CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2024; 34 (4): 0094-0112
DOI: 10.59440/ceer/192176
Original Research Article

ANALYSIS OF THE EFFECTIVENESS OF A TECHNOLOGICAL SOLUTION TO SIMULTANEOUSLY MITIGATE SOIL DEGRADATION AND CONTROL THE INFESTATION OF INVASIVE PLANTS

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Abstract

Geotextile-based products have been considered as an adequate alternative to mitigate soil degradation processes, either by erosion or invasion by weeds. Thus, we assessed the efficiency of a bag confectioned with jute fabric and filled with mowed grass. We constructed six experimental plots considering two experimental conditions - three with the control (uncovered) and three covered with the product we generated (jute bag). We conducted the study during a rainy period and analyzed the efficiency of the product using the indicators: soil-chemical balance (including organic matter), soil-water repellence (hydrophobicity), changes in the microtopography of the plots, and emergence and growth of plants. We identified that within the study period, the engineered product provided effective protection to the soil surface, mitigating erosion processes, as well as delaying the rise of weeds (21% reduction). The soil's chemical and physical indicators evidenced that the soil was moderately improved. In this way, we argue that the product presents sufficient conditions to be an economically accessible alternative to control the soil degradation processes since it is simple and rapid to be manufactured and it uses materials that were initially considered waste, therefore being ecologically correct and interesting.

Keywords: biodegradable material-based geotextile, jute fiber, soil reinforcement, leaching, vegetation growth control

1. INTRODUCTION

1.1. Soil degradation

Soil degradation is accompanied by human development through the exploitation and occupation of land over the centuries. The non-use or misuse of practices of soil protection or conservation exposes the soil to accelerated degradation processes, such as water erosion and the uncontrolled introduction of weeds worldwide [1, 2].

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In the context of invasion by weeds, it might occur an imbalance of nutrients due to different forms of growth and storage or processing of materials, alteration in the telluric microbiological community, alteration of the propensity of the site to processes such as fires or water infiltration, diminishing the crop potential among other types of impacts [3]. Although some claim that the presence of weeds can benefit the soil (for example Singh et al. [4]), their massive presence can be highly harmful to the local environment. For example, forest restoration activities can be harmed by the invasion of these species [5], or they are usually host species of some types of disease or even favor the spread of fire in some locals [6]. That is why the control of these species is worthy of attention and there are ecologically correct and much better alternatives than simply pouring poison into the environment to control them.

1.2. Soil and Land quality indicators

Soil quality indicators are soil variables that represent system conditions or the ability of the soil to perform system functions. The attributes of a potential indicator are sensitivity and speed to change, ease of measurement and interpretation, as well as the possibility of repeatability of the method, reversibility to allow monitoring, and knowing what effect there was due to the intervention: positive, null, or negative. Different variables are related to the respective basic functions they measure.

Some functions include forms of interaction among soil and water, controlling the regulation and partitioning of water and solutes flow, regulating carbon and nutrient cycling, and providing physical stability for plants and animals, as well as providing support for structures associated with anthropogenic environments [7, 8]. For example: Differences in the wettability pattern considered in soil science and engineering occur according to the constituent elements of the soil, its state of drying, wetting, or waterlogging, as well as the quantification methods. For this, there are several methods of process quantification. One of the most used is the Water Droplet Penetration Time – WDPT which is the method used in this study.

Complementally, land quality might be conceptualized as the ability of the land to perform specific functions without being degraded [9]. Land quality indicators embrace soil quality indicators and other indicators, such as the percentage of covered/protected surface, the intensity of infestation of the cover by invasive plant species, and existing biodiversity on the soil.

1.3. Alternatives for soil reinforcement and mitigations of the process of degradation

Techniques aiming to control the rising and expansion of weeds are mostly based on chemical methods (use of herbicides) and/or non-chemical methods (fire and mowing) [10]. The choices and applications of techniques are usually determined based on cost and the availability of alternatives proposed to landowners. Such techniques, when misused, can bring adversities that directly affect the development of fauna and flora [11, 12]. Furthermore, if the vegetation is removed from the soil surface, the soil becomes vulnerable to weather agents, strengthening the cycle of degradation [13].

Hence, an alternative to consider is the use of some kind of cover that simultaneously reinforces the soil and protects it against weather agents and (re)colonization of weeds, such as geotextiles [14, 15, 16]. However, such an alternative still needs technical improvements and is achievable only for small places (reduced areas). For example, due to the high production cost, a wide area of inorganic materials in geotextiles is limited [17, 18]. Geotextiles can be manufactured with synthetic fiber, but they are difficult to decompose. This can cause long-term environmental problems. Additionally, when the terrain or building site is cleaned (the undesirable plants are removed) the waste or residue usually becomes a problem. In some agricultural lands, it is common to use straw mulch to reduce rainfall impact and erosion process that could affect soil nutrients [19].

Fortunately, this problem might be converted into a solution, aiming to abate the costs of the application of a geotextile to control soil degradation and infestation by weeds [17]. Many types of natural fibers have the potential to be used for soil reinforcement and this potential is variable between materials due to their mechanical properties such as traction and flexion, strength (for example abrasion resistance), and stiffness [16]. For example, integrating geotextiles made using natural fiber (jute), filled with straw, has been tested by Tsuchiya [20], and Silva et al. [21] for protecting and reconditioning degraded soils, avoiding the invasion by weeds. This technology was created and has been improved [20, 21].

In this study we presumed the following hypothesis: (i) a bag manufactured with jute tissue and filled with dry grass has the potential to cover the ground surface to the point of hampering the growth of weeds; (ii) the product can keep the geotechnical, physical structures and chemical characteristics of the soil, reducing the degrading effects of the erosive process. Therefore, the goal of this project was to test the effectiveness of the bag as a constrictor of the emerging and growth of weeds, and simultaneously as an alternative technique for erosion control and soil reinforcer, using the material readily available for use (mown grass).

2. MATERIALS AND METHODS

2.1. Study Area Characterization

We developed the study in the Campus of the Faculty of Technology of Sorocaba (FATEC-SP), São Paulo State, Brazil (Fig. 1 - see also KML supplementary file). The local is a rectangular terrain of 25 width and 6 m length, with a slope of 59º (166%). The experiment started on December 16th of 2019, which corresponds to the rainy period for our region and was carried out for 136 days.

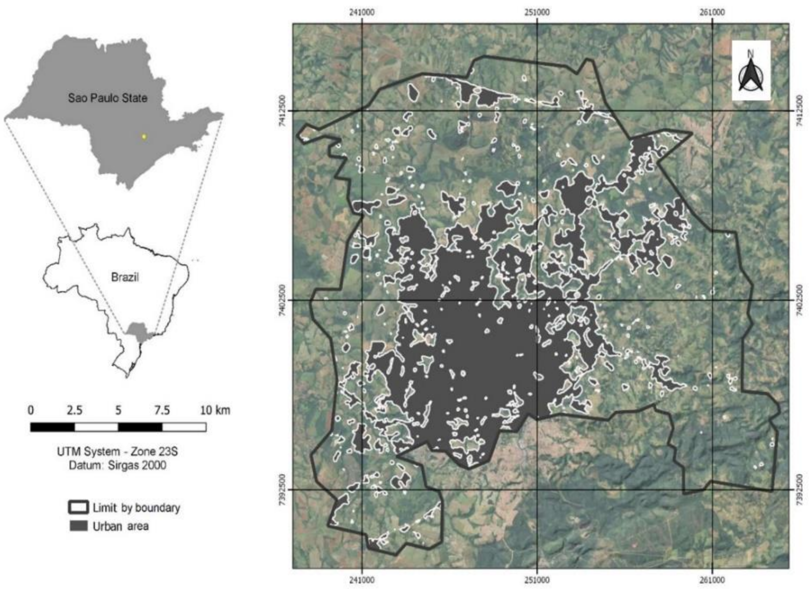

Fig. 1. Location map of study region. Source: modified from Bortoleto et al. [22]

2.2. Preparation of the Experimental Plots

After choosing the area for the experiment, we cleaned the terrain We placed the generated material (straws or scalped grass) for drying in a shadowed area and protected from rain, until the day of filling the bags.

Next, we subdivided the terrain into six identical rectangular plots. We constructed the plots with reused wood boards. Each plot was 1 meter in width by 6 m in length. The declivity of the plots was in the direction of the length of the plot. We considered three plots as control units (soil surface kept uncovered) and three plots as treatment units (we placed the bags).

We used the following materials for the construction of the experiment: 100 m jute roll; 10 kg of dry straw for each bag; 70 m of wooden boards (to delimit the experimental plots); and small wooden stakes (see supplementary file S1, link in the end of the manuscript).

We used three bags, one for each experimental plot of the treatment condition. We manufactured each bag with 12 meters of jute tissue and placed this material outstretched on the ground. Next, we placed 10 kg (dry weight) over six meters of such jute tissue, and we placed the other six meters of jute tissue over the straw. As a result, the product had three layers: two jute tissues (upper and lower layers) and a middle layer with a straw between the two layers of jute tissue, imitating a three-layer sandwich. Just after cleaning the surface and before placing the bags on the ground, we applied 1L of the herbicide glyphosate (Citromax®) diluted in approximately 30L of water, and spread the solution uniformly over the whole terrain, using manual sprinklers. Here, our goal was to inhibit the growth of plants with roots in the soil (which remained after mowing) or to inhibit the germination of the seed bank present there. This is a point of innovation concerning the experiment of the first version of this product designed and previously tested [20, 21]. On the slope, the bags were rolled up and positioned in the respective plots (Fig. 2).

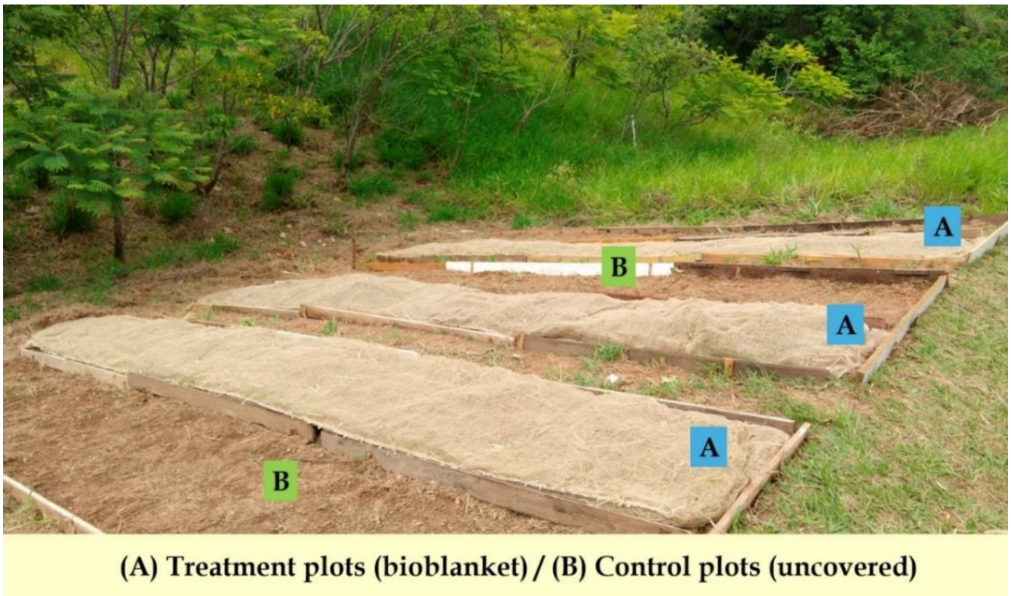

Fig. 2. Experimental area after positioning the bags

2.3. Obtention of the Rainfall Database

We acquired the rainfall data (height of rain, in millimeters per day) from December 2019 to April 2020 from a rainfall gauging station located approximately 100 meters from the study site. Such rainfall gauge belongs to the Brazilian National Institute of Meteorology and the data are available on the webpage of the institution [23].

2.4. Gathering samples, data, and physical and chemical analysis of the soil

In the superficial layer the soil is predominantly yellowish-browned. In terms of texture, it is classified as sandy loam, once there is 23.0% of silt, 17.5% of clay, and 59.6% of sand, with the 59.6% sand subdivided into 48.9% of fine sand and 10.7% of coarse sand [20, 21]. For chemical analyses, we proceed as follows.

Before constructing the experimental plots, considering that the terrain has soil with uniform characteristics, we collected small portions of soil in several parts and joined and mixed them in a recipient, resulting in a single composite sample. We sent part of this sample to a laboratory for analysis. The parameters analyzed were Phosphorus (H_2 PO_4^-), Potassium (K+), Calcium (Ca2+), Magnesium (Mg2+), Sulphur (SO_4^(2-)), Copper (Cu2+), Iron (Fe2+), Manganese (Mn2+), Zinc (Zn2+) and Cation Exchange Capacity (CEC). The team of the laboratory proceeded with the analyses following the methodologies proposed by Raij et al. [24] and presented in Table 1. The CEC was determined by sum of Calcium, Magnesium, Potassium and the Potential Acidity. After concluding the experiment, we collected a small portion of soil at two points of each plot of the treatment plots and mixed them, resulting in a composite sample according to the experimental condition. We proceeded the same with the control parcels. Hence, we sent part of these samples to the same laboratory for analysis of the same parameters cited earlier.

Table 1. Summarization of methods of analysis of the soil chemical parameters

Parameters	Method
P, K, Ca, Mg	Resin
B	Hot water
Cu, Fe, Mn, Zn	diethylenetriaminepentaacetic acid (DTPA)

Source: Tsuchiya [20].

Also, in our laboratory and using the other part of each sample, we analyzed the pH and the Electrical Conductivity (EC). For both parameters, we took one single aliquot of 20 ml from each sample (after drying). In a beaker, we added 40 ml of distilled water, mixed the solution gently using a glass stick, and the sample was kept stopped for 30 minutes. Next, we gently mixed the solution, and using a single multiparameter probe, we measured both parameters.

We estimated the soil bulk density by gently nailing a metallic cylinder of 100cm3 in the soil surface. The cylinder was gently removed, cleaned (the outer part) and transported to laboratory. In laboratory the sample was oven dried (80oC) until stabilization of mass and weighted. Next, the cylinder was completed cleaned, washed, dried and weighed. We subtracted the value of total mass (soil + metallic ring) by the mass of the ring and the used the resulting value (dry mass of soil) for computing the soil density, by dividing the mas by volume.

Complementarily, we also monitored the variation of total carbon (TOC) in the soil. Hence, biweekly we took a soil sample from each plot and, in the laboratory, after drying the sample, we took an aliquot of 20 g (dry weight) and put it in an oven for 120 min (440oC). Then, after lowering the temperature, the sample was weighed again. Then, we used Equation 2.1 to determine the organic matter and Equation 2.2 to quantify the TOC present in each treatment.

$$\mathrm{OM}\ (\%) = \left[\frac{\mathrm{IM} - \mathrm{FM}}{\mathrm{FM}}\right] \cdot 100 \tag{2.1}$$

Where:
OM = Organic Matter.
IM = the initial mass before being calcined (g).
FM = the final mass after calcination (g).

$$\mathrm{TOC} = \frac{\mathrm{OM}}{1.72} \tag{2.2}$$

Where:
TOC = Total Organic Carbon (dag.kg-1).
OM = Organic Matter (dag.kg-1).

2.5. Microtopography Analysis

Along each plot each 1 meter we stretched a string transversely across the plot, 15 cm above the ground level. The string acted as a guide. Along this “transect”, each 10 cm, and using plastic tape (measurer) we measured the distance from the ground to the string [25].

We annotated the data in a digital spreadsheet and transferred it to software to permit the interpolation of data and generation of the charts. After several tests, we concluded that the Kriging method of interpolation presented the best performance, and this was then considered to generate the definitive charts [26]. We prepared all charts with a color palette and kept them at the same scale for all plots.

We proceed with this work in all plots on two occasions: before and after the period of the experiment.

2.6. Water Infiltration Test

We used a graduated polyvinyl chloride (PVC) pipe 200 mm long and 100 mm diameter. In each experimental plot, we carefully inserted the PVC pipe into the ground surface (approximately 20 mm deep, taking care to avoid leaks on the basis). In each essay, we filled it with water up to the 0 mm mark on the graduated scale. Then, we timed the infiltration of the water in the soil. We performed the test in triplicate before starting the experimental period, adopting the condition of the soil uncovered.

Then, we repeated the test at the end of the experiment, selecting a centralized location within each experimental plot. In all plots, 6 infiltration tests were carried out, 3 referring to the control units and 3 treatment units. The data obtained were arranged in spreadsheets for the elaboration of the infiltration curve, converting the infiltration rate values to (mm.h-1), allowing a comparison. Furthermore, we sampled soil concomitantly with the water infiltration test to quantify, in the laboratory, the soil moisture.

2.7. Soil-Water Repellence Tests

We quantified and classified the soil according to the level of affinity to the water employing the Water Droplet Penetration Time (WDPT) method [20, 27]. On site, using a 3 mL plastic Pasteur pipette and distilled water, we drip a drop of water keeping the pipette always in the same position (horizontal) and height from the ground surface (10 cm), and measure the time of penetration of the drop into the soil. We classified the data following the suggestions proposed by Bisdom et al. [28].

2.8. Monitoring of the Vegetation Growth

We monitored the vegetation growth by taking a set of systematic, orthogonal photos biweekly with the camera of a Motorola One Hyper smartphone with a resolution of 64 MP. The photos were always taken from the same location in each plot, based on a 1 m x 1 m quadrant carefully placed on the ground to serve as a reference.

We treated the photos using the free App Color Analysis. The App converted the photos into numeric values (percentages) of pixel occurrence of each color. We classified the data by groping the colors into clusters: beige represented the organic wastes over the soil, brown represented exposed soil, and green represented live, growing plants.

2.9. Statistical Analysis of Data

The conducted statistical analysis by elaborating and testing the hypotheses are described ahead. The statistical tests were always chosen after we analyzed the necessity of previous normality tests.

Hypothesis 1: influence of bags in appearing and growing of vegetation.
H0: the averages of % of green in the bag plots are not significantly lower than in the control plots.
H1: the averages of % of green in the bag plots are significantly lower than in the bag plots.
We applied the test considering a significance level of 95%, H1 being considered true when the p-value < 0.05. The sample size for each treatment (“n”) was 30 means.

Hypothesis 2: influence of bag in conserving soil chemical elements (nutrients), physic-chemical parameters, and soil-water relationships.
H0: the averages of the values sampled in the bag treatment were not significantly different from the control.
H1: the averages of the values sampled in the bag treatment were significantly different from the control.

In this case, different statistical tests were applied for parameters in which the sample size was < 15. The statistical test applied for the indicators hydrophobicity and electrical conductivity was the t-test for two samples, after confirmation of the normality test for both parameters. The test was applied with a significance level of 95%, H1 being considered true when the p-value < 0.05. Otherwise, it is assumed that the results were not significantly different in the analyzed conditions.
About the hydrophobicity, 3 outlier values were eliminated from the samples, maintaining a sample size of 27 means. The sample size of electrical conductivity was 20 samples per treatment. Total organic carbon (TOC) was submitted to the non-parametric Kruskal-Wallis test. The non-parametric test was applied due to the sample size being < 15, which is equivalent to 10 samples per treatment. In this case, the quantitative values were related to the respective treatments adopted in the datasheet. In the statistical analysis of the Kruskal-Wallis test, mean rank values calculated from the similarity between the data obtained by the treatments are attributed.

3. RESULTS

3.1. Rainfall data

During the period of the experiment, if we consider the entire month of December of 2020, we recorded 795 mm. In this scenario, this month had rainfall practically equal to February (each month represented 32% of the total depth). On the other hand, if for December we compute only the experiment period, whose rainfall depth was 83 mm (Fig. 3), then the total depth is 623 mm and February of 2021 represents 41.1% of the total period. Such a period characterizes a rainy period, having rainfall events with a high potential to cause erosion in soils unprotected and/or highly vulnerable to this process.
Fig. 3 also shows historical monthly averages for a period of 30 years (1981 – 2010), allowing an inference about a possible alteration in the regional rainfall regime because of climate change, as will be discussed in the section Discussion.

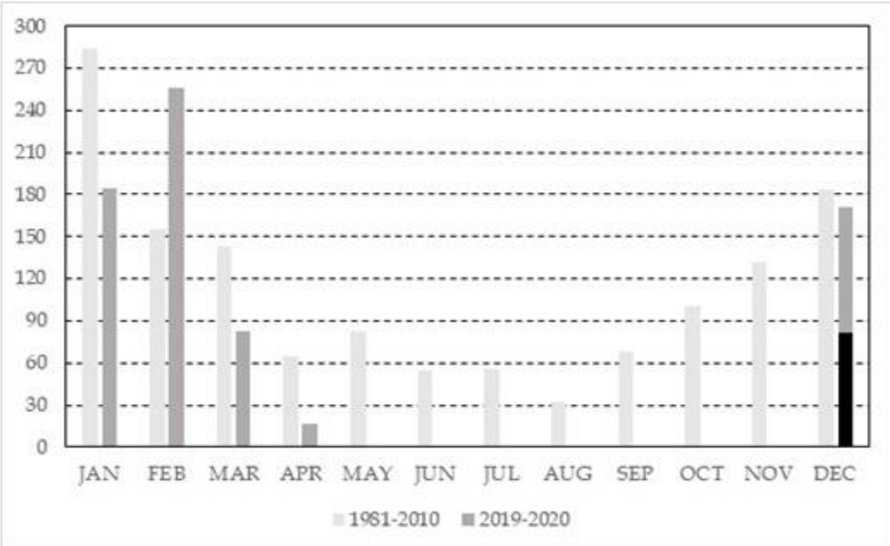

Fig. 3. Rainfall depths (mm). Source of data: [22]

3.2. Microtopography Analyses

Microtopographical analysis revealed that the bag was effective in protecting the soil surface. The bag mitigated the erosion process in two ways: avoiding the splashing of particles by intercepting rainwater droplets and preventing the formation of excessive runoff, which would cause both sheet erosion and erosion in channels. The predominant range of groove depth in the surface of the plots of the "treatment" experimental condition is between 3.5 to 5.5 cm (see supplementary file S2). In the control plots, P3 and P6 were the ones that suffered the greatest impact from the erosion process, predominating the presence of furrows with more than 6 cm in depth. The control plots showed increasing values in depths when we compared the state of the surface of each plot before and after the experiment period.

3.3. Water Infiltration Test

The curve generated with the data gathered in the parcels of the control condition presented the highest infiltration rate during the first 12 min of the experiment, being approximately 800 mm.h-1. Stabilization of infiltration rates occurs after 15 min for the three curves (Fig. 4). Concurrently, we recorded the soil moisture at the instant of the experiment. The results were: before the experiment: 23.6%, after the experiment (condition control): 7.1%, after the experiment (condition treatment): 9.5%.

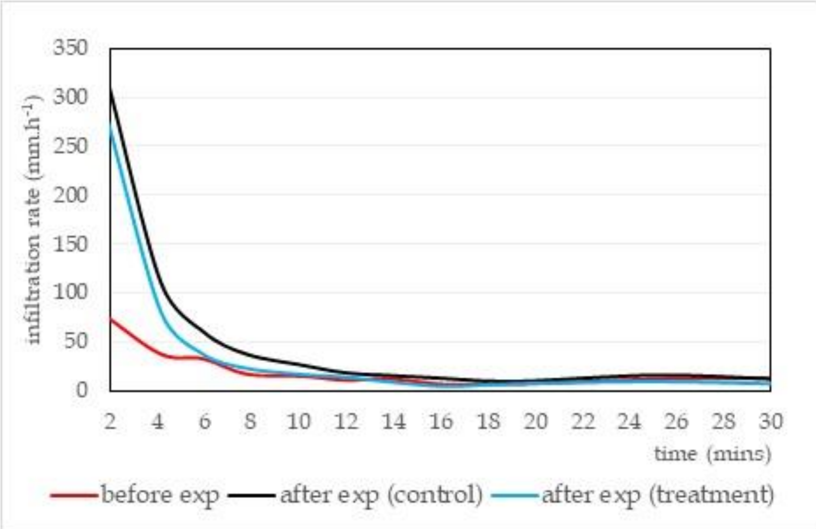

Fig. 4. Infiltration rates before and after the experiment, and for both experimental conditions

3.4. Physical and Chemical Analyses

We classified the texture of the local soil as sandy loam since it presented 59.6% sand, 17.4% clay, and 23.0% silt [20]. On the variation of the water content in the soil, in all collections, we recorded higher water content in the soil of the plots covered by the bag. The smallest recorded difference was 4.7%, while the largest was 12.4% and the overall mean difference was 9.2%. The water content in the soil is a variable of rapid variation and the presence of the jute bag had an influence, notably when the water content was lower (Fig. 5).

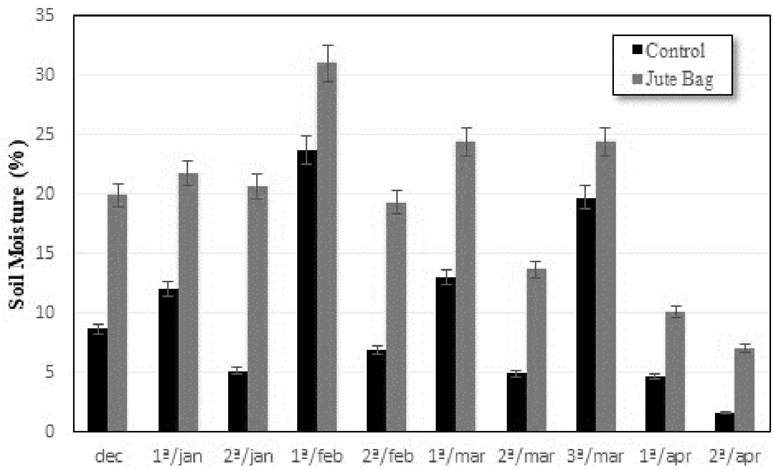

Fig. 5. Comparison between the soil moisture and the experimental conditions

The analysis of the soil density revealed that, after the experiment was finished, in the plots whose soil was uncovered during the experiment period, the density remained the same about the initial moment, while the soils that remained under the jute bags had the density reduced (Table 2).

Table 2. Average soil density obtained before and at the end of the experiment

Experimental condition	Soil bulk density (g.cm^{-3})
Before starting the experiment	1.38
After finishing the experiment (jute bags)	1.23
After finishing the experiment (control)	1.38

The data concerning electrical conductivity denote that the local soils are not saline, due to the constantly low values recorded (Fig. 6). The values were always close to each other for both experimental conditions, the values of the control condition were higher, and sometimes the values of the treatment condition were higher. Hence, we perceive that the jute bag had nil influence on this parameter, not being positive, but not being negative, however.

3.5. Chemical and physical-chemical parameters

Regarding soil chemical analysis, we found that the presence of the jute bag did not provide significant gain or enrichment of nutrients (at least during the study period), but rather provided conservation of most of the existing nutrients in the soil. We reported stability or augment in the value of the concentration of potassium, boron, iron, and zinc (Table 3).
The ability to maintain soil nutrients by the jute bags is corroborated by the data about the Cation Exchange Capacity (CEC). The CEC represents an indicator of the soil's capability to hold positively charged ions. We then verified that during the 136 days (experimental period), there was constant protection in the plots of the treatment condition and, in the plots of the control condition, as the weeds grew, so did the cover over the soil and, therefore, some protection was emerging and increasing, as the weeds were intentionally not controlled by the researcher team. This is a possible explanation of the similarity of the data.

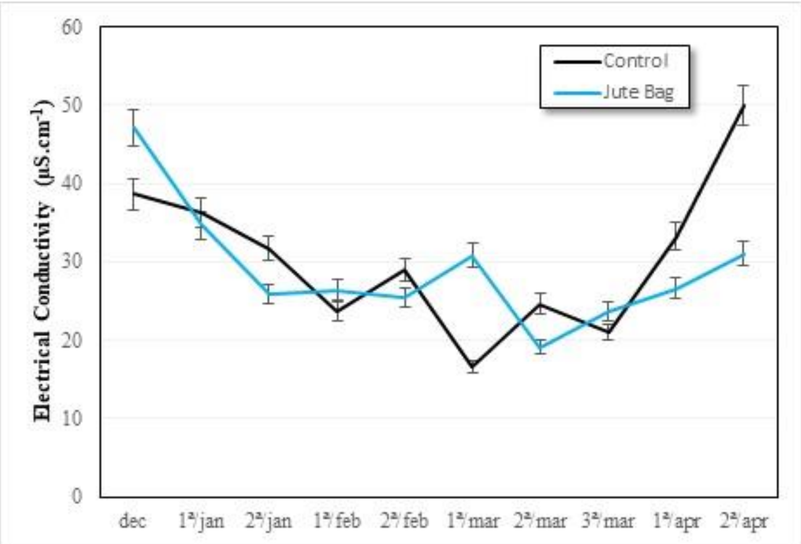

Fig. 6. Comparison of Electrical Conductivity (EC) values in the control and treatment plots

Apropos the carbon concentration in the soil, the medium values of the plots of the treatment condition ranged from 1.6% to 3.1%, representing a total average value of approximately 2.3%. In the control condition, carbon concentrations ranged between 1.5% and 2.5%, with the total average value corresponding to 2.0% (Fig. 7). The Kruskall-Wallis test revealed that for the 95% significance level, the means obtained were not significantly different, which characterizes that the hypothesis is null for the conditions of the experiment.

Table 3. Values for pH, content of nutrients, and CEC present in soil samples for initial conditions and for treatment/control. For CEC, the values in parenthesis represent the percentage that the cationic fraction $H^+ + Al^{3+}$ represents in the total value of the CEC

Parameter	Before experiment	After experiment	
		Treatment	Control
pH (dimensionless)	5.0	5.2	5.1
P ($mg.dm^{-3}$)	3	2	1
K ($mmolc.dm^{-3}$)	2.5	3.5	3.3
Ca ($mmolc.dm^{-3}$)	23	17	16
Mg ($mmolc.dm^{-3}$)	9	8	6
$H^+ + Al^{3+}$ ($mmolc.dm^{-3}$)	31	28	16
S-SO_4 ($mg.dm^{-3}$)	7	6	4
B ($mg.dm^{-3}$)	0.07	0.12	0.15
Cu ($mg.dm^{-3}$)	0.2	0.1	0.2
Fe ($mg.dm^{-3}$)	14	32	16
Mn ($mg.dm^{-3}$)	11.4	10.4	11.4
Zn ($mg.dm^{-3}$)	0.8	0.8	2.8
Base Saturation (%)	53	29	25
CEC ($mmolc.dm^{-3}$)	66.5	56.5	41.3

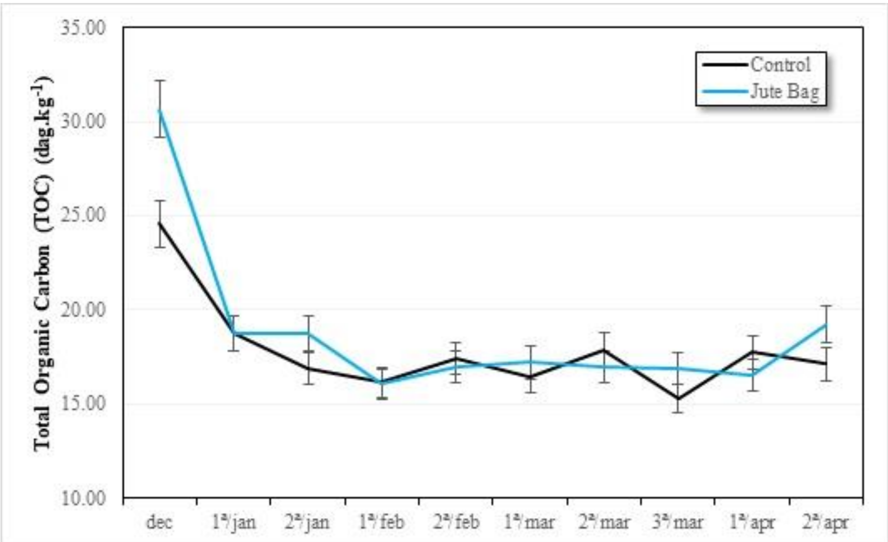

Fig. 7. The average concentration of TOC

Comparable to the soil nutrient data, the carbon data also point to similar values throughout the experimental period, confirmed by the results of the Kruskal-Wallis test, although there was a difference between the values in the first sampling. In both experimental conditions, there was a notable decay between the first and second sampling dates, with subsequent stability of the values. This notable decay should be probably associated with the leaching of the dissolved fraction of organic matter and/or rapid decomposition of the labile fraction of organic matter since the curves generated in this study have similar aspects to the curve of the labile fraction presented by Prescott and Vesterdal [29] and the reasons explained by the authors fit with the scenario reported in this study.

Interestingly, different from what we expected, the decomposition process that occurred in the organic material present in the jute bags did not reflect an increase of C in the soil. We had the prediction that over time, due to the process of physical breakdown of the grass fibers that were inside the bags, the smaller particles would migrate to the soil through the action of rainwater and with that would increase the content of C in the soil, but this fact was not observed, however.

3.6. Soil-water repellence assessment

The presence of the jute bag provoked an increase in water repellence by the soil of the treatment condition plots in the first half of the experimental period, evidenced by the differences in the penetration time of the water drop in the soil (Fig. 8) and confirmed by the statistical test at 95% confidence. During the second half, the hydrophobicity decreased in the plots of jute bags, while the time of penetration of drop water in the plots uncovered discreetly decreased. The dynamic reported about the covered plots is certainly a reflection of the change in the characteristics of the organic material present in the bags. If the C content was not changed, the soil-water ratio somehow reflected the migration of organic compounds contained in the filling material of the bags to the soil.

3.7. Vegetation Growth Analysis

Through the analysis of the photos taken during the period of the experiment, we noticed that the most predominant species is the brachiaria (*Brachiaria decumbens* Stapf) in all experimental plots (see supplementary file S3). The control plots had a gradual vegetation growth (Fig. 9), with vegetation occupation of approximately 7% during the first day of January 20th and stabilizing around 50% after March 20th. On the other hand, plots treated with a bag had late and attenuated growth. The vegetation developed from the second sampling on January 20th at approximately 2% and stabilized at 17% from March 20th.

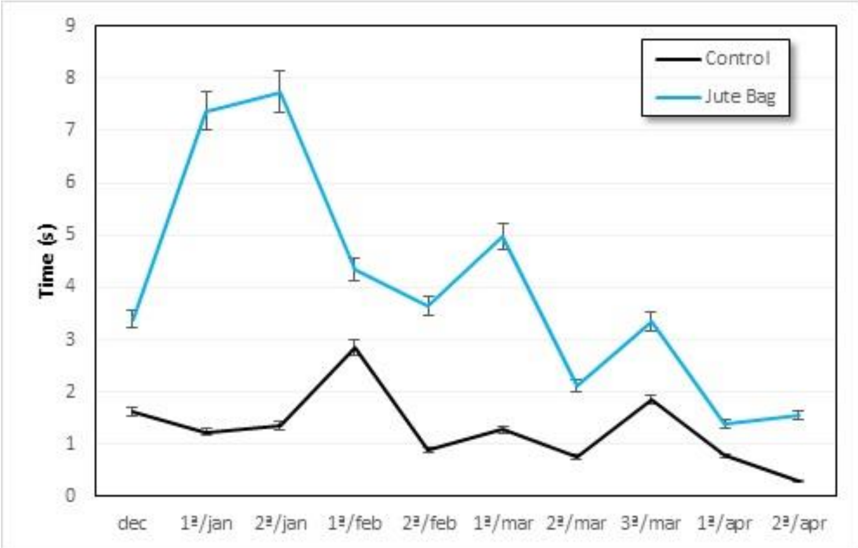

Fig. 8. Differences in the pipetted droplet dissipation for soil hydrophobicity test in the control and treatment experimental conditions

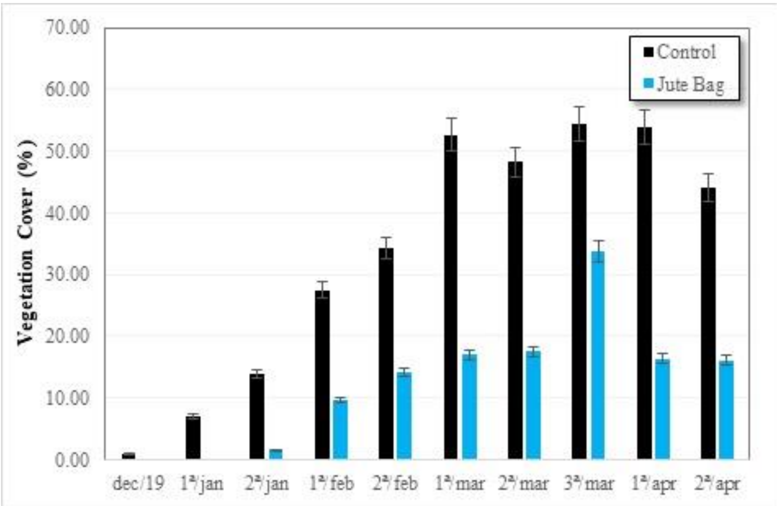

Fig. 9. Vegetation cover (% of green) in the plots of the control and treatment experimental conditions

After applying the t-test for the 2 treatments, a difference of 21.08% was obtained between the means. The average % of green for the covered plots (treatment) was considered significantly lower than the control plots at a probability of 5%. The test still indicates that the difference would still be significant for standards equivalent to a probability of 1%. This result validates the effect of vegetation control after the soil surface with the bag.

4. DISCUSSION

4.1. Rainfall database analysis

The local climatological normal shows that the month of January tends to be the month with the highest volume of rainfall. However, in the period in which we experimented, February of 2021 was the month with the highest volume of rainfall surpassing the historical average presented. January, March, and April of 2021 presented volume well below the average and tended to decrease as time progressed towards the middle of the year, which corresponds to the usually dry winter in the region.

Even so, the rains that occurred characterized erosion, evidenced by the topographic maps, and the fact that the soils were not covered (plots of the control condition) showed the capacity of local rains to trigger erosion and the need to keep the soil protected. This scenario highlights the demand for products or materials generated, for example, in this work presented here or similar ones, as reported by Nsiah and Schaaf [17]. Natural infrastructure as reported here can be considered as a measure to help make places more resilient in the face of global climate changes, which tend to be more and more severe over the years [13, 15, 17].

4.2. Changes in Microtopography

Understanding the changes caused in the soil surface on a microtopographical scale simplifies the identification of the points or regions on the surface most affected by the erosive action of rainfall, as well as the phase of the erosion process [30]. In terms of the effectiveness of this evaluation method (microtopographical analysis), we understand that it was efficient, and its efficiency is concerned with the fact that it is a simple and low-cost alternative to detail the erosion process, including the detachment, transport, and deposition of particles, as well as to identifying where and how the technology presented here (jute bag) works to prevent erosion.

Regarding the treatment condition plots, the surface maps evidenced that a part of the sediments was displaced over the previously identified furrows, reducing the surface texture and the downhill channels. On the other hand, there was an increase in the size of the furrows in the control plots, a result enhanced by soil exposure.

Utilizing plant fiber enhances the integrity of the granular soil matrix and uniform behavior, since it creates a better bridge between the individual particles, promoting erosion resistance [16]. In our experiment, the application of the jute bag proved to be efficient in terms of soil protection, contributing also to protection against detachment (soil splash) and reducing the velocity of surface runoff that could arise in moments of intense rainfall [21]. This fact corroborates the findings of Silva et al. [21] where the authors recorded a statistically significant difference in terms of soil loss in covered and uncovered plots with a product very similar to that tested in this experiment.

4.3. Water Infiltration Test

Soil water infiltration is influenced by rainfall characteristics, soil physical properties, terrain slope gradient, soil cover type, and soil surface roughness [31]. High infiltration rates are characteristic of sandy and dry soils [32]. The soil in our study area has sand as the main granulometric fraction and we verified that in the dry situation, there is a strong infiltration capacity in the first minutes. The infiltration curves showed that there was little difference between the infiltration rates and the conditions established throughout the experiment. The main change was detectable in the first 12 min, in which the control condition had a peak of 800 mm.h-1, and the experimental condition treatment was approximately 380 mm.h-1. This difference may be related to soil moisture at the time of measurement, since, at least in the short term, the protective and reinforcing action of the jute bag is on the soil (surface) and not in the soil (depth).

Likewise observed by Sanyal [33], once laid on the soil the jute bag retains part of the water that would be lost through the evaporation process. Hence, considering that wet soils will have a lower initial infiltration rate than dry soil until both conditions reach the same plateau (this rate is called the stable infiltration rate, showing a constant value until all the water has infiltrated), it is possible to presume that the jute bag had an immediate initial influence, reducing infiltration rates, but it is not possible to state that the soil became more permeable after placing the jute bag material in the soil.

4.4. Soil Chemical and Physical Indicators

Regarding the soil bulk density, we found a slight change in the plots of the experimental condition treatment (average value of 1.23 g.cm-3). Such a value was lower than the initial, and that was for the control condition.

The soil of the plots of the experimental condition treatment was kept moist even in the months with lower precipitation. The importance of maintaining soil moisture is related to the availability of water for plants, as well as the development of fungal species. Although they were not identified during the experiment, mycorrhizae, through a symbiotic relationship of mutualism with plant roots, can assist in the uptake of nutrients and function as biological indicators [34].

The soil's electrical conductivity (EC) is usually associated with the presence of some salts related to soil fertility [35] and the presence of water. Comparatively, among studies involving EC in soil, Romeo et al. [36] carried out tests to verify possible changes in the soil after burning in a coniferous area. The samples of the work indicated small variations in the EC according to the depth and degree of severity of the areas affected by the fire. Compared with the application of jute bags, despite the studies having different soil conditions, both showed non-significant variations between the samples collected up to 5 cm deep, except for the plots in which the authors considered the average degree of soil severity. Regarding the loss of nutrients by the leaching process, the jute bags evidenced the capacity to minimize the loss of nutrients by keeping concentrations close to the amounts originally identified at the beginning. Some protection mechanisms can be highlighted: protection against the direct impact of raindrops on the soil surface, protection against the formation of runoff, mitigation of water loss by evaporation, and provision of organic material as the material decomposes and incorporates it into the soil [37].

4.5. Soil-water repellence (SWR) assessment

SWR affects several soil physical processes. Exemplifying, surface water infiltration may be altered according to the land qualities, which may increase the probability of runoff and soil erosion. SWR can also lead to preferential movement in the forms of fingers, macropores, and pipes due to the occurrence of repellent hydrophobic soil organic elements [38, 39]. Additionally, soil water repellence is related to factors such as moisture, amount of organic matter, production of hydrophobic substances by vegetation, and angulation of soil aggregates [40].

In our experiment, we focused on understanding how the application of the jute bags would influence the relations of water affinity or repellence by soil. Thus, we observed that the dissipation time of water drop was longer in the plots with the jute bag, but in both conditions, the average values remained less than 5 seconds, characterizing a hydrophilic condition. The variation may be associated with the substances released by the organic matter used to fill the jute bags, which could lead to an increase in hydrophobicity. We understand that this is a positive property of the jute bag, as it protects the soil without significantly altering its water-relationship characteristics [41].

In terms of soil moisture, we observed that the months with the highest volume of rain had a longer time for droplet dissipation, especially for the plots covered with jute bags. Studies show that the decomposition of certain organic substances, such as waxes, can generate a hydrophobic layer, which could lead to a decrease in water infiltration and an increase in surface runoff, so it would be a possibility for other researchers to compare the hydrophobicity of the soil after geosynthetic decomposition [42].

4.6. Monitoring of the Invasive Vegetation Growing

Our photographic analysis showed that the plots of the experimental condition treatment presented weed emergence only after the second month. On the other hand, the control plots had continuous growth right after the beginning of the experiment, until they reached a level of approximately 50% of soil cover. Comparatively, covering the soil with a jute-based bag reduced growth during the stabilization period by about 30%. We proposed a preventive method of weed control, trying to control the emergence of the seedlings. Invasive species generally have ample potential to colonize open spaces where sunlight hits the soil surface with frequency and intensity [43]. Hence, the predictable mechanism of interference of the jute bag on the soil surface is to reduce the rate of seed germination of heliophyte species (heliophytes constitute a group of plants that occur in open environments such as clearings, strips, areas impacted by fire, etc.), preventing sunlight from reaching the upper surface of the soil. This block prevents the activation of physiological mechanisms of germination, such as heating, hormonal activation and drying.

5. FINAL REMARKS

This study helped us elucidate that the role of the jute bag on the soil is a reinforcer and, at least in the short term, it does not alter the soil chemically nor physically since during the period of the experiment, no significant physical and/or chemical changes were noticed, neither negative nor beneficial in the depth of the soil.

The microtopographical analysis showed the potential of the jute bag to protect the soil, indicating that the protective effect on the soil occurs by cushioning the impact of the erosive force of raindrops, preventing the splashing of soil particles, and preventing the formation of runoff, preventing o Formation of erosion channels.

Based on our data and some published studies, we suggest that when it is desirable or necessary to continue to protect the soil through biostructures such as the one presented here, because of the biodegradation process of all the material (jute fabrics and filling material), after approximately 100 days a new bag should be put in place, but the old material (jute bag residue), if still present, would not need to be removed.

ACKNOWLEDGMENTS

The authors gratefully thank FATEC for providing the area for the experiment, and Unesp, for providing the laboratories and equipment for study.

FUNDING

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brazil (CAPES) – Finance Code 001.

CONFLICT OF INTEREST STATEMENT

We declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from both authors, upon request.

SUPPLEMENTARY, ANONYMOUS FILES CAN BE ACCESSED BY THE LINK BELOW

https://drive.google.com/drive/folders/1X_0a_tk0nQGtdt6NtUYvMMAQT-Cng4Re?usp=sharing

REFERENCES

1. Nayakekorale, HB 2020. *Soil Degradation*. In: The Soils of Sri Lanka: World Soils Book Series. 1st ed. Switzerland: Springer Nature: 103-118.
2. Slenicka, P, Zouhar, J, Molnarova, KJ et al. 2020. Trends of soil degradation: Does the socio-economic status of landowners and land users matter? *Land Use Policy* **95**, 1-8.
3. Wolfe, BE and Klironomos, JN 2005. Breaking new ground: soil communities and exotic plant invasion. *Bioscience* **55**, 477-487.
4. Singh T, Choudhary, A and Kaur, S 2023. Weeds can help in biodiversity and soil conservation. Indian *Journal of Weed Science* **55**, 133–140.
5. Wallace, KJ, Laughlin, DC and Clarkson, BD 2017. Exotic weeds and fluctuating microclimate can constrain native plant regeneration in urban forest restoration. *Ecological Applications* **27**, 1268-1279.
6. Rao, VS 2000. *Principles of weed science*. CRC Press, 2nd edition.
7. USDA (United States Department of Agriculture) 2015. *Soil Quality Indicators: Chemical Indicators and Soil Functions*. Factsheet. See https://www.nrcs.usda.gov/sites/default/files/2022-10/chemical_indicators_overview.pdf
8. Stefanoski, DC, Figueiredo, CCD, Santos, GG and Marchão, RL 2016. Selecting soil quality indicators for different soil management systems in the Brazilian Cerrado. *Pesquisa Agropecuária Brasileira* **51**, 1643-1651.
9. Dumanski, J and Pieri, C 2009. *Land Quality Indicators (LQI): Monitoring and Evaluation*. In: Land Use, Land Cover and Soil Sciences-Volume II: Land Evaluation, Oxford, UK, 160.
10. Nuñez, MA, Chiuffo, MC, Torres, A et al. 2017. Ecology and management of invasive Pinaceae around the world: progress and challenges. *Biological Invasions* **19**, 3099-3120.
11. Badía, D, López-Garcia, S, Martí, C et al. 2017. Burn effects on soil properties associated to heat transfer under contrasting moisture content. *Science of the Total Environment* **601-602**, 1119-1128.
12. Hagner, M, Mikola, J, Saloniemi, I et al. 2019. Effects of glyphosate-based herbicide on soil animal trophic groups and associated ecosystem functioning in a northern agricultural field. *Scientific Reports* **9**, 13.
13. Lal, R, Blum, WE, Valentin, C and Stewart, BA 2019. *Methods for Assessment of Soil Degradation*. CRC press. Ed 1, Florida, USA.
14. Chmura, D, Salachna, A, Broda, J et al 2022. Multifunctional Geotextiles Produced from Reclaimed Fibres and Their Role in Ecological Engineering. *Materials* **15**, 7957.

15. Mohamed, WW, Osman, N and Abdullah, R 2022. A review of bioengineering techniques for slope stability in Malaysia. *International Journal of Environmental Science and Technology* **20**, 1-16.
16. Shalchian, MM and Arabani, M 2022. A Review of soil reinforcement with planetary fibers. *Journal of Soil Sciences and Plant Nutrition* **22**, 4496-4532.
17. Nsiah, PK and Schaaf, W 2019. The potentials of biological geotextiles in erosion and sediment control during gold mine reclamation in Ghana. *Journal of Soils and Sediment* **19**, 1995-2006.
18. Wu, H, Yao, C, Li, C et al. 2020. Review of application and innovation of geotextiles in geotechnical engineering. *Materials* **13**, 1774.
19. Sun, Z, Wang, Y and Sun, L 2022. Effects of straw mulching on soil nutrient content and microbial community on the gentle slope arable land in dryland farming. *Archives of Agronomy and Soil Sciences* **69**, 1-12.
20. Tsuchiya, LH 2017. *Effectiveness of the integrated use of two soil conservation and recovery techniques (mulch and hydroseeding): comparison of soil losses and soil organic matter dynamics*. Monography (in Portuguese), São Paulo State University (UNESP), Institute of Science and Technology, Campus Sorocaba.
21. Silva, AM, Tsuchiya, LH, Mendes, PB et al. 2019. Jute bioblanket as a soil rehabilitation strategy in Sorocaba, Brazil: Soil chemistry and SWOT approaches. *Environmental Quality Management* **29**, 125-137.
22. Bortoleto, LA, Rodgers, J and da Silva, AM 2022. Detecting and Restoring Gaps Among Forest Patches: AN Achievable and Replicable Proposal to Boost the Landscape Connectivity. *Civil and Environmental Engineering Reports* **32**, 62-84.
23. INMET – Brazilian National Institute of Meteorology 2022. *Normal Climatológica do Município de Sorocaba de 1981-2010*. See https://portal.inmet.gov.br/?r=clima/normaisclimatologicas.
24. Raij, B van, Andrade, JC de, Cantarella, H and Quaggio, JA 2001. *Análise Química para Avaliação da Fertilidade de Solos Tropicais*. Instituto Agronômico de Campinas, Campinas, 285 p.
25. Silva, AM, Moradi, E, Rodrigo-Comino, J and Cerdà, A 2019. Spatial variability of soil roughness in persimmon plantations: A new combined ISUM (improved stock unearthing method) approach. *Ecological Indicators* **106**, 105528.
26. Guangren, S 2014. *Kriging*. In: Data Mining and Knowledge Discovery for Geoscientists. Elsevier. 238-274.
27. Doerr, SH, Shakesby, RA and Walsh, R 2000. Soil water repellency: its causes, characteristics, and hydro-geomorphological significance. *Earth-Sciences Reviews* **51**, 33-65.
28. Bisdom, EBA, Dekker, LW and Schoutte JFT 1993. Water repellency of sieve fractions from sandy soils and relationships with organic material and soil structure. *Geoderma* **56**, 105-118.
29. Prescott, CE and Vesterdal, L 2021. Decomposition and transformations along the continuum from litter to soil organic matter in forest soils. *Forest Ecology and Management* **498**, 119522.
30. Ta, N, Zhang, C, Ding, H and Zhang, Q 2020. Effect of tillage, slope, and rainfall on soil surface microtopography quantified by geostatistical and fractal indexes during sheet erosion. *Open Geosciences* **12**, 32-241.
31. Pereira, LC, Balbinot, L, Matus, GN et al. 2022. Aspects of forest restoration and hydrology: linking passive restoration and soil–water recovery in Brazilian Cerrado. *Journal of Forestry Research* **5**, 1-11.
32. Beven, K and Germann, P 2013. Macropores and water flow in soils revisited. *Water Resources Research* **49**, 3071-3092.
33. Sanyal, T 2017. *Jute, Jute Fiber, and Jute Yarn*. In: Jute Geotextiles and their Applications in Civil Engineering. 1st ed. Singapore: Springer Nature: 7-17.

34. Carneiro, RFV, Júnior, FMC, Pereira, LF et al. 2012. Fungos micorrízicos arbusculares como indicadores da recuperação de áreas degradadas no Nordeste do Brasil. *Revista Ciência Agronômica* **43**, 648-657.
35. Diatta, AA, Fike, JH, Battaglia, ML et al. 2020. Effects of biochar on soil fertility and crop productivity in arid regions: a review. *Arabian Journal of Geosciences* **13**, 1-17.
36. Romeo, F, Marzilliano, PA, Turríon, MB, and Muscolo, A 2020. Short-term effects of different fire severities on soil properties and Pinus halepensis regeneration. *Journal of Forestry Research* **31**, 1271-1282.
37. El-Beltagi, HS, Basit, A, Mohamed HI et al. 2022. Mulching as a sustainable water and soil saving practice in agriculture: A review. *Agronomy* **12**, 1881.
38. Moura, AS 2018. *Hydrophobicity in sandy and clayey soils under different uses in the semi-arid region of Pernambuco. Dissertation* (in Portuguese), Federal Rural University of Pernambuco, Garanhuns Academic Unit, Garanhuns, Pernambuco, Brazil.
39. Huang, J and Hartemink, AE 2020. Soil and environmental issues in sandy soils. *Earth-Sciences Reviews* **208**, 103295.
40. Hermansen, C, Moldrup, P, Müller, K et al. 2019. Organic carbon content control the severity of water repellency and the critical moisture level across New Zealand pasture soils. *Geoderma* **338**, 281-290
41. Movasat, M and Tomac, I 2021. Assessment of physical properties of water-repellent soils. *Journal of Geotechnic and Geoenvironment* **147**, 06021010.
42. Maia, CMBF, Dedecek, R and Malucelli, CS 2005. Identificação de Repelência à Água em Solos sob Plantios Florestais. Colombo, PR, Embrapa Florestas. *Technical Report* **147**, 1-6.
43. Vasic, V, Konstantinovic, B and Orlovic S 2012. *Weeds in forestry and possibilities of their control*. In: Weed control. IntechOpen 147-170.