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# Soil compressibility and least limiting water range of a constructed soil under cover crops after coal mining in Southern Brazil

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ABSTRACT

The use of cover crops affects the support capacity of soil and least limiting water range to crop growth. The objective of this study was to quantify preconsolidation pressure ($\sigma_p$), compression index (CI) and least limiting water range (LLWR) of a reclaimed coal mining soil under different cover crops, in Candiota, RS, Brazil. In the experiment, with randomized blocks design and four replicates, the following cover crops (treatments) were evaluated: *Hemarthria altissima* (Poir.) Stapf & C.E. Hubbard, treatment 1 (T1), *Paspalum notatum* Flüggé, treatment 4 (T4), *Cynodon dactilon* (L.) Pers., treatment 5 (T5), control *Brachiaria brizantha* (Hochst.) Stapf, treatment 7 (T7) and without cover crop treatment 8 (reference treatment, T8). Soil compression and least limiting water range were evaluated with undisturbed samples at a depth of 0.00–0.05 m. In order to evaluate parameters of soil compressibility, the soil samples were saturated with water and subjected to −10 kPa matric potential and then submitted to a uniaxial compression test under the following pressures: 25, 50, 100, 200, 400, 800 and 1600 kPa. Cover crops decreased the preconsolidation pressure of constructed soils after coal mining and the greatest soil reclamation was obtained with the *H. altissima* cover crop, where the lowest degree of soil compactness and soil load capacity were observed. Soils cultivated under *H. altissima* or *B. brizantha* presented the highest least limiting water range and these two cover crops generated similar soil critical bulk density obtained by least limiting water range and soil load support capacity.



## 1. Introduction

The Brazilian reserves of mineral coal reaches 32 billion tons, with approximately 89% in Rio Grande do Sul state (SEMC, 2009). The main reserve is located in the municipality of Candiota. Coal is an important energy resource, and its exploration produces the accumulation of residues, changing soil physical, chemical and biological parameters (Shrestha and Lal, 2011). The reclamation of mining area, specially in Candiota attempts to restore the landscape and soil characteristics, which consists in levelling of the removed geological layers and the reconstruction of the topsoil followed by the cultivation of crop species.

The soil construction process of mining areas is characterized by the traffic of heavy machinery which results in soil compaction (Schroeder et al., 2010), increasing soil bulk density, decreasing soil porosity, causing restrictions to crop development. The use of cover crops to minimize soil compaction is a strategy for soil recovering (Hamza and Anderson, 2005; Jimenez et al., 2008). Plants with aggressive root systems that have the ability to break the layer of compacted soil, besides protecting the soil surface, form pores important for soil water movement and gases diffusion (Müller et al., 2001)

The maintenance of appropriate physical conditions to crop growth depends on the knowledge of soil compression behavior (Severiano et al., 2008). The preconsolidation pressure represents the bearing capacity of the soil (Krümmelbein et al., 2010). Damage will occur when applied stress exceeds the carrying support capacity of the soil (Dias Junior and Pierce, 1996). The compression index obtained by the virgin compression line (Chaplain et al., 2011), indicates the soil susceptibility to compaction, or soil resistance to compaction (Keller et al., 2011). The compaction degree expresses the relative soil compaction and it is useful to indicate changes in several soil physical parameters, such as saturated soil hydraulic conductivity and soil macroporosity (Reichert et al., 2009).

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The least limiting water range (LLWR) is an indicator of soil physical quality associated to plant growth and productivity (Olibone et al., 2010), because it integrates soil resistance, air porosity and soil water content (Silva et al., 2009). Ideal conditions for plant growth are associated to the value of 10% air porosity (Grable and Siemer, 1968; Bowen et al., 1994) and 2 MPa soil resistance to root development (Taylor et al., 1966; Silva et al., 1994). However, other critical values are indicated for Ultisols and Oxisols (Severiano et al., 2008; Reichert et al., 2009; Lima et al., 2010).

Very few studies attempt to associate the effect of cover crops on soil compressibility and least limiting water range values of constructed soils in coal mining areas. Therefore, the aim of this study was to evaluate the performance of four different cover crops on soil compressibility and least limiting water range of a reclaimed soil in a coal mining area, in Southern Brazil (Candiota, Rio Grande do Sul state).

## 2. Materials and methods

### 2.1. Study area

The study was carried out in a mined coal area of the Companhia Riograndense de Mineração (CRM), located in the municipality of Candiota, Rio Grande do Sul state (31°33′51.8″ S, 53°43′28.1″ W), Brazil. The climate is of Cfa climatic type according to Köppen's classification and the specific area is representative of a subtropical marine environment with a subhumid summer and the remaining seasons humid or superhumid (Moreno, 1961).

The constructed soil in the experimental area was mainly formed by B horizon (0.30–0.40 m soil depth), classified before mining as Alfisol (NRCS, 2010). Prior to experiment design establishment, soil was chiseled down to an approximate 0.15 m depth. After chiseling, limestone (10.4 ton ha$^{-1}$ PRNT of 100% effective calcium carbonate equivalent) and mineral fertilizers (5-20-20, which is equivalent to 900 kg ha$^{-1}$) were applied. In all spring seasons during the experimental period, mineral nitrogen fertilizer (40 kg ha$^{-1}$ of ammonium sulphate) was applied, and manual weeding control was done.

The experiment was established in November/December 2003 and the experimental design consisted of randomized blocks with four replicates. Each block was composed of 21 experimental plots (20 m$^2$ per plot). Seven treatments were implemented in each block with three replications: T1 – constructed soil with Limpograss (*H. altissima* (Poir.) Stapf & C.E. Hubbard); T2 – constructed soil with Tifton Grass (Bermuda grass) (*Cynodon dactilon* (L.) Pers.) + Pinto peanut (*Arachis pintoi*); T3 – constructed soil cultivated with Limpograss + Pinto peanut; T4 – constructed soil cultivated with Bahia grass (*P. notatum* Flüggé); T5 – constructed soil cultivated with Tifton grass; T6 – Pensacola + -Pinto peanut; and T7 – control: constructed soil cultivated with Beard grass (*B. brizantha* (Hochst.) Stapf). Data from treatments 2, 3 and 6 were excluded from the present study because of the major crop establishment problems. An adjacent uncultivated reference plot (named herein as T8 treatment) was implemented with the objective of comparing results from all treatments.

### 2.2. Soil sampling

On April 2009, disturbed soil samples were collected from the 0.00–0.05 m layer to determine soil particle-size distribution (Gee and Bauder, 1986), soil organic carbon (Tedesco et al., 1995) and soil particle density (Pd) (Embrapa, 1997). Results are presented in Table 1.

From the same soil layer, 40 undisturbed soil samples (4 randomized blocks × 5 treatments × 2 replicates per plot) were collected using steel cylinders (0.030 m of height and 0.0485 m of diameter) to determine bulk density, total porosity, macroporosity and soil compressibility parameters and 280 undisturbed soil samples (56 samples per treatment: 4 blocks × 2 replicates per plot for each one of 7 evaluated matric potentials) were collected to determine the least limiting water range (LLWR) parameter.

### 2.3. Soil physical analysis

Each steel cylinder containing a soil sample was stored and protected in a plastic lined box and horizontally laid for transport to the laboratory. All soil samples were saturated in water for 24 h and then equilibrated at a standard tension of 6 kPa using a tension table to determine macroporosity and microporosity values (Embrapa, 1997). The same soil cylinders were also equilibrated at a tension of 10 kPa using pressure plates (Klute, 1986) for the uniaxial compression test. The mean soil moisture content of all the soil samples was of 0.23 g g$^{-1}$. Subsequently, pressures of 25, 50, 100, 200, 400, 800 and 1600 kPa were applied (Silva et al., 2007), and the displacement at each applied pressure was recorded. Afterwards, the soil samples were oven dried at 105 °C for 24 h and soil bulk density was calculated (Grossman and Reinsch, 2002).

The soil compression curve was graphically constructed plotting the logarithm of the applied loads (*x* axis) and soil bulk density values (*y* axis) for each sample. Preconsolidation pressure ($\sigma_p$) and compression index (CI) values were calculated according to Dias Junior and Pierce (1995). Soil compression curves were normalized to eliminate the initial soil compaction effect as showed by Kondo and Dias Junior (1999), where the soil bulk density value at the end of each applied pressure (Bdr) was divided by the soil bulk density value obtained in the field (Bd). The degree of compactness (DC) was calculated by the ratio of initial Bd and the reference soil bulk density values (Bdref), which were obtained through pressure applications of 200, 400, 800, 1600 kPa in the laboratory. The DC obtained in each preconsolidation pressure was also evaluated.

**Table 1**
Mean values of clay, sand and silt content, soil organic carbon (OC), soil particle density (Pd) and soil textural class in the 0.00 and 0.05 m layer of a constructed soil under different cover crops in a coal mining area in Candiota, RS, Brazil.

| Treatments[a] | Clay (g kg$^{-1}$) | Sand (g kg$^{-1}$) | Silt (g kg$^{-1}$) | SOC (g kg$^{-1}$) | Pd (Mg m$^{-3}$) | Textural class |
|---|---|---|---|---|---|---|
| T1 | 463.62 | 298.08 | 238.30 | 7.60 | 2.60 | Clayed |
| T4 | 474.21 | 291.88 | 233.91 | 7.69 | 2.63 | Clayed |
| T5 | 469.55 | 283.75 | 246.70 | 8.16 | 2.61 | Clayed |
| T7 | 452.55 | 289.66 | 257.79 | 7.78 | 2.60 | Clayed |
| T8 | 456.66 | 311.75 | 231.59 | 6.98 | 2.63 | Clayed |
| Mean value | 463.32 | 295.02 | 241.66 | 7.64 | 2.61 | |
| Coefficient of variation (%) | 1.92 | 3.61 | 4.43 | 5.59 | 0.58 | |

[a] Treatments: T1: constructed soil cultivated with *Hemarthria altissima*; T4: constructed soil cultivated with *Paspalum notatum*; T5: constructed soil cultivated with *Cynodon dactilon*; T7: constructed soil cultivated with *Brachiaria brizantha*; and T8: constructed soil without cover crop.