# Vegetative cover index for different bioengineering techniques executed in the Simplício Hydroelectric Power Plant - FURNAS

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ABSTRACT
This study aims to evaluate the efficiency of bioengineering techniques of slopes surface protection in the development of vegetation over a period of two years and three months. For this purpose, different techniques were executed in two experimental facilities located on the slopes near the Simplício Hydroelectric Power Plant – FURNAS in Brazil. High-resolution images of the slopes' frontal view were obtained in 15-days intervals visits to the experimental facilities. The images were treated and submitted to a computational algorithm that, based on three-color bands, provided the vegetation cover index for each technique adopted. The results showed that only one technique presented an acceptable value of vegetation cover index throughout the period evaluated and most of the techniques applied have shown to be sensible to climatologic conditions.

## 1. INTRODUCTION

Superficial erosion on slopes consists of a process of separation and transport of sediments that have been reported since the early 16th century (Taunay 1914). This process occurs mainly through the action of water (water erosion) attached to the removal of existing vegetation, disturbance in the slope superficial soil (e.g., compaction, loss of fertility), steeper slope surfaces, among other factors. Since in Brazil the erosion is predominantly caused by water, it is divided into laminar erosion (caused by the impact of the rainfall water drops) and linear erosion (caused by point accumulation and runoff resulting in furrows, ravines, and gullies; Bertoni and Lombardi, 1999). Erosion and subsequent sedimentation are responsible for environmental impacts on adjacent watercourses. Moreover, when not treated properly, it may compromise the lifetime of equipment and concrete structures (of geotechnical works) due to abrasion (Coelho, 2007). In this way, the protection and control of erosion process impact not only in the design of geotechnical works but also in the operational costs.

The erosion control aims to minimize the erosion potential of disturbed sites and restrict the transport of sediments from these sites (Atkins et al. 2001). For effective erosion control, temporary and/or permanent control methods should be included in the design, construction, and subsequent maintenance, of geotechnical works (Johnson et al., 2003). In this sense, the correct use of superficial soil protection with plants (vegetation) or other erosion control techniques should involve (Howell 1999; USDA 2016): i) adequate planning, ii) field survey, iii) knowledge of soil characteristics, slope stability, and environmental conditions and iv) knowledge of surface and sub-surface hydrological characteristics.

The techniques adopted for superficial slope protection involves the isolated use of living elements (vegetation) or inert elements (e.g., rocks, wood, geosynthetics; Kruedener, 1951). However, field studies have shown that the use of bioengineering systems (bio-technical systems), that means, techniques that combine living and inert elements for superficial slope protection, are more attractive (technical and economic aspects) than the isolated techniques (Gray and Leiser 1982). In this system, inert structural elements provide immediate resistance to erosion processes and soil mobilization and transportation. Once the vegetation is established, the roots entered inside the superficial soil and provide a combined structure. Over time, the inert structural elements decrease its importance in the system meanwhile the vegetation increases its importance and reinforces the system as a whole (Gray and Sotir 1996).

In this way, this study aims to evaluate the evolution of vegetation developed in slopes' superficial soil through four different bioengineering techniques in slopes of the Simplício Hydroelectric Power Plant – FURNAS in Brazil. Furthermore, this study assesses the behaviour/resistance of vegetation to climatic events throughout the analyzed period and the soil's fertility influence of the areas that the techniques were applied.

## 2. MATERIALS AND METHODS

### *2.1 Location and soil fertility of the experimental facilities*

This study reports tests performed in two experimental facilities (EF) that consists of slopes located on riverbanks of the Paraíba do Sul river, near to the Simplício Hydroelectric Power Plant in Brazil. The areas under study were demarcated (fences), using appropriate materials and equipment, to avoid traffic and trampling of people and animals. As this study concerns about the development of vegetation in the superficial soil of slopes, the soil fertility of both experimental facilities (Table 1) was verified through the exchangeable calcium (Ca), aluminum (Al) and magnesium (Mg) contents, potassium (K) and phosphorus (P) contents available, as well as the hydrogen ion concentration (pH) and organic matter (O. M.) content.

Table 1. Soil fertility of the experimental facilities EF1 and EF2

| Local | Ca [meq/100cm³] | Al [meq/100cm³] | Mg [meq/100cm³] | K [ppm] | P [ppm] | pH | O. M. [%]. |
|---|---|---|---|---|---|---|---|
| UE1 | 1,0 | 0,2 | 0,3 | 12 | 1 | 5,7 | 0,21 |
| UE2 | 1,0 | 0,1 | 0,3 | 24 | 2 | 5,8 | 0,03 |

### *2.2 Materials*

Both experimental facilities were divided into sections (11 sections (S01 - S11) for EF1 and 14 sections (S01 - S14) for EF2) and different engineering solutions for slope surface protection were investigated, as described in Table 2. The execution of the techniques was preceded by the preparation of the slope surface, which means, cleaning, removal of bulges and poorly consolidated soil masses, and manual conformation. These procedures were adopted along with the entire superficial soil of the slopes in the experimental facilities to provide adequate slope (inclination) for the execution process. After surface preparation, each technique was installed contiguously on a section of each experimental facility, as exemplified in Figure 1. This study presents the results obtained from four different techniques (materials described in Table 2) in each experimental section.

Table 2. Materials used for erosion control of the slope surface and their respective location in experimental facilities.

| Code | Description | Location |
|---|---|---|
| MAN | Manual seeding | EF1-S08<br>EF2-S07 |
| MT | Manual seeding attached to Organic Sediment Retainers (OSR; 0.20m x 2.00m) composed of herbaceous straw and coconut fiber, wrapped in polypropylene fabric. | EF1-S11<br>EF2-S12 |
| CCS | Flexible confinement cell system composed of the combination of triaxial geogrids and geotextile made of organic (coconut) fibers - mass per unit area of 450 g/cm². | EF1-S01<br>EF2-S02 |
| BLK-01 | Flexible coconut fiber blankets (joined with polypropylene nets) covered by flexible synthetic fabric on both sides (top and bottom). Total mass per unit area equal to 400 g/cm². | EF2-S09 |
| BLK-02 | Flexible coconut fiber blankets (joined with polypropylene nets) covered by two flexible synthetic fabric on top and one flexible synthetic fabric on the bottom. Total mass per unit area equal to 600 g/cm². | EF2-S11 |

Figure 1. Contiguous execution of the bio-technical systems along with the experimental facilities.

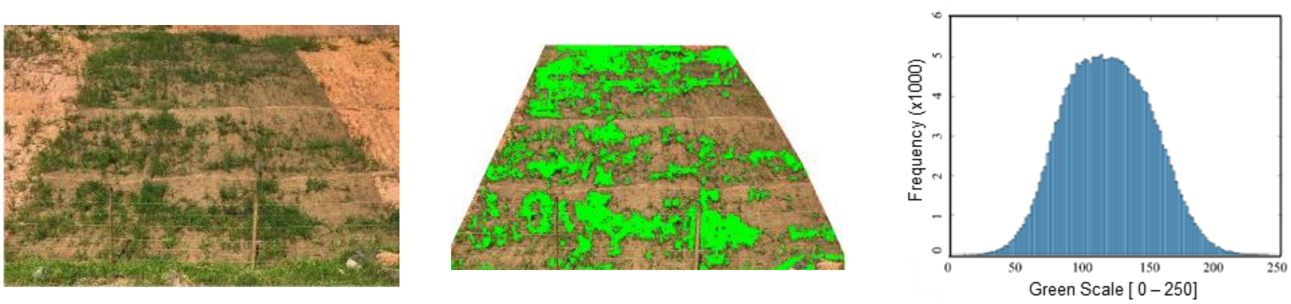
### *2.3 Monitoring of the experimental facilities*

The monitoring took place through 15-days interval visits (started December 2016), where all the sections of each experimental facility were carefully visited and inspected over a period of two years and three months. High-quality images were taken from the front view of each slope section always at the same angle. In addition, local qualitative analyses, reported by evaluation cards, assessed the i) phytosanitary conditions of the vegetation, ii) indices of vegetative cover, iii) nutritional status, iv) pest attack, v) indices of settling and rooting, and vi) conditions of materials and structures. Due to the existence of diagnostic bias of the above-mentioned characteristics, the results were not reported in this study because they require a detailed investigation that takes into account the bias error. During the visits, preventive and corrective actions were required to control leaf-cutting ants, leaf chlorosis and fence conditions.

### *2.4 Determination of the vegetative cover index*

The images obtained during slope surface monitoring were used to calculate the vegetative cover index (factor C of Revised Soil Loss Equation - RSLE) through a computer code (algorithm) in the MATLAB software, developed and improved based on Meyer and Camargo Neto (2008). Despite it is a semi-quantitative analysis of the vegetation cover development in the investigated sections, it is ideal to verify the vegetation behavior/resistance over the years (climatic changes), especially at the dry spell and its recovery at the wet spell.

Before submitting the images to the software, all images were treated so that areas located outside the evaluated section were excluded. In the software, three-color bands (Red-Green-Blue scale; RGB) were extracted from each treated image and the mean and standard deviation for each color were determined. Based on the preliminary mapping of the color bands, the area with vegetation cover was defined as the pixels that are inside a 95% confidence level of the mean value found (i.e., that fall within two standard deviations from the mean) and with red and blue color values lower than the green color value. The vegetative cover index was defined by the ratio of the number of green pixels to the total number of pixels (white pixels were excluded from the analysis). This process was repeated automatically for all images obtained from the sections reported in this study. Figure 2 exhibits an original image without any treatment (Figure 2a), the same image, now treated (exclusion of the contiguous section area from the image) and with the green pixels delimited by the software (Figure 2b) and the frequency distribution of the green colors in the green scale (Figure 2c).




(a) (b) (c)

Figure 2. Image analysis procedure: (a) original image (untreated), (b) treated image submitted to the software, (c) and green scale frequency distribution.

## 3. RESULTS AND DISCUSSION

The algorithm used in the numerical analyses did not exhibit adequate results in the binary identification of green and non-green colors (especially at dry spells periods) for vegetation with low chlorophyll indexes. However, the data obtained allows the assessment of climatologic changes, that means, the evolution and/or behavior of the vegetation during dry and wet spells cycles. In this way, despite this analysis does not indicate an accurate vegetation cover level, the vegetation cover index allows a more comprehensive analysis of the physiological state presented by the vegetation used. Figure 3 exhibits the results of the vegetation cover index for the techniques reported in this study.

The manual seeding technique exhibited similar results in both experimental facilities. Figure 3a indicates that this treatment did not present a satisfactory vegetation cover index (above 70%) at any moment. For the two years and three months period investigated, the vegetation cover index was less than 30%. A significant effect on the vegetation physiological status caused by the variation in the available water and sunlight – due to the dry (between the months of April and September) and humid (between the months of October and March) spells – was observed. Furthermore, generalized laminar erosion and small grooves were observed along the slope surface of these sections (EF1-S08 and EF2-S07).

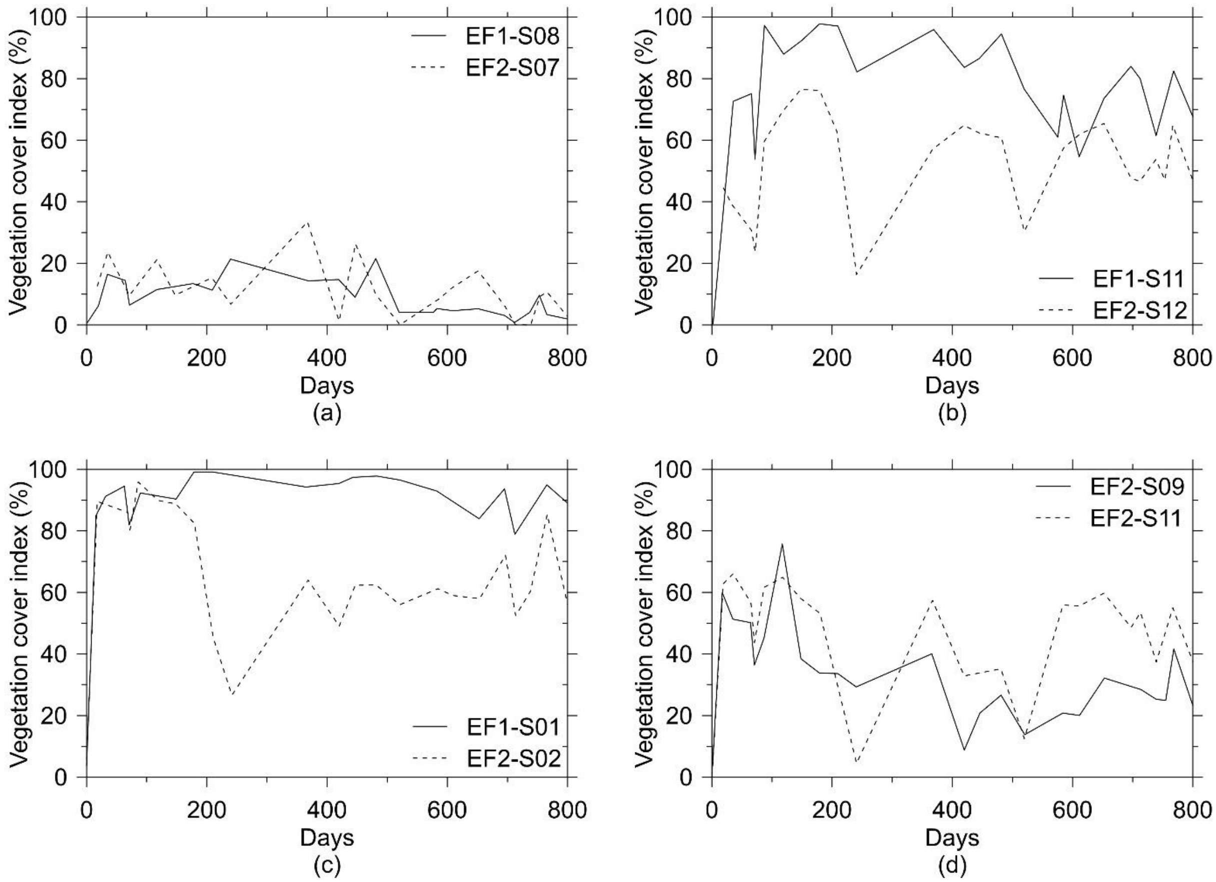



Figure 3. Evolution of the vegetation cover index for techniques (a) MAN, (b) MT, (c) CCS and (d) BLK-01 and BLK-02.

The adoption of Organic Sediments Retainers (OSR) to the manual seeding technique, proves to increase the vegetation cover index values (Figure 3b) compared to the isolated manual seeding technique. In the first experimental facility (EF1-S11), satisfactory levels of vegetation cover index were evident up to 500 days with a small variation. However, after this period (500 days), the vegetation cover index decrease and presented large variation along the next 300 days due to severe climatologic changes, especially at hard dry spells. For the other experimental facility, this mixed technique (manual seeding + ORS) exhibited a short period of satisfactory vegetation cover index (150 – 180 days) and a huge variety of this index along the two years and three months of inspections. This result proves that this technique is vulnerable to climatologic changes (cycles of dry and wet spells). However, the difference between the vegetation cover index between the two experimental facilities investigates may indicate that the second one (EF2) was subjected to harder climatologic changes than the first one (EF1). Further studies are required to validate this assumption.

Considering the flexible confinement cell system (CCS) executed in the first experimental facility (EF1-S01), the vegetation cover index (Figure 3c) was higher than 80% for all periods investigated and does not suffer significant changes due to climatologic conditions. At 90 and 720 days, the unexpected reduction in the vegetation cover index is explained by lower rainfall rates in these periods. The section in the experimental facility 2 (EF2-S02) presented an excellent vegetative cover index up to 180 days (Figure 3c). After this period, the vegetation condition was deteriorated, indicated by a small number of green colors in the whole section area. The vegetation cover index restarted to increase after 220 days due to intense wet spell, but not exhibited satisfactory values (over 70%) for the remaining period.

Finally, Figure 3d exhibits the vegetation cover index results for similar techniques executed in the experimental facility 2 (EF2-S09 and EF2-S11). In summary, both sections did not exhibit satisfactory vegetation cover index along the investigated period. After a short period with a good vegetative cover index up to 150 days, this index decrease along the remaining period. Sudden decreases in the vegetation cover index were observed in a dry spell and a significant recovery occurred in the wet spells. For all periods investigated, the amount of vegetation that covers the slope's superficial soil was not adequate to prevent the laminar erosion process. Once again, the vegetative cover index proves to be influenced by the climatological changes of the region.

The differences between the values of the vegetation cover index resulting from the execution of the same technique in different experimental facilities cannot be associated with the soil fertility of the experimental facilities (small differences are evident in Table 2). The differences in the vegetation cover index may result from factors related to the executive process and mainly due to climatologic changes (cycles of dry and wet spells). Thus, a controlled executive process and a careful evaluation of the local climatologic changes are important to define the best technique to be adopted in each particular case.

## 4. CONCLUSION

In this study, different techniques for erosion protection of slopes' superficial soil were applied and monitored (over two years and three months) in two experimental facilities located near to the Simplício Hydroelectric Power Plant - FURNAS in Brazil. The numerical modeling carried out to assess the vegetation cover index of the slope surface is adequate to evaluate the influence of climatic effects (dry and wet spells) on the vegetation evolution.

The first experimental facility exhibited higher values of vegetation cover index compared to the second one, which indicates the existence of variability in vegetation development. Since similar soil fertility results were observed, the variability may be caused by the physical characteristics of the materials adopted, executive processes and/or by the climatologic changes that occurred in the experimental facilities.

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