Changes in the Physico-Chemical Properties of Degraded Soils in Response to the ReviTec Approach Applied at Gawel (Far-North Cameroon)

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Abstract: A heavily degraded hardé area in the community of Gawel (Extreme Nord) was rehabilitated with a ReviTec approach. To evaluate the efficiency of introduced plants for rehabilitation, the site was monitored with the BioSoilPlot experiment over two years during the dry and rainy seasons (January 2018/2019, June 2018/2019, respectively). ReviTec was applied to accelerate ecological succession and improve the establishment of vegetation on these degradation-prone sites (Gawel 1 and Gawel 2). Growth volume, height and percentage cover of the herbaceous plants and soil physical and chemical parameters were assessed. Growth volume increased in both sites between 2018 and 2019 with *Pennisetum pedicellatum* exhibiting the highest values (Gawel 1: 3.41 dm$^3$/m$^2$ and 3.50 dm$^3$/m$^2$; Gawel 2: 3.47 dm$^3$/m$^2$ and 3.62 dm$^3$/m$^2$). Bunds were suitable for herbaceous growth, *Sesbania sesban* having the highest growth height (Gawel 1: 1.91 cm and 1.95 cm; Gawel 2: 1.95 cm and 1.97 cm) and *Pennisetum pedicellatum* the best percentage cover (Gawel 1: 53% and 58.33%; Gawel 2: 40.67% and 56.67%). Soil changed from sandy and strongly acid to clay-loam and slightly acid at Gawel 1, and from sandy and strongly acid to clay-loam and alkaline at Gawel 2. Soil water content and soil nutrient had increased within the ReviTec site compared to the outside with the application of compost-biochar-mycorrhiza treatment as the most promising over the two years of monitoring. Such results suggest that ReviTec approach can be used in sustainable restoration of soil hardé.

Keywords: soil rehabilitation; ReviTec; herbaceous species; soil hardé; Cameroon; BioSoilPlot; structures

1. Introduction

Soil is a vital and indispensable resource on which development, independence, food security, economic growth and sustainability of any nation depends [1]. Thus, sustainable land use and protection of soils play a key role in food, climate, and human security [2]. Fertile soils are a non-renewable resource by human time spans as their formation and renewal could take hundreds, if not thousands of years [3]. For this reason, the human management of soil resources will have wide-ranging consequences on human security for generations to come [4]. Despite this, land degradation has become a global problem occurring in most terrestrial biomes and agro-ecologies in both low income and highly industrialized countries [4]. Globally, it is estimated that about one fifth of Earth’s land area (more than 2 billion hectares) is degraded, including more than half of all agricultural land [5], affecting more than a billion people all over the world [6]. Africa is the most affected, with about 46% of degraded areas and at least 485 million (65%) people affected [7]. Sub-Sahara Africa, especially the Sahel area is experiencing a constantly growing environmental degradation characterized by more than 65 percent of agricultural land degraded [8]. In Cameroon, about 25% of the surface area belongs to arid land and is undergoing soil deterioration. This degraded land with soil hardé is dispersed throughout the Far North
region of Cameroon [9–11] and affect the livelihoods and well-being of the poorest households [12]. Sol hardé borrowed from the Fulfulde language, which commonly designates any land that is not very suitable for cultivation [13] is characterized by a massive and compact sandy clay surface, covered with a thick film of beating. The need to prevent further land degradation and to rehabilitate degraded lands is especially important now because the demand for accessible productive lands is increasing with an increase in the human population and consequent increased food consumption [14].

Despite the urgent need for preventing and reversing land degradation, the problem has yet to be appropriately addressed [15]. Various remediation technologies are being used for restoration of natural resources but most of them have additional impacts and are not ecologically safe [14]. Even policy actions for sustainable land management remain inconsistent and often ineffective [16]. Such technologies and policy frameworks to combat land degradation need to be supported by evidence-based and action-oriented research [17]. The past studies on land degradation had played a useful role in highlighting land degradation as a globally critical issue. However, most of them tended to focus only on simpler relationships, such as soil erosion and its impact on crop yield, while ignoring the broader values of land ecosystem services, various off-site and indirect costs in their analytical frameworks [18]. Therefore, ambitious reforestation programs aimed at restoring the degraded ecosystem in Sudano–Sahelian savannah through reforestation activities; sensitization were initiated by the Cameroon Government [19] and NGOs (“Green-Sahel” operation in 2008) to revitalize these degraded lands and convert it step by step into more productive lands. The losses from land degradation include not only environmental degradation cost measured directly on-site (e.g., soil loss and nutrient depletion), but also the cost of indirect and off-site environmental impacts (e.g., siltation of water bodies, water pollution, and biodiversity declines) [20].

To help efficiently combatting soil degradation and desertification, the soil and vegetation environmentalists of KeKo—Kesel, Koehler and Associates Biologists and the Centre for Environmental Research and Sustainable Technology (UFT) at the University of Bremen developed an ecological approach of revitalization technology called ReviTec [21]. This technology is based on experience from long-term ecological research [22]. It aims at rehabilitating essential ecosystem services of soil to allow for adapted forestry, pastures and agriculture. This eco-technology is a widely applicable tool for the initiation and acceleration of ecological succession with a mosaic-type exposure of a special substrate mixture which may be filled in biodegradable bags for erosion control [23]. The substrate consists of soil (e.g., excavation materials) and composts enhanced with locally available amendments to improve water holding capacity and nutrient status. Bio-activation with site-specific soil biota is important, including mycorrhiza fungi. Purposive sowing and planting of target and nurse plants complete the activation. The ReviTec bags can be flexibly exposed to the topography and modularly arranged in structures, such as small islands, bunds, demi-lune (half-moons), etc. These micro-topographies provide safe sites for natural colonization and function as collectors for sediment, water, and biota, and subsequently disperse these to the surrounding [24]. The concept covers three levels of scale with diverse functions. The basic model is a bag made of degradable fabric, filled with substrate (30 L) specifically amended with abiotic and biotic elements (bio-activation) to initiated and accelerated ecological succession [24]. The bags protected the substrate and promoted initial erosion control [25]. In Cameroon, three teaching, research and demonstration sites have been implemented since 2012 for the rehabilitation of soil hardé at Maroua (Salak, Boula-Mokong and Gawel) in the Far North.

Several rehabilitation trials of this type of soil have been undertaken through government actions as well as NGOs. But these have increased their limits because they are less suitable with unsatisfactory results. ReviTec technology, which combines both traditional (Zai, bund, planting hole, etc.) and scientific methods, has, on the other hand produced very satisfactory results in time and space.
The objective of this work was to identify and analyze the main mechanisms underlying the impact of the ReviTec approach in the success of vegetation (grass, herbs). We hypothesized that ReviTec structures soften soil hardé, provide “safe sites” and are favorable for the development of soils organisms. Measuring dynamic soil properties, such as soil organic carbon, soil structure, nitrogen, and water-holding capacity can be used both to compare the efficacy of different introduced organisms (vascular plants-grasses, effective mycorrhiza and soil amendments with the ReviTec substrates: Biochar, compost, matrix) in different sites.

2. Materials and Methods

2.1. Study Area and Treatments

The study areas were located in the Far North Region of Cameroon. It extends globally between 10°23'05" and 10°42'00" North and between 14°03'27" and 14°21'00" East [26]. Specifically, the study was carried out on the highly degraded lands (soil hardé) in the two experimental ReviTec sites Gawel1 (GW1: 10°40'536" N, 14°10'256" E, 475 m asl) and Gawel2 (GW2: 10°39'076" N, 14°09'121" E, 492 m asl), of Gawel locality (department of Diamare) in the Far North-Cameroon (Figure 1) located in the semi-arid dry land region and belonging to the Sudano-Sahelian agroecological zone. This zone is characterized by a mean annual rainfall between 500 and 900 mm [27]. Specifically, Gawel has an annual rainfall of 841 mm with a mean annual temperature of 27.7 °C (Figure 2). The two sites having respectively 5 ha and 27 ha.

Figure 1. Map of Far-North Cameroon with the location of Gawel.
Figure 2. Gawel climate graph.

For monitoring of vegetation (only herbaceous because almost all trees planted on structures died by suffocation) and soil parameters, six BioSoilPlots (BSP) were used (3 for both sites). This tool (BSP) enables monitoring of ReviTec activities over numerous years. A BSP consists of three circles with different radius and different measurements made in it: Inner circle (3 m radius, 30 m²), middle circle (11 m radius, 400 m²) and large circle (25 m radius, 2000 m²). BSP is centered to a ReviTec structure (midpoint of half-mount, bund or island); center points of the BSP have to be marked with a durable label (stick of steel, hit into soil, with label of number weld on) and estimate GPS coordinates of this midpoint; BSP have to be distributed more or less regularly over the site, but they should represent the relevant vegetation of the site and should include as many tree species as possible; the plots should not overlap; BSP, in summary, cover 10% of the whole site (Figure 3).

The ReviTec site of Gawel was installed to combat degradation with ReviTec structures (Figure 3) and specific treatment. The applied treatment includes loamy sand plus compost (made from aero anaerobic decomposition of cow dung and plant material) mixed with additive elements such as mycorrhiza and biochar (provided by GIZ project SFID at Mbang), all filled in the bags. All bags were amended with Brachiaria and Pennisetum seed. For the six monitored BSP, a total of 614 bags were applied to build ReviTec structures: Islands (64), Bund (310), Demi-lunes (240); only the latter two were analyzed (islands were not representative; there were only two island structures at GW1). To build a structure, we needed four bags for Island, ten bags for Bund and five bags for Demi-lunes. These structures have advantages of the water harvesting and runoff directing for the growth and survival of the vegetation.
The monitored vegetation includes *Brachiaria brizantha*, *Pennisetum pedicellatum* (seed were introduced) *Sesbania sesban* and *Boreria chaetocepha* (established spontaneously with time). Our design consists of compost, biochar and mycorrhiza (cpbcmy) treatment applied on structures and two controls (ctrl 1: out of ReviTec fence without vegetation (outside the ReviTec site) and ctrl 2: planting hole (out of structure) inside the ReviTec without bags and any substrate) (Table 1).

**Table 1.** Treatments used within the context of ReviTec.

| Treatments                      | Codes   | Seed | Bag | Substrate (%) |
|--------------------------------|---------|------|-----|---------------|
| control 1                      | ctrl 1  | #    | #   |               |
| control 2                      | ctrl 2  | #    | #   |               |
| planting hole                  |         |      |     |               |
| Compost + Biochar + Mycorrhiza | cpbcmy  | #    | #   | 70 20 10      |

|                          | Sandy Loam | Compost (cp) | Biochar (bc) | Mycorrhiza (my) |
|--------------------------|-------------|---------------|--------------|-----------------|
| ctrl 1 = control out of fence, ctrl 2 = control within fence, cp = compost, bc = biochar, my = mycorrhiza, Inoc = inoculum.

2.2. **Sampling**

The data collection was organized in two repetitions per year, one in the dry season and the other in the rainy season. The first collection was carried out in 2018, in January, in the middle of the dry season, and in July, in the beginning of the rainy season, while the second was carried out in 2019 during the same months as those of the first monitoring.
At each site (GW1 and GW2), grass and herbs species distributed on structures within three plots, known as BioSoilPlot (BSP), each representing a replication (Figure 4), were observed at each monitored period (Figure 5).

**Figure 4.** BioSoilPlot design (after Basic design principles for the ICP forests monitoring networks, [28]).

![BioSoilPlot diagram](image)

**Figure 5.** Plan of sampling on structures. The square shapes represent the bags filled with substrate on which the vegetation evolves. Red dots illustrate sampling positions in microplots marked by cut-outs on structures.

Eight (08) structures randomly selected (Bund and Demi-lune) in plots were assessed for data collection. A total of 48 structures were selected and investigated randomly (Table 2).
Table 2. Sum of selected structure for monitoring in the whole of BSP of different site.

|       | BioSoilPlot1 | BioSoilPlot2 | BioSoilPlot3 | Total |
|-------|--------------|--------------|--------------|-------|
|       | Bu | DL | Bu | DL | Bu | DL | Bu | DL | Bu | DL |
| GW1   |    |    |    |    |    |    |    |    |    |    |
|       | 6  | 6  | 3  | 11 | 6  | 4  | 15 | 21 |
| installed | 4  | 4  | 3  | 5  | 5  | 3  | 12 | 12 |
| monitored | 4  | 4  | 3  | 5  | 5  | 3  | 12 | 12 |
| GW2   |    |    |    |    |    |    |    |    |    |    |
|       | 7  | 11 | 6  | 9  | 3  | 7  | 16 | 27 |
| installed | 4  | 4  | 5  | 3  | 3  | 5  | 12 | 12 |
| monitored | 4  | 4  | 5  | 3  | 3  | 5  | 12 | 12 |

Bu: Bund DL: Demi-lune GW: Gawel.

2.3. Assessment of Grass Growth

Parameters evaluated were height, percentage cover of the four grasses of each BioSoilPlot. Growth height in cm was measured with a decameter. Percentage cover of each species was estimated with direct observation. These parameters allow one to calculate the growth volume as follows:

\[
\text{Growth volume} = \frac{\text{percentage cover} \times \text{mean growth height}}{10}\text{cm}^3/m^2.
\]

Growth volume is an indicator for the overgrown 3D space as an easy to assess roughness parameter.

2.4. Assessment of Soil Characteristics

2.4.1. Soil Sampling

Soil samples were collected within the BioSoilPlot (in one hand in the bags and in another hand outside of structures) and outside of the ReviTec site (near the fence). As our soils are hard, a ‘V’ shape cut up to 15 cm depth was made. Soil of the pit was removed from the surface up to a 15 cm depth from both sides using a hand auger. This scraped soil was collected in a plastic bowl. This sample was known as the ‘primary’ sample. Such primary samples should be approximately the same weight. After collecting at least 30–35 primary samples per treatment, we mixed all the samples in a plastic bowl thoroughly and drew about $\frac{1}{2}$ to 1 kg composite sample by a quartering method. Samples in the bowl were labelled and divided into approximately 4 equal parts. Two opposite portions of samples were discarded, while the remaining 2 portions were again thoroughly mixed and again divided in to 4 equal parts and 2 opposite parts again discarded. This procedure continued until $\frac{1}{2}$ to 1 kg of the sample remained in the bowl. This was known as the composite sample, which was a true representative of the area. The airtight containers of polythene bags 6 × 9” made of film about 0.13 mm thick, which was sealed by twisting or tying the neck or by means of rubber bands or adhesive tape, which were used to contain soil samples. These samples were dried, broken and sieved (2 mm) before laboratory analysis. These prepared soil samples were used for the following analyses.

2.4.2. Soil Texture

The relative mass of sand, silt and clay in the soil sample (thus, the texture) was determined by the method proposed by David, Wilson and Card [30]. Soil was spread and air-dried on a newspaper. Gravel, stones, trash and roots were removed and aggregates were crushed. Soil was then filled in a tall slender jar (like a quart jar) $\frac{1}{4}$ full. Water was added until the jar was $\frac{3}{4}$ full and a teaspoon of powdered, non-foaming dishwasher detergent was added. The jar was sealed with a tight-fitting lid, shaken manually for 10 to 15 min to break the soil aggregates, and then left undisturbed. Soil particles settled by gravity according to size. After 1 min, the depth of the sand fraction was marked on the jar, after 2 h the depth of silt, and after 2–3 days, when the water was clear, the depth of the clay fraction, was marked. The depth of the three fractions was measured in mm and respective percentages were calculated in relation to total depth. These values were used to determine the soil texture class with the United States Department of Agriculture (USDA) soil texture triangle.
2.4.3. Soil Water Content

We determined soil water content gravimetrically [31]. Eight grams of composite sub sample of soil was taken to the lab for accurate weighing with weigh boats. After weighing fresh mass, the soil was dried in an oven for over twenty-four hours at 105 °C and reweighed repeatedly until the mass ceased to change.

\[
\text{Water content (g): WC (g) = FM − DM} \quad \text{(1)}
\]

\[
\text{Percent water content (% DM): WC (%) = } 100 \times \frac{WC (g)}{DM} \quad \text{(2)}
\]

FM = fresh mass (g); DM = dry mass (g).

2.4.4. Soil Chemical Factors

Soil Organic Carbon (SOC)

SOC content was determined using the Walkley–Black wet oxidation method with \( \text{K}_2\text{Cr}_2\text{O}_7 \) [32]. 10 mL of 1N \( \text{K}_2\text{Cr}_2\text{O}_7 \) and 20 mL conc. \( \text{H}_2\text{SO}_4 \) (containing \( \text{Ag}_2\text{SO}_4 \) were added to 1g dry mass of soil and then thoroughly mixed. The reaction was allowed to proceed for 30 min. The reaction mixture was diluted with 200 mL water and 10 mL of \( \text{NaF} \) solution and 2 mL of diphenylamine were added and then filtered. The solution was titrated with standard FAS \[\text{Fe (NH}_4\text{)}_2 (\text{SO}_2\text{)}_2\] to a brilliant green color. The blank without soil was run simultaneously.

\[
\text{SOC} \% = \frac{10 \times (\text{blank} − \text{Reading}) \times 0.003 \times 100}{\text{DM}}
\]

SOC = soil organic carbon, DM = dry mass of soil (105 °C).

Soil pH

Soil pH was measured potentiometrically with a calomel electrode in a mixture of soil:water at a ratio of 1:2.5 m/m [33].

Total Nitrogen (N)

Total nitrogen concentration was determined using the Kjeldahl digestion method [34]. Steam distillation with \( \text{NaOH} \) after Kjeldahl digestion of 1g of soil with \( \text{H}_2\text{SO}_4 \) and \( \text{K}_2\text{SO}_4 \)-catalyst mixture. Ammonia liberated by steam distillation was collected in boric acid-indicator solution and determined by titration with 0.02N sulphuric acid. Simultaneously; blank sample (without soil) was run.

Phosphorus (P)

The Olsen method of extraction and the ascorbic acid method of analysis were used to estimate extractable soil phosphorus [35]. 2.5 g grams of soil (DM) were extracted with 50 mL of 0.5M \( \text{NaHCO}_3 \). The extract was filtered and a 5 mL aliquot was taken to develop the color by the ascorbic acid method. Once developed, the color was read on a spectronic 20 at 880 nm.

Potassium (K)

Potassium in all soils was extracted using the ammonium acetate procedure [35]. Five grams of soil were extracted with 25 mL of 1N \( \text{NH}_4\text{OAc} \) (Ammoniumacetate) for five minutes. The extracts were filtered through Whatman No. 1 filter paper and measured with a flame photometer (FP 8400, A. KRUSS Optronic, Hamburg, Germany) after calibration.
2.5. Statistical Analysis

Data were analyzed separately for growth volume, height, soil water content, organic carbon, organic matter content, total nitrogen, extractable phosphorous and potassium. All data concerning herbaceous species were log transformed in order to normalize them.

For all above mentioned data except growth volume, where Kruskal–Wallis test + pairwise U-test was applied, Test of distribution and then analysis of variance (ANOVA) was conducted using the XLStat version 2016 with the following model of analysis: \( Y_{ijk} = u + S_i + Y_j + e_{ijk} \) where: \( Y_{ijk} \) is the dependent variable (e.g., carbon), \( u \) is the overall mean, \( S_i \) is the effect of treatment or species, \( Y_j \) is the effect of year and \( e_{ijk} \) is the random error.

Statistical differences between means were assessed using the Tukey range test.

3. Results and Discussion

3.1. The Growth Volume of Grass Species

Between the two monitoring periods 2018/2019 at GW1, growth volume significantly decreased between years for \( B. brizantha \) \((p = 0.018) \) or increased for \( P. pedicellatum \) \((p < 0.0001) \) and \( S. sesban \) \((p < 0.0001) \). On the opposite, no significant difference was observed in the growth volume of \( B. chaetocepha \) \((p = 0.12) \) between years 2018 and 2019.

During the first monitoring in January, all grass species were dried (growth volume = 0) which is why this month was not represented in the table; with the time, they started to re-grow. Growth volume varied from 0.00 dm\(^3\)/m\(^2\) in January for all species, at 3.41 dm\(^3\)/m\(^2\) in July 2018 and 3.50 dm\(^3\)/m\(^2\) in July 2019 for \( P. pedicellatum \), 2.90 dm\(^3\)/m\(^2\) in July 2018 and 3.06 dm\(^3\)/m\(^2\) in July 2019 for \( S. sesban \) and 2.51 dm\(^3\)/m\(^2\) in July 2018 and 2.71 dm\(^3\)/m\(^2\) in July 2019 for \( B. chaetocepha \). Contrary to those, \( B. brizantha \) showed an important decrease in growth volume, with a significant variation from 3.32 dm\(^3\)/m\(^2\) in July 2018 to 1.68 dm\(^3\)/m\(^2\) in July 2019. This could justify the reduction of the growth volume of \( B. brizantha \) from years 2018 to 2019.

There was a significant difference in growth volume between all the different species during the same month of monitoring with \((p < 0.0001) \) in July 2018 and \((p = 0.002) \) in July 2019.

At the GW2 ReviTec site, growth volume of \( P. pedicellatum \), \( S. sesban \) and \( B. chaetocepha \) increased with time, but \( B. chaetocepha \) did not exist in this site in July 2018, while \( B. brizantha \) considerably decreased in growth volume. In January, all species were dried (no growth volume of fresh mass) as in GW1; however, in July all grass species were fresh and colonized the structures. Growth volume varied from 0.00 dm\(^3\)/m\(^2\) in January for all species, at 3.47 dm\(^3\)/m\(^2\) in July 2018 and 3.62 dm\(^3\)/m\(^2\) in July 2019 for \( P. pedicellatum \), 2.78 dm\(^3\)/m\(^2\) in July 2018 and 3.02 dm\(^3\)/m\(^2\) in July 2019 for \( S. sesban \) and 2.90 dm\(^3\)/m\(^2\) in July 2018 and 2.71 dm\(^3\)/m\(^2\) in July 2019 to 2.74 dm\(^3\)/m\(^2\) in July 2019 for \( B. brizantha \). The \( p \)-value of all these species was very significant \((p < 0.0001) \) when compared to their variation in growth volume between different months of monitoring and even between the same months of monitoring.

Our finding supposed that, despite this high growth volume at the beginning of the survey, \( B. brizantha \) seemed to have the ability to grow very fast, but with low adaptability to drought. This decrease of \( B. brizantha \) seemed to show that its disappearance with time could be explained by the fact that it was an introduced species, used to initiate and accelerate ecological succession. After ecosystem services were achieved, it seems that native species started to recolonize the different sites. This very fast colonization could be due to the short rainy season that characterizes Sahelian zones. Herbaceous species are mainly annual plants reported to survive drought by modifying their life cycle \[36\]. It is why, in these sites, growth volume of each species recorded for our study significantly varied with time (Table 3). \( P. pedicellatum \) and \( S. sesban \) were the most colonized species. Similar results were observed by Barbier et al. \[37\] in the context of increase in yield, who reported that the dominant crops are millet and sorghum due to building stone bounds in
the fields to capture runoff and reduce erosion during the short rainy season in the Sahel, thus indicating the effectiveness of ReviTec to accelerate ecological succession.

Table 3. Increases in growth volume (dm²/m²) of herbaceous species per monitoring period at GW1 and GW2.

| Species/Periods       | July 2018 | July 2019 | p-Value | July 2018 | July 2019 | p-Value |
|-----------------------|-----------|-----------|---------|-----------|-----------|---------|
| Brachiaria brizantha  | 3.32 ± a  | 1.68 ± b  | 0.018 **| 3.25 ± b  | 2.74 ± c  | <0.0001 ****|
|                       | (0.10)    | (1.58)    |         | (0.04)    | (0.12)    |         |
| Pennisetum pedicellatum| 3.41 ± a  | 3.50 ± b  | <0.0001 ****| 3.47 ± b  | 3.62 ± a  | <0.0001 ****|
|                       | (0.02)    | (0.01)    |         | (0.05)    | (0.02)    |         |
| Sesbania sesban       | 2.90 ± b  | 3.06 ± b  | <0.0001 ****| 2.78 ± b  | 3.02 ± a  | <0.0001 ****|
|                       | (0.07)    | (0.02)    |         | (0.10)    | (0.05)    |         |
| Boreria chaetocepha   | 2.51 ± c  | 2.71 ± abc| 0.12    | 0.00 ± a  | 2.35 ± a  | <0.0001 ****|
|                       | (0.22)    | (0.23)    |         | (0.00)    | (0.04)    |         |
| p-value               | <0.0001 ****| 0.002 *** |         | <0.0001 ****| <0.0001 ****|         |

GW: Gawel. Letters represent change in composition of means between species during the same month (red color) and between periods (black color) of monitoring. Number in bracket represent standard deviation. Significance levels are indicated by **** p < 0.0001. *** p < 0.005. ** p < 0.05.

3.2. Effect of Structures on Growth Height of Herbaceous Species in Both Sites

3.2.1. Development of Growth Height of Herbaceous Species

Table 4 summarizes data on difference in growth height between Bu and DL at GW1 and GW2 during the survey. It is indicated in Table 4 that growth height of all species was strongly influenced by structures at the GW1 site, with better growth on Bu than on DL during the different monitoring periods, except *B. brizantha* in July 2018, for which no significant different was perceived (p = 0.856). However, at GW2 site, growth height did not seem to be influenced by structures for almost all the species except *S. sesban* and *B. brizantha* that were strongly influenced by structures in July 2018 than in July 2019, although no significant difference was perceived for *B. brizantha* in July 2019. *S. sesban* and *B. brizantha* developed better on Bu than DL. At GW1 or GW2, Bu seemed to have been suitable for herbaceous growth, even if the differences were sometimes not significant. Similar result was observed by Ponce-Rodríguez et al. [38] who highlighted the importance of the effect of stone bunds on the growth of herbaceous vegetation. According to Klik et al. [39], the areas near the stone bunds offer better conditions for the development of the vegetation due to the retention of solids and the accumulation of mulch (organic matter, litter, etc.) which is dragged towards the stone bunds. In many cases the genetic aspect of these differences was known for many years as in the case of certain mutants [40]. As the soil water content was weak, it may impact on the plant growth according to the theory that says that plant growth is related to the tenacity with which water is held by the soil [41].

3.2.2. Development of Growth Height and Cover of Herbaceous

Figure 6a,b summarizes the variation in growth height according to percentage cover on Bu and DL at the GW1 and GW2 sites during the survey. Figure 6 reveals that growth height varied depending on the site, structure and species. Almost all the herbaceous species showed a decrease in growth height during the whole monitoring periods, except for *B. chaetocepha*, for which growth height had increased in both sites on Bu and DL. The best growth height was observed with *S. sesban* and *P. pedicellatum* in both sites on Bu and DL. Either at GW1 or GW2 sites, percentage cover increased for all the herbaceous species on different structures. *P. pedicellatum* showed the best proportion of growth cover. It seems to be the dominant and most adapted species on Bu and DL in both sites.
Table 4. Comparison of growth height (cm) of herbaceous species between different structures in both sites.

| Monitoring Period | Species               | GW1       | GW2       |
|-------------------|-----------------------|-----------|-----------|
|                   | BU        | DL       | p-Value   | BU        | DL       | p-Value   |
| July 2018         | Brachiaria brizantha | 1.75 a (0.04) | 1.70 a (0.02) | 0.856     | 1.77 a (0.06) | 1.62 b (0.05) | 0.005 ** |
|                   | Pennisetum pedicellatum | 1.89 a (0.05) | 1.71 b (0.05) | 0.0008 *** | 1.90 a (0.05) | 1.86 a (0.06) | 0.922 |
|                   | Sesbania sesban      | 1.91 b (0.06) | 1.76 b (0.05) | 0.006 **  | 1.99 a (0.04) | 1.81 b (0.08) | <0.0001 **** |
|                   | Boreria chaetocepha  | 1.78 a (0.06) | 1.55 b (0.04) | <0.0001 **** | 0 b (0) | 0 b (0) | 1.000 |
| July 2019         | Brachiaria brizantha | 1.76 a (0.07) | 0 b (0) | <0.0001 **** | 1.63 b (0.01) | 1.58 b (0.07) | 0.952 |
|                   | Pennisetum pedicellatum | 1.91 a (0.04) | 1.72 b (0.07) | 0.006 **  | 1.95 a (0.01) | 1.92 a (0.06) | 0.994 |
|                   | Sesbania sesban      | 1.95 a (0.04) | 1.78 b (0.09) | 0.01 **   | 1.97 a (0.01) | 1.82 b (0.06) | 0.015 ** |
|                   | Boreria chaetocepha  | 1.72 a (0.05) | 1.55 b (0.05) | 0.01 **   | 1.64 a (0.08) | 1.63 a (0.08) | 1.000 |

GW: Gawel; Bu: Bund; DL: Demi-Lune. Letters represent change in composition of means growth height of species between different structures during the same month of monitoring. Number in bracket represent standard deviation. Significance levels are indicated by **** \( p < 0.0001 \). *** \( p < 0.001 \). ** \( p < 0.05 \).

There was a substantial and stable difference between species in the patterns of development strategies. The reliability of these differences from season to season and species to species indicates that they result from different inherited strategies of plant growth [42].

3.3. Influence of ReviTec Treatment on Soil Texture and pH

Table 5 indicates that soil texture and pH were strongly influenced by ReviTec treatment (cpbcmy) at both sites compared to ctrl 1 \( p < 0.0001 \). At GW1 or GW2 ReviTec site, soil texture outside ReviTec site was sandy and their pH were acidic, as described by Seiny-Boukar [36]. It remained unchanged during the survey. The soil of Gawel was naturally degraded and characterized by a very thin layer of humeferous surface horizon which covers a fairly compact soil layer (2–20 cm to 30 cm) impermeable to water, which inhibits the growth of roots [9], is acidic \( 5 < \text{pH} < 6 \) and is deprived of exchangeable bases \( \text{CEC} = 5–10 \text{ meq/100 g} \) [26]. Thus, without any activity, it will remain unchanged, confirming why we observed the stability of soil texture in the control area (ctrl 1) either at GW1 or GW2. This could be due to the coarse soil texture that hinders soil aggregation. Duong, Penfold and Marschner [43] found that, in sandy soils with less than 13% clay, such improvements were not possible.

Within the ReviTec sites, there were variations of these parameters with time. Few differences in texture were observed on cpbcmy treatment compared to control (ctrl 2), but the highest variation of soil texture was observed on cpbcmy treatment. Soil pH on these two plots was alkaline at GW1 and GW2. Substrate filled in ReviTec bags in addition with the activity of soil organisms attracted by the earlier vegetation established on structures contributed to the modification of soil texture and pH, thus improving soil quality and CEC. Substrates used in ReviTec such as compost, mycorrhizae and biochar might have influenced the soil particles by binding them together, as was demonstrated by Duong, Penfold and Marschner [43] who reported that organic amendments improve aggregate stability directly by binding of clay and indirectly by increasing microbial activity and the production of binding agents. One of the main strategies of the ReviTec approach is to improve biodiversity by attracting beneficial organisms such as ants and termites. These organisms are known to be the ecosystem engineers as they ensured greater mineralization of clay and silt that permitted high biogenic structures of soil [44].
Figure 6. Variation in growth height and percentage cover of herbaceous on the different structures during the two monitoring periods July 2018/19. GW: Gawel; Bu: Bund; DL: Demi-Lune. The error lines represent standard deviation. Growth height is represented by the bar chart and percentage cover, by the curve.
Table 5. Variation of soil texture and soil pH under the influence of ReviTec treatment at GW1 and GW2 sites.

| Period | GW1 | | | GW2 | | |
|--------|-----|--------|-----|--------|--------|-----|
|        |     | January | July |         | January | July |
|        | ctrl 1 | ctrl 2 | cpbcmy | p | ctrl 1 | ctrl 2 | cpbcmy | p | ctrl 1 | ctrl 2 | cpbcmy | p |
| % Clay | 3.15<sup>b</sup> | 1.96<sup>b</sup> | 39.56<sup>a</sup> | <0.0001<sup>b</sup> | 14.63<sup>c</sup> | 40.31<sup>a</sup> | <0.0001<sup>b</sup> | 1.84<sup>b</sup> | 25.75<sup>a</sup> | 21.63<sup>a</sup> | <0.0001<sup>b</sup> | 6.63<sup>c</sup> | 15.44<sup>b</sup> |
| % Silt | 5.42<sup>b</sup> | 25.17<sup>a</sup> | 1.96<sup>c</sup> | <0.0001<sup>b</sup> | 1.94<sup>b</sup> | 16.07<sup>a</sup> | <0.0001<sup>b</sup> | 8.52<sup>a</sup> | 4.20<sup>b</sup> | 3.13<sup>b</sup> | <0.0001<sup>b</sup> | 1.24<sup>c</sup> | 11.23<sup>b</sup> |
| % Sand | 91.43<sup>a</sup> | 72.87<sup>b</sup> | 38.48<sup>c</sup> | <0.0001<sup>b</sup> | 83.43<sup>a</sup> | 43.62<sup>c</sup> | <0.0001<sup>b</sup> | 89.64<sup>a</sup> | 70.05<sup>b</sup> | 75.24<sup>b</sup> | 0.0055<sup>b</sup> | 92.13<sup>a</sup> | 73.33<sup>b</sup> |
| Texture | Sandy | Sandy | Sandy | Sandy | Sandy | Sandy | Sandy | Sandy | Sandy | Sandy | Sandy | Sandy | Sandy |
| pH | 5.71<sup>b</sup> | 6.87<sup>ab</sup> | 7.38<sup>a</sup> | 0.049<sup>b</sup> | 5.46<sup>b</sup> | 7.17<sup>a</sup> | 0.001<sup>b</sup> | 5.64<sup>b</sup> | 7.28<sup>a</sup> | 7.23<sup>a</sup> | 0.026<sup>b</sup> | 6.46<sup>a</sup> | 7.18<sup>a</sup> |

GW: Gawel; ctrl 1: control out of fence; ctrl 2: control within fence; cp: compost; bc: biochar; my: mycorrhiza; p: p-value. Letters represent change in composition of means of each soil particle and pH between treatments during the same month of monitoring. Number in bracket represent standard deviation. Significance levels are indicated by **** ** p < 0.0001, *** p < 0.001, ** p < 0.01, * p < 0.05.
3.4. Influence of ReviTec Treatment on Soil Moisture Content

Figure 7 illustrates the influence of ReviTec treatment on soil moisture content at GW1 and GW2 ReviTec sites. It can be seen from this figure that soil moisture was very high in July. This might be due to the downward movement of water at the beginning of the rainy season. There was a pronounced difference in soil water content between treatment and controls of both sites. Soil moisture inside the ReviTec site was higher than outside during all the different monitoring periods in both sites. This difference could be due to the sandy soil texture of ctrl 1. It is known that this class of soil is characterized by low water holding capacity [45]. Furthermore, the plots containing cpbcmy treatment had more water than ctrl 2; however, both had a positive effect on water content. The higher value of water content on the plot with cpbcmy treatment could be explained by the fact that soil texture clearly changed with cpbcmy addition. This change in texture could be explained by the effect of the migration of particles trapped by the structures attributable to hydrological processes such as heavy rains, infiltration, and preferential flow [46]. Usually, in the Sahel, precipitation is accompanied by strong north-easterly winds [47], which diverts raindrops from their vertical trajectory [48], so that the windward sides of microdunes receive more rainwater per unit area and are more subject to splash. Splashes preferentially transfer soil particles downhill, which prevents crust development and maintains good water infiltrability [46]. The addition of clay to sandy soils has been reported to increase water and nutrient holding capacity for sandy soil [49–51] due to the high binding capacity of clay and therefore could also reduce nutrient leaching from compost.

Soil texture and soil organic matter (SOM) seem to be the key components that determine soil water holding capacity. This result disagreed with that of other authors who found significant effects of composts on several physical properties of coarse-textured soils (bulk density, porosity, infiltration rates, saturated hydraulic conductivity), but no effects on soil water retention [52,53]. Surface area is a very important soil characteristic, as it influences all of the essential functions of fertility, including water, air, nutrient cycling and microbial activity. The limited capacity of sandy soil to store water and plant nutrients is partly related to the relatively small surface area of its soil particles [54]. Coarse sands were said to have a very low specific surface of about 0.01 m$^2$ g$^{-1}$, and fine sands about 0.1 m$^2$ g$^{-1}$ [54].

3.5. Influence of ReviTec Treatment on SOC and N

Evaluation of the ReviTec treatment on soil C and soil N data from cpbcmym compared to ctrl 1 and ctrl 2 in Table 6 revealed that one of the major soil fertility constraints of sub-Saharan Africa is low inherent nutrient reserve as previously reported [55]. For instance, soil nutrient inside the ReviTec site was higher than outside during all the different monitoring periods at both sites. As expected, this difference could be attributed to the sandy soil texture of ctrl 1 characterized by low water holding capacity [45] and where organic matter decomposition is constrained by unfavorable conditions for microbial activity [56–58]. However, plots with cpbcmym treatment had more nutrients than ctrl 2; however, both had a positive effect on water content compared to ctrl 1. In these plots, the positive effects of organic amendments on aboveground phytomass have been attributed to increases in soil microbial activity and nutrient availability [59–61]. However, results could also be influenced by higher water availability due to increased SOM. Then, the effects of organic amendments on plant biomass would depend on the balance between nutrient (especially nitrogen and carbon) and water supply.
Figure 7. Influence of ReviTec treatment on soil moisture content (mean ± Std) at GW1 and GW2 ReviTec sites. GW: Gawel; ctrl 1: control out of fence; ctrl 2: control within fence; cp: compost; bc: biochar; my: mycorrhiza. Letters a, b and c represent difference in composition of means between treatments during the same month of monitoring. The error lines represent Standard deviation.
Composts were reported to have major effects not only on soil physical, but also on soil chemical property [62,63]. As expected, compost treatment significantly increased SOC content compared to controls. Several studies have indicated that compost and biochar amendment increase SOC and N content [64,65]. However, total N content was higher in cpbcmy treatment compared to controls. This increase of total N may be due to the sorption potential of biochar that reduced N mineralization and leaching [66]. Our finding is in accordance with Laird et al. [67] who found that biochar amendments significantly increased total N value in soil or the ability of mycorrhiza to mobilize nutrients, including N in the soil [68]. The ratio C/N is generally favorable for mineralization processes supporting the development of belowground biomass and of the subsequent food web.

The persistence of SOC is related to the content of reactive mineral particles such as clay and silt that contribute to SOM stabilization, physical protection from decomposers and soil structure formation [69,70]. In sandy soils, these processes are much less effective, and the persistence of added SOC was reported to be more related to the degradability of the organic matter itself [53,57,71]. This depends on the composition of the original materials used for composting, i.e., the amount and proportion of recalcitrant C [72], and whether the final product was screened, as unscreened composts rich in slowly decomposable C were often recommended to enhance infiltration into compacted soil and reduce evaporation of soil water [73,74].

3.6. Influence of ReviTec Treatment on Soil Extractable P and Exchangeable K

Table 7 illustrates the influence of ReviTec treatment on soil extractable P and exchangeable K at GW1 and GW2 ReviTec sites and indicated that all these elements were higher in July than in January (Table 7). This might be due the downward movement of water at the beginning of the rainy season. Soil-extractable P and exchangeable K increased significantly inside the ReviTec and clearly changed with Cpbcmy addition, which still had visible residual organic materials on the surface after four years of application. Duong et al. [42] pointed out that organic amendments improve aggregate stability directly by binding of clay and indirectly by increasing microbial activity and the production of binding agents. However, they found that in sandy soils with less than 13% clay, such improvements were not possible. The influence of biochar on microbial populations in soils could not be neglected. It should be noted that soil microbial biomass commonly increases with increasing clay content, as reported by several authors [75–77], and this response is generally attributed to the increased surface area [76]. Surface area is a very important soil characteristic, as it influences all of the essential functions for fertility, including water, air, nutrient cycling and microbial activity. The higher surface areas of finer-textured soils can result in increased total water content and improved physical protection from grazers.
Table 6. Soil organic carbon (SOC), total nitrogen (N) and C/N ratio recorded at GW1 and GW2 ReviTec sites.

| Treatments | Months | 2018 |  | 2019 |  | 2018 |  | 2019 |  | 2018 |  | 2019 |  |
|------------|--------|------|---|------|---|------|---|------|---|------|---|------|---|
|            |        | SOC (%) | N (%) | C/N | SOC (%) | N (%) | C/N | SOC (%) | N (%) | C/N | SOC (%) | N (%) | C/N |
| ctrl 1    | Jan    | 1.50 (0.02) | 0.47 (0.07) | 3.26 (0.51) | 1.71 (0.07) | 0.57 (0.03) | 2.99 (0.02) | 1.34 (0.00) | 0.47 (0.00) | 2.83 (0.01) | 2.28 (0.01) | 0.57 (0.00) | 3.98 (0.04) |
|           |        | 2.28 (0.01) | 0.57 (0.00) | 3.98 (0.02) | 2.60 (0.01) | 0.62 (0.08) | 4.20 (0.01) | 2.47 (0.01) | 0.66 (0.01) | 3.75 (0.01) | 2.52 (0.02) | 0.63 (0.02) | 3.99 (0.26) |
| ctrl 2    | Jan    | 3.03 (0.00) | 0.56 (0.01) | 5.43 (0.11) | 3.42 (0.01) | 0.84 (0.04) | 4.09 (0.02) | 3.20 (0.08) | 0.72 (0.08) | 4.50 (0.00) | 2.91 (0.00) | 0.76 (0.01) | 3.84 (0.05) |
|           | Jan    | 2.60 (0.02) | 0.57 (0.02) | 4.95 (0.19) | 2.30 (0.00) | 0.61 (0.05) | 4.97 (0.01) | 1.83 (0.01) | 0.55 (0.08) | 3.40 (0.06) | 2.74 (0.07) | 0.52 (0.07) | 5.30 (0.86) |
|           | Jul    | 2.90 (0.01) | 0.68 (0.01) | 4.30 (0.06) | 3.02 (0.00) | 0.89 (0.03) | 3.41 (0.01) | 2.86 (0.08) | 0.72 (0.08) | 4.01 (0.00) | 2.96 (0.06) | 0.74 (0.06) | 4.01 (0.35) |
| cpbcmy    | Jul    | 3.57 (0.01) | 0.71 (0.00) | 5.01 (0.02) | 3.52 (0.01) | 0.94 (0.06) | 3.74 (0.02) | 3.68 (0.06) | 0.84 (0.06) | 4.41 (0.03) | 3.10 (0.00) | 0.81 (0.03) | 3.84 (0.15) |
|           | Jan    | 1.00 (0.00) | 0.12 (0.00) | 0.94 (0.00) | 0.94 (0.00) | 0.12 (0.00) | 0.94 (0.00) | 0.94 (0.00) | 0.12 (0.00) | 0.94 (0.00) | 0.94 (0.00) | 0.12 (0.00) | 0.94 (0.00) |
|           | Jul    | 2.60 (0.02) | 0.57 (0.02) | 4.95 (0.19) | 2.30 (0.00) | 0.61 (0.05) | 4.97 (0.01) | 1.83 (0.01) | 0.55 (0.08) | 3.40 (0.06) | 2.74 (0.07) | 0.52 (0.07) | 5.30 (0.86) |
|           | Jul    | 2.90 (0.01) | 0.68 (0.01) | 4.30 (0.06) | 3.02 (0.00) | 0.89 (0.03) | 3.41 (0.01) | 2.86 (0.08) | 0.72 (0.08) | 4.01 (0.00) | 2.96 (0.06) | 0.74 (0.06) | 4.01 (0.35) |
| cpbcmy    | Jul    | 3.57 (0.01) | 0.71 (0.00) | 5.01 (0.02) | 3.52 (0.01) | 0.94 (0.06) | 3.74 (0.02) | 3.68 (0.06) | 0.84 (0.06) | 4.41 (0.03) | 3.10 (0.00) | 0.81 (0.03) | 3.84 (0.15) |

GW: Gawel; ctrl 1: control out of fence; ctrl 2: control within fence; cp: compost; bc: biochar; my: mycorrhiza; C: Carbon, N: total nitrogen; Jan: January; Jul: July; p: p-value. Letters represent change in composition of means of each soil nutrient between treatments during the same month of monitoring. Number in bracket represent standard deviation. Significance levels are indicated by **** p < 0.0001, *** p < 0.005, ** p < 0.05.
Table 7. Soil extractable P and exchangeable K recorded at GW1 and GW2 ReviTec sites.

| Treatments | Months | GW1 2018 | GW1 2019 | GW2 2018 | GW2 2019 |
|------------|--------|----------|----------|----------|----------|
|            |        | P (%) | K (%)  | P (%) | K (%)  | P (%) | K (%)  | P (%) | K (%)  |
| ctrl 1     | Jan    | 2.44 c (0.05) | 20.87 c (0.75) | 2.70 c (0.18) | 28.00 c (1.00) | 2.37 b (0.39) | 20.07 c (0.06) | 3.04 c (0.01) | 28.67 b (0.58) |
| ctrl 2     | Jan    | 5.06 b (0.02) | 28.67 b (0.57) | 5.89 b (0.05) | 38.10 b (0.10) | 4.18 b (0.23) | 26.77 b (0.49) | 5.47 b (0.65) | 28.00 b (0.10) |
| cpbcmy     | Jan    | 7.58 a (0.06) | 39.10 a (0.10) | 9.24 a (0.05) | 43.10 a (0.10) | 7.43 a (0.60) | 37.73 a (0.55) | 8.31 a (0.29) | 38.17 a (0.15) |
|            |        | 1.000 | 0.996  | 0.999 | 0.994 | 0.979 | 0.998 | 0.982 | 0.996 |
|            |        | 5,237.716 | 821.698 | 1,647.060 | 522.088 | 69.197 | 1,301.642 | 81.996 | 793.864 |
|            |        | <0.0001 **** | <0.0001 **** | <0.0001 **** | <0.0001 **** | <0.0001 **** | <0.0001 **** | <0.0001 **** | <0.0001 **** |
| ctrl 1     | Jul    | 2.53 c (0.17) | 21.2 c (0.20) | 3.52 c (0.06) | 35.03 c (0.50) | 2.80 c (0.13) | 27.1 c (0.10) | 3.13 b (0.00) | 28.67 c (0.58) |
| ctrl 2     | Jul    | 5.46 b (0.65) | 44.1 b (0.10) | 7.26 b (0.70) | 59.10 b (0.10) | 5.28 b (0.29) | 28.1 b (0.10) | 6.68 a (0.47) | 32.10 b (0.10) |
| cpbcmy     | Jul    | 8.32 a (0.05) | 56.10 a (0.10) | 9.36 a (0.00) | 60.50 a (0.45) | 7.89 a (0.29) | 45.00 a (0.20) | 8.41 a (0.54) | 46.10 a (0.10) |
|            |        | 0.986 | 1.000  | 0.986 | 1.000 | 0.993 | 1.000 | 0.983 | 0.999 |
|            |        | 109.038 | 47,160.500 | 104.221 | 8,259.284 | 211.622 | 15,175.500 | 84.569 | 2,172.349 |
|            |        | <0.0001 **** | <0.0001 **** | <0.0001 **** | <0.0001 **** | <0.0001 **** | <0.0001 **** | <0.0001 **** | <0.0001 **** |

GW: Gawel; ctrl 1: control out of fence; ctrl 2: control within fence; cp: compost; bc: biochar; my: mycorrhiza; P: soil extractable P; K: soil exchangeable K; Jan: January; Jul: July. Letters represent change in composition of means of each soil nutrient between treatments during the same month of monitoring. Number in bracket represent standard deviation. Significance levels are indicated by **** p-value < 0.0001, *** p-value < 0.005.
4. Conclusions

The ReviTec approach, which combines both traditional (Zai, bund, planting hole, etc.) and scientific methods, has produced very satisfactory results concerning the rehabilitation of soil hardé. ReviTec, as it is embedded in an ecosystem approach, can be adapted as soft eco-technology to the specific needs of a degraded or degradation-prone area. At Gawel sites, soil was considered as hardé or degraded vertisols, almost bare and uninhabited by soil organisms before the implementation of ReviTec. At the end of each survey in July, all the spaces either at GW1 and GW2 sites were covered by herbs, but with some bare spaces still observed. The results show considerable differences in the performance of soil parameters. Treatment within the ReviTec context significantly affected the physical and chemical soil properties, such as pH, texture, water content, available P, available K, total nitrogen content and carbon content. Referring to outside (ctrl 1), soil changed from sandy and strongly acidic to clay-loam and slightly acid at GW1, and from sandy and strongly acidic to clay-loam and alkaline at GW2. Substrate filled in ReviTec bags influenced the soil particles by binding them together and improved aggregate stability directly by the binding of clay and indirectly by increasing microbial activity and the production of binding agents. Soil water content and soil nutrient (N, P) content increased inside the two ReviTec sites compared to outside (ctrl 1). Maximum values were obtained with the cpbcmy amendment. ReviTec structures revealed their capacity to improve soil quality. Thus, the ReviTec approach can be used for sustainable restoration of soil hardé. With these results, Cameroon, with the support of national and international organizations, can rely on this ecotechnology to restore their degraded land to be in step with sustainable development.

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