing values of shrubs, *M. tenella*, and capoeira covers (cf. Figure 3). Results of soil compaction showed a significant increase of values with time, except the values in 2.5 cm of control and in 40 cm depth of *trt2* (Table 4). *Trt1* showed significant ($p < 0.05$) surface compaction after treatment in the upper 2.5 cm-soil layers. *Trt2* showed significant higher not lower values, and values after treatment were statistically the same as *trt4* (all $p > 0.05$). The number and mean weights of pigs are shown in Table 5. After the subtractions of the additional barbwire strand costs of 0.94 US$, therefore, the mean economic gain of the three farms was 682.39 US$/ha, reaching from 506.56 US$ to *farm2* until 814.06 US$/ha on *farm3*.

Table 2. Number of capoeira tree individuals/6.25 m^2, mean tree heights of the five highest trees at *time1* and *time2*, and mean number of capoeira saplings (just *time3*) plus standard deviations ($n = 3929$). $^{a–c}$ Values in the same column with the different superscript letters are significantly different from each other at $p < 0.05$. $^{1–2}$ Values in the same row with the different superscript numbers are significantly different from each other at $p < 0.05$ (for capoeira tree number, mean tree heights, and capoeira saplings number, calculated, respectively).

	Capoeira Trees *time1* [#]	**Capoeira Trees *time2* [#]**	**Mean Tree Heights *time1* [m]**	**Mean Tree Heights *time2* [m]**	**Capoeira Saplings *time3* [#]**
	$n = 1440$		$n = 1129$		$n = 960$
trt1	5.84 (0.47) ^{ab1}	6.13 (0.54) ^{a1}	1.0 ^{a1} (0.6)	1.1 ^{a1} (0.4)	2.56 (2.8) ^{a}
trt2	7.07 (0.45) ^{a1}	6.42 (0.41) ^{a1}	1.3 ^{b1} (0.7)	1.3 ^{b1} (0.6)	2.64 (2.8) ^{a}
trt3	5.52 (0.40) ^{b1}	4.55 (0.45) ^{b1}	0.9 ^{a1} (0.7)	1.3 ^{b2} (0.4)	2.84 (3.0) ^{a}
trt4	6.52 (0.41) ^{ab1}	3.77 (0.29) ^{b2}	1.1 ^{a1} (0.6)	1.5 ^{c2} (0.5)	1.33 (1.8) ^{b}

Three day laborers on *farm1* needed nine days to do the work of *trt3* (=405 R$), while on *farm2* just four day laborers spent six days (=360 R$), and on *farm3* three day laborers seven days (=315 R$). Thus, there were mean costs of 360 US$/ha with a standard deviation of 45 US$. *Trt1* needed just some financial investments for the joint installation of the whole experiment. However, in reality, there would be just minor costs for farms, as cowboys just had to get cattle from the degraded plots in the morning and bring them back in the evening. This action would consume at maximum one hour per day, morning and evening herding together, which would imply (15 R$/8 working hours = 1,88 R$ per day), again 0.94 US$ extra-costs per day.

Table 3. Ground cover of spontaneously growing herbaceous legumes at *time1* and *time2* plus standard deviations (n = 3929). $^{a–c}$ Values in the same column with the different superscript letters are significantly different from each other at $p < 0.05$, $^{1–2}$ Values in the same row with different superscript numbers are significantly different from each other at $p < 0.05$.

	Legume Cover *time1* [%]	Legume Cover *time2* [%]
	n = 1360	
trt1	6.9 ^{a1} (11.0)	14.4 ^{a2} (19.4)
trt2	15.6 ^{b1} (20.6)	15.4 ^{a1} (18.5)
trt3	20.3 ^{bc1} (25.1)	29.2 ^{b2} (27.0)
trt4	24.0 ^{c1} (28.4)	14.4 ^{a2} (19.7)

Table 4. Soil bulk densities [MPa = 100 N/cm^2] at *time1* and *time2* in six different soil depths with standard errors in brackets (n = 893). $^{a–d}$ values within the same depths (*time1* + *time2* together) with different superscripts are significantly different at $p < 0.05$ (experimental unit n = 3).

	time1			
Depths	***trt1***	***trt2***	***trt3***	***trt4***
2.5 cm	1.88 (0.13) ^{a}	1.95 (0.13) ^{a}	1.71 (0.14) ^{a}	2.05 (0.14) ^{a}
5 cm	2.07 (0.13) ^{ab}	2.21 (0.13) ^{ab}	1.82 (0.15) ^{a}	2.25 (0.12) ^{b}
10 cm	2.21 (0.13) ^{ab}	2.37 (0.11) ^{a}	1.90 (0.16) ^{b}	2.43 (0.10) ^{a}
15 cm	2.18 (0.13) ^{ab}	2.32 (0.16) ^{ab}	1.90 (0.16) ^{a}	2.40 (0.11) ^{b}
20 cm	2.12 (0.14) ^{a}	2.24 (0.18) ^{a}	1.68 (0.12) ^{b}	1.98 (0.14) ^{ab}
40 cm	1.56 (0.09) ^{a}	1.34 (0.17) ^{a}	1.38 (0.11) ^{a}	1.40 (0.05) ^{a}
	time2			
Depths	***trt1***	***trt2***	***trt3***	***trt4***
2.5 cm	2.95 (0.18) ^{b}	3.06 (0.19) ^{bc}	2.63 (0.19) ^{bc}	2.44 (0.15) ^{ac}
5 cm	3.04 (0.15) ^{cd}	3.51 (0.19) ^{bcd}	3.43 (0.20) ^{c}	2.84 (0.17) ^{bd}
10 cm	3.06 (0.14) ^{c}	3.77 (0.15) ^{c}	4.20 (0.18) ^{c}	4.01 (0.19) ^{c}
15 cm	3.26 (0.15) ^{c}	3.86 (0.17) ^{c}	4.05 (0.25) ^{c}	4.67 (0.14) ^{c}
20 cm	3.34 (0.20) ^{c}	3.61 (0.19) ^{c}	3.45 (0.27) ^{c}	3.42 (0.29) ^{c}
40 cm	2.51 (0.16) ^{b}	3.26 (0.22) ^{ab}	4,29 (0.19) ^{b}	4.21 (0.21) ^{b}

Table 5. Pig weights [in kg] at *time1* and *time2* with standard deviations in brackets.

	Number of Pigs	Mean Pig Weights [kg/pig]	Total Pig Weight before [kg/0.5 ha]	Total Pig Weight after [kg/0.5 ha]	Total Weight Gain [kg; %]	Economic Gain from Pigs [US$/ha]
farm1	14	20.1	281 (20.0)	572 (25.0)	291; +104%	727.50
farm2	11	24.0	264 (17.3)	467 (18.7)	203; +77%	507.50
farm3	10	29.8	298 (15.5)	624 (21.6)	326; +109%	815.00
mean	11.7	24.6	281.0	554.3	273.3	683.33

4. Discussion

The results mean that the use of domestic pigs, to break up the dense weed canopies (juquira), can be a promising and cheap option for Amazonian smallholders. Although pigs could not entirely match manual clearing with hoes, their impacts on bare soils and the weedy shrub vegetation were considerable in major parts of the plots which, however, is not so striking in the presented data. The presentation problem was that pigs burrowed the soil not as evenly as day laborers but were most active along fences and in corners of the plots. Here, they cleared almost the complete area, showing strong border effects. However, as agricultural experimental stations, in general, are designed to try to blank out border effects, like it was also intended in this trial, the burrowing effects of pigs are therefore underrepresented in the data. Next to corners and fences, the animals showed also excellent clearing results around their shelters and along animal tracks, which was done as efficiently as by manual hoeing. While human activity is rather expensive, pigs returned at least a modest economic gain during the same time by gaining weight. However, these gains are mainly caused by additional feed supply that was provided, as it is usually done on smallholdings. It remains unclear how much pigs really foraged from degraded pastures and how much the provided feed contributed to weight gains. Data also indicate that *trt2* kept open the bare soil patches for a much longer time than *trt1* or even *trt3*, enlarging the period of favorable conditions for sexual reproduction of the capoeira trees, i.e., seed-germination and seedling growth of target tree species.

Vegetation succession and development after *trt2* are well known to be highly dynamic and heterogeneous and usually showed a significant increase of species richness [55–57,64]. Some experiences from the humid tropics showed that pig-scarification can even lead to an establishment of special pioneer tree species [57,65]. However, most of the benefiting plants are noxious weeds that are well adapted to unstable and dynamic environments [56,57,64]. Although grass and *B. verticillata*-layers were significantly reduced, *trt1* impact was negligible and open spots were distributed rather patchy on the plots. Therefore, ecological effects were not strong enough to induce considerable open areas for tree regeneration, and, on the few open patches, soils got more compacted by trampling or resting cattle (Figure 4a; see below). It remains to be seen if the additional dung import from adjacent pasture grazing during the day will enhance at least capoeira seed rain via cowpats. Nutrients, however, are expected to be imported by both domestic animal species, in the case of pigs via fodder or by the organic household wastes.

(**a**) (**b**) (**c**)

Figure 4. Selected examples of effective soil opening effects of the treatment (without control): (**a**) *trt1* (left) trampled patches inside the plots during staying overnight; (**b**) *trt2* (centre) burrowed the soils especially along the fences; (**c**) *trt3* (right) with spared young target trees of capoeira succession and remaining litter on the ground.

Our soil compaction data revealed the well-known trampling effect of cattle that lead to compacted upper soil layers [14]. However, soil compaction by *trt1*, as made evident by soil physical properties, can be accepted just for the 2.5 cm variables, i.e. surface compaction. It should be also noticed that *trt1* started from the lowest value of all treatments in the 2.5 cm-layer (e.g., 1.88 MPa). *Trt2* did not show the desired effects, as soil compaction was higher after treatment effect and the same as control (all $p > 0.05$). This *trt2*-effect can be probably explained by the above-mentioned border effects, as pigs preferred to mainly burrow along fences and started from slightly higher values (Figure 4b). Values of manual clearing were mostly in between the other treatments but showed much higher values in the 5-cm layer, probably due to the fact that the uppermost soil layer was scratched by day laborers to eliminate the juquira (Figure 4c). Significant higher compaction values on all treatment might be explained by season, as soil compaction often depends on the soil moisture contents and thus on rainy or dry seasons [14,19,42]. The period for seed germination and establishment of target forest trees seem to be limited under all treatments, indicated by the distinctively re-bouncing shrub-values at *time3*. This was found also in other studies, where livestock grazing did change soil infiltration rates, soil bulk density, and soil porosity, but the effects were quickly reversed following cessation of grazing and had little detrimental effect on tree production [66]. The present study aimed to evaluate the chances for germination and sprouting of seedlings and sapling from seeds, which depends on the conditions in which the land was abandoned after the agricultural cultivation (juquira phase). The further vegetal succession progress [67] should be monitored through the coming years (conclusion section).

Extra-fencing with three additional strands of barbwires was necessary to hold pigs on the plots, needing extra labor/money of farmers. However, in practice, even five wires were not able to completely avoid escapes from plots. Especially, piglets can hardly be secured but also mature pigs tried to refuge the longer they stayed there. However, while piglets willingly come back later to their mother pigs, mature pigs will not return and can cause severe damages on adjacent fields. Additionally, once pigs escape, it is difficult to catch them again and it often takes half a day for three agricultural workers at a minimum to bring all escaped animals back to plots. Once a plot is sufficiently burrowed, shifting to the next plots is necessary and causes extra-fencing, pig catching, and labor time again. However, the modest economic gains can be used to compensate parts of these additional costs. However, as management time is always scarce on smallholdings and pastures have to be checked almost on a daily basis, it will be a difficult task for busy Amazonian peasant farmers to optimize the ecological services of these animals.

Another promising alternative animal species for the desired ecological effects is perhaps the Collared Peccary (*Pecari tajacu* L., Tayassuidae, Portuguese: cateto) that might provide even better ecological effects and production features than domestic pigs [68,69]. However, as there are almost no practical experiences with the species on-farm, and animals can cause serious damage in case of escapes in the agro-scapes, or can even be dangerous for people, this idea was disregarded for this experiment. However, we would like to recommend research upon this species, hypothesizing that *P. tajacu* might create higher proportions of small gaps in weed canopies (juquiras) than domestic pigs, while taking better advantage of the nutrient-poor natural resources on degraded tropical pastures than the Landrace pigs. It assumedly will receive higher prices on local markets, and will be better adapted to the ecological conditions of the northeastern Amazon [68,69].

Instructing day laborers to hoe the shrubs was easy and there were no further problems to slash the shrubs while sparing the capoeira trees and legumes. Difficulties just occurred when weedy shrub patches grew in conjunction with valuable capoeira trees so that there was the danger to damage target trees while withdrawing disturbing shrubs. However, clearing activities can be weary after some hours so that tired workers unintentionally damage target forest trees. In practice, it is not possible to completely eliminate shrubs from plots, as some up-rooted shrubs start to root again. However, removing the shrub litter from plots is too expensive. Initially, all replication blocks seemed to have the same degradation stage, fully covered with *B. verticillata* and *M. tenella* and very few capoeira trees. However, at *time3*, it became clear that *farm1* had much more capoeira trees rooting firmly in the ground, while *farm3* almost had none.

5. Conclusions

The proposed agricultural technique to use pigs or cattle to break up the juquira layers for accelerated capoeira restoration is a low-input method and thus suitable for smallholders of the NE-Amazon. Large agricultural enterprises will prefer to plant tree saplings or to dig up and fertilize lands with big agricultural implements, but these high-input agricultural management tools are hardly acceptable for smallholders, as the direct financial return is often low. However, as generally reforestation techniques are not easily realizable for Amazonian peasant farmers, adoption rates of this technique might be critical, especially if the success is not fully guaranteed after one year or even endangered to be destroyed by uncontrolled fires of neighboring farms [11,41]. Moreover, in the humid tropics, smallholders usually have to combat against the lush vegetation and a high amount of labor and money is permanently spent to keep the vegetation under control. Thus, motivation to invest labor and money to combat the aggressive and fast growing weed canopies (juquira) aiming at fostering a successful establishment of capoeira on fallow land is limited. However, a kick-off action to break once the weedy shrub canopies might be acceptable for smallholders if an obvious acceleration of the establishment of capoeiras can be achieved. Because once smallholders understood the importance of agricultural systems as multifunctional landscapes, they also will be convinced about the necessity to invest in the agronomic and economic benefits of secondary forest fallow dynamics [35]. This is all the more applicable because pigs are almost omnipresent on Amazonian smallholdings [58] and farmers like to keep them. Besides protecting their areas from fire [8,41,43], the investigation into the capoeira will not only secure livelihoods of farmers [13], but will also substantially contribute to the conservation of the indigenous flora and fauna [37,44]. At first glance, the results are just valid for a limited region in the center of the Bragantina region. However, our approach is in best accordance with global efforts of 'provisioning, regulating and maintaining cultural ecosystem services' [70] that might be suitable also for other Amazonian regions or beyond, in the humid neotropics [71]. Finally, the further vegetal succession process, subsequent to the four different starting conditions/treatments of juquira, requires the implementation of standardized methods of surveillance and monitoring to assess the progress of further successional phases (capoeira rala—actual capoeira—capoeirão) [67], until the stage of the secondary forest reaching the maximum succession is completed.

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