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Relationships between leaf water potential and soil water potential in grasses subjected to water stress

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Abstract

For grasses and other crops in general, soil water potential has been widely studied to determine if there is a deficit or excess of water content in the soil. However, the plant water absorption process is not only modulated by soil water potential but also by the combination of meteorological, soil depth, and crop canopy factors, which could be elucidated through water relations responses. The objective of this work was to compare the water relations of grass species established in different soil depths and subjected to water stress. Santo Agostinho (*Stenotaphrum secundatum*), Esmeralda (*Zoysia japonica*), Tanzania (*Panicum maximum*) and Tifton 85 (*Cynodon* spp.) were used in this trial. The four species of grasses were tested in four different soil rooting depths: 10, 20, 30 and 40 cm. The grasses were irrigated at soil moisture field capacity level, until the time of imposing the water stress period. Soil depth had a direct influence on leaf water potential and soil water potential. Moreover, correlation coefficients are higher in deeper soil profiles. The strongest correlations between leaf water potential and soil water potential were found in the deeper soil depth treatments. Therefore, for the soil depth treatment of 40 cm, the average R^2 for the four species was 0.55, the highest being 0.70 in Tanzania grass. It is possible to relate leaf water potential and soil water potential independently of the grass species used or the depth of soil available to the roots, which would allow the creation of new irrigation management strategies.

Keywords

Water relations; Soil depth; Soil water availability.

Introduction

Irrigation is a key tool for increasing crop productivity, but its non-precise aplication can cause problems with salinization, lixiviation, and waste of water and energy (Wichelns & Qadir, 2015). Research efforts in recent years have concentrated on improving water use efficiency through different techniques (Kang et al., 2017). Knowledge of plant root behavior under water stress is an important aspect for the development of technologies.

According to de Melo & van Lier (2021), the water status of plants is modulated by the crop's ability to absorb the water stored in the soil and the combination of meteorological factors interacting with the crop canopy. Therefore, all species of plants, even cultivars, have demonstrated different adaptions to these source-sink limitations (Medrano et al., 2015).

The response of plants to soil water potential has been widely studied (Chaves et al., 2022; Costa et al., 2019; Costa et al., 2020a; Hura et al., 2007; Quiloango-Chimarro et al., 2021; Tapparo et al., 2019). However, soil water potential is not necessarily indicative of plant water status in the soil depth explored by the root system (Carlesso, 1995; Coolong et al., 2012). For example, as the soil dries out, plants have more difficulty absorbing water. Therefore, in situations of water stress, the physiological and morphological processes of the plant are subject to adaptations (Chaves et al., 2021; Costa et al., 2018; Jaleel et al., 2009).

The chemical, physical and biological characteristics of the soil directly influence the amount of soil water available to plants (Cardoso et al., 2013). Thus, a physical change such as soil compaction, will alter root structure and thus water availability. There is a lack of information on how the plant reacts to water deficits under shallow and deeper soil profiles. In addition, grasses used in this trial cover soils differently, which affects the evapotranspiration rate (Kang et al., 2017).

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Plant water status is modulated by soil water potential in the root zone and by the atmospheric evaporative demand that influences the response of physiological processes (Jaleel et al., 2009). Brady et al. (1974) concluded that the most reliable technique for assessing plant water status is leaf water potential. In addition, the measurement of predawn leaf water potential reflects the balance between the plant and the soil water potentials (Donovan et al., 2001). Therefore, Coolong et al. (2012) demonstrated that there is a significant relationship between soil water potential and leaf water potential when plants are subjected to water stress.

It was hypothesized that leaf water potential and soil water potential are closely related under water deficit, regardless of soil root depth. Therefore, this study aimed to analyze the relationships between leaf water potential and soil water potential in grasses subjected to water stress and at different soil root depths.

Materials and methods

The experiment was installed in a rain shelter environment of the Department of Biosystems Engineering at the "Luiz de Queiroz" College of Agriculture/USP, located in Piracicaba, SP. The climate of the region is humid subtropical, which according to the Köppen climate classification is of the Cwa type.

The soil used in the experiment was classified as red-yellow latosol (EMBRAPA, 2013) with a sandy loam texture (17% of clay, 8% of silt and 75% of sand). The plots consisted of large vases in which a layer of crushed stone was placed at the bottom and a soil layer on top of it according to the root depths treatments: 10, 20, 30 and 40 cm; these two layers were separated by a non-woven geotextile.

The species evaluated were the grasses: Tanzania (TF), Tifton 85 (TZ), Esmeralda (ES) and Santo Agostinho (AS). The experiment was drip irrigated in each box and the water amount was calculated according to the soil water potential, to keep soil moisture level at field capacity condition. Irrigation management was performed using tensiometry in a similar way to that shown in Costa et al. (2020b).

The experiment was established in six randomized complete blocks, being four soil depth levels (0, 10, 20, 30) and four grasses (TF, TZ, ES, AS). All plants were irrigated at soil field capacity level until the moment of water stress imposition, which consisted of dry-off period of five consecutive days, applied eleven times during the evaluation period.

Leaf samples were taken every day during the 5 days of water stress. Before 6:00 a.m., six to ten leaves of the same appearance were randomly collected from each plot and placed in hermetic plastic bags in a styrofoam box with ice. At the same time, soil water potential was measured using puction tensiometers. The installation was carried out according to soil depth: up to 20 cm of soil, a tensiometer was installed at 10 cm depth, and for depths up to 40 cm, two tensiometers were installed, the first at 10 cm and the second at 30 cm depth.

Under laboratory conditions, leaf water potential was measured as soon as possible using a Scholander pressure chamber (Figure 1A). The average pressurization rate was 1 to 1.5 bars per second to avoid hydraulic or reading point losses (Figure 1B). Leaves used to measure leaf water potential (Figure 1C) were selected according to each species: for Santo Agostinho and Esmeralda grass, 2+ and 3+ leaves cut near the collar (point of insertion of the leaf with the sheath) were used (Figure 1D), while for Tifton 85 and Tanzania, the 3+ leaf was used.

The relationship between leaf water potential and soil water potential was performed through linear regressions using R and Microsoft Excel. The coefficient of determination (R^2) of the relationships in the different soil depths and grasses were calculated. In addition, to compare soil water potential among species, the linear models for each soil depth treatment were plotted.

Results and discussion

In Figure 2 it is presented the relationship between leaf water potential and soil water potential in *Panicum maximum* cv. Tanzania. An increasing linear relationship is observed as water stress increases for all soil depths. In all soil profiles at the end of 5 days of stress, soil water potential increased to about 0.075 MPa. Leaf water potential for plants in the deeper soil profile treatments was higher, indicating that they suffered more stress (Figure 2A and 2B). In contrast, plants grown in shallow profiles had smaller decreases in leaf water potential (Figure 2C and 2D).

The rapid increase in soil water potential may be associated with the large leaf area of this variety (Pacheco et al., 2017), which also has a large area of uncovered soil, factors that favor greater evapotranspiration. The differences in leaf water potential between shallow and deep profiles differ from those reported by Bucci et al. (2009), who suggest lower leaf stress when plants have a deeper root system. This variety probably concentrates the root system in the shallow profile, but due to the complexity of root measurements involved, it could be another topic of interest.

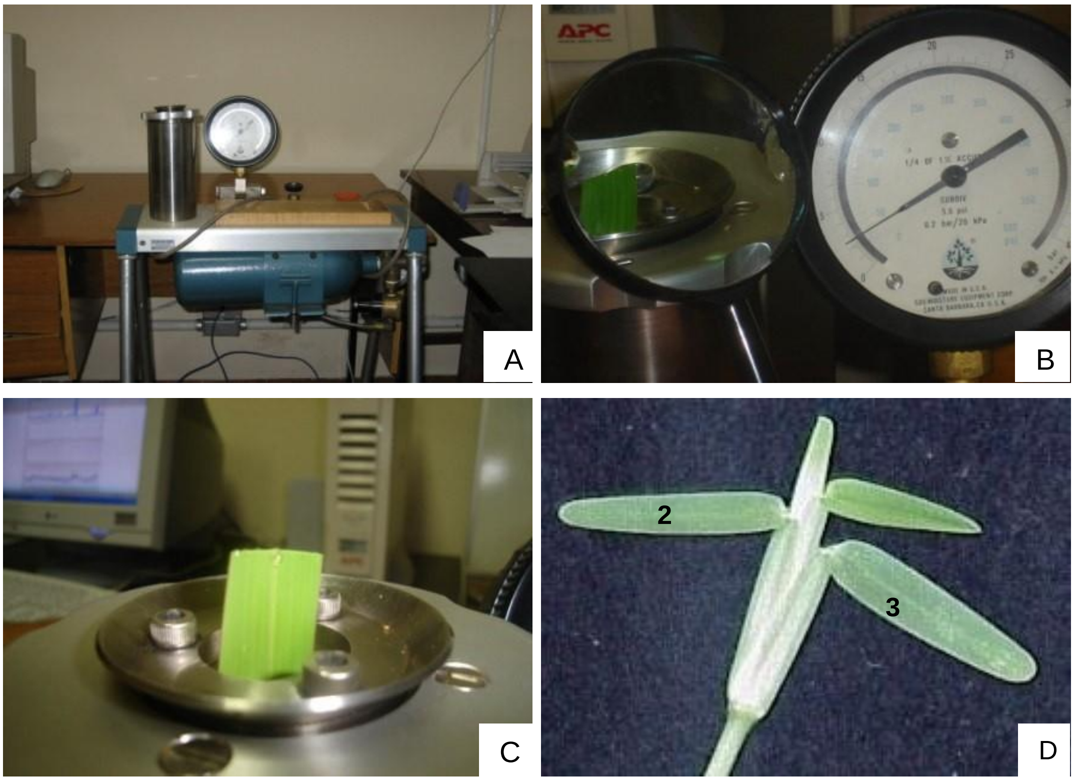

Figure 1. Details of the measurement of the leaf water potential of grasses. A, pressure chamber used in this trial; B, pressure chamber at the moment of the leaf tension reading; C, example of grass leaf cutting and positioning in the pressure chamber; D, leaf conformation in the tiller of Santo Agostinho grass.

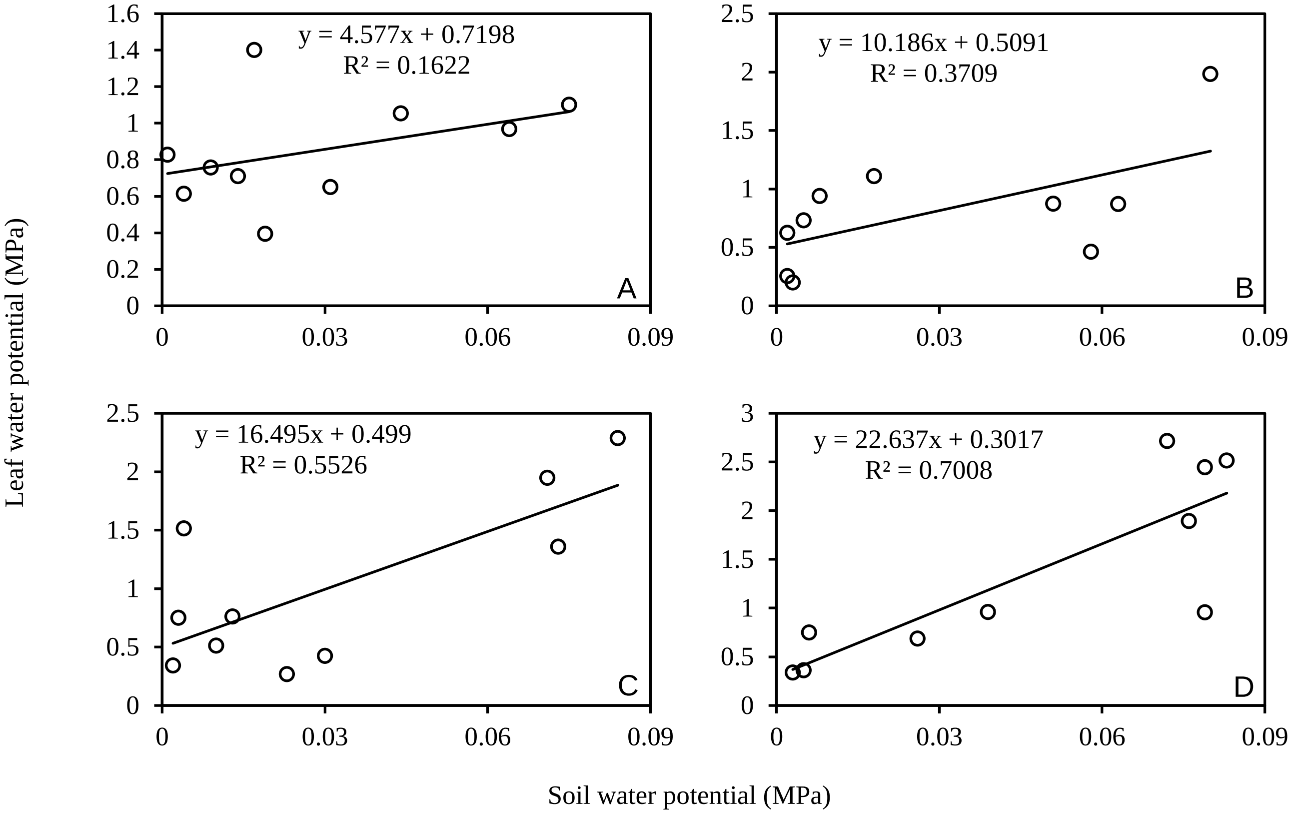

Figure 2. Dynamics of the leaf water potential as a function of the soil water potential in Tanzania grass subjected to five days of irrigation withholding. A, 10 cm of soil profile; B, 20 cm of soil profile; C, 30 cm of soil profile; and D, 40 cm of soil profile.

In Figure 3 it is presented the relationship between leaf water potential and soil water potential in *Cynodon* sp. var. Tifton 85. This grass shows greater values of leaf water potential even on the first day of the water shortage. In contrast to *Panicum Maximum*, this species in shallow soil profiles where root volume is small shows little reduction in soil water potential and leaf water potential (Figure 3C and 3D). In deep profiles, there was a higher soil water potential and leaf water potential, suggesting that a larger root system volume also favors a higher water demand (Figure 3A and 3B). The differences with the literature suggest that the experimental conditions limited the exploration of water by the root system and favored a greater root mass in the deep profiles. For example, it was demonstrated that deeper root systems even reallocate water under stress situations (Peek et al., 2006).

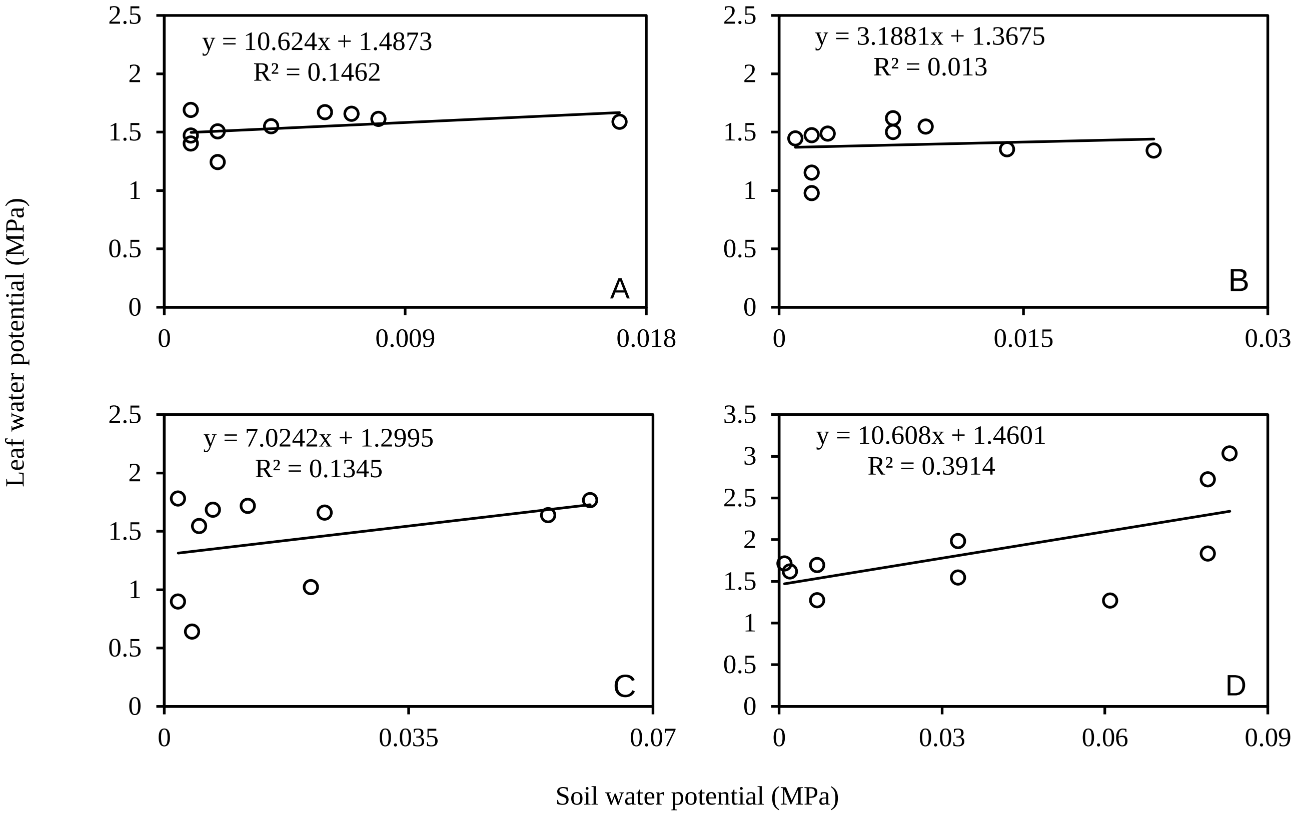

Figure 3. Dynamics of the leaf water potential as a function of the soil water potential in Tifton 85 grass subjected to five days of irrigation withholding. A, 10 cm of soil profile; B, 20 cm of soil profile; C, 30 cm of soil profile; and D, 40 cm of soil profile.

Figure 4 shows the relationship between leaf water potential and soil water potential in Zoysia japonica var. Esmeralda. Water stress decreased the soil water potential for the shallow soil profile (10 cm), whereas for the other treatments (20, 30 and 40 cm) it remained close to field capacity. On the other hand, leaf water potential increased only for the shallow soil profile treatment and showed a tendency to reduce leaf water potential for the other treatments (20, 30, and 40 cm).

There is evidence that predawn leaf water potential in some species does not necessarily equilibrate with the soil water potential when they are subjected to well-watered conditions (Donovan et al., 2001). In addition, Mwendia et al. (2017), studying leaf water potential for grasses in tropical environments (East Africa), observed greater variations in leaf water potential when plants were between well and mildly stressed conditions.

In Figure 5 it is presented the relationship between leaf water potential and soil water potential in *Stenotaphrum secandatum* var. Santo Agostinho. This species presented the weak correlations among the studied grasses for the shallow soil profiles (10 and 20 cm). This could be because Santo Agostino tends to show a greater variation of leaf water potential under well-watered or mild drought stress conditions (Miller and McCarty, 2001). Leaf water potential and soil water potential were similar to those of *Zoysia japonica*. Overall, it was observed that a shallow soil profile of these two grasses delays the occurrence of water stress (Figure 4D and Figure 5D). This was expected since these two species have the characteristic of entirely covering the soil, thus favoring the reduction of evapotranspiration.

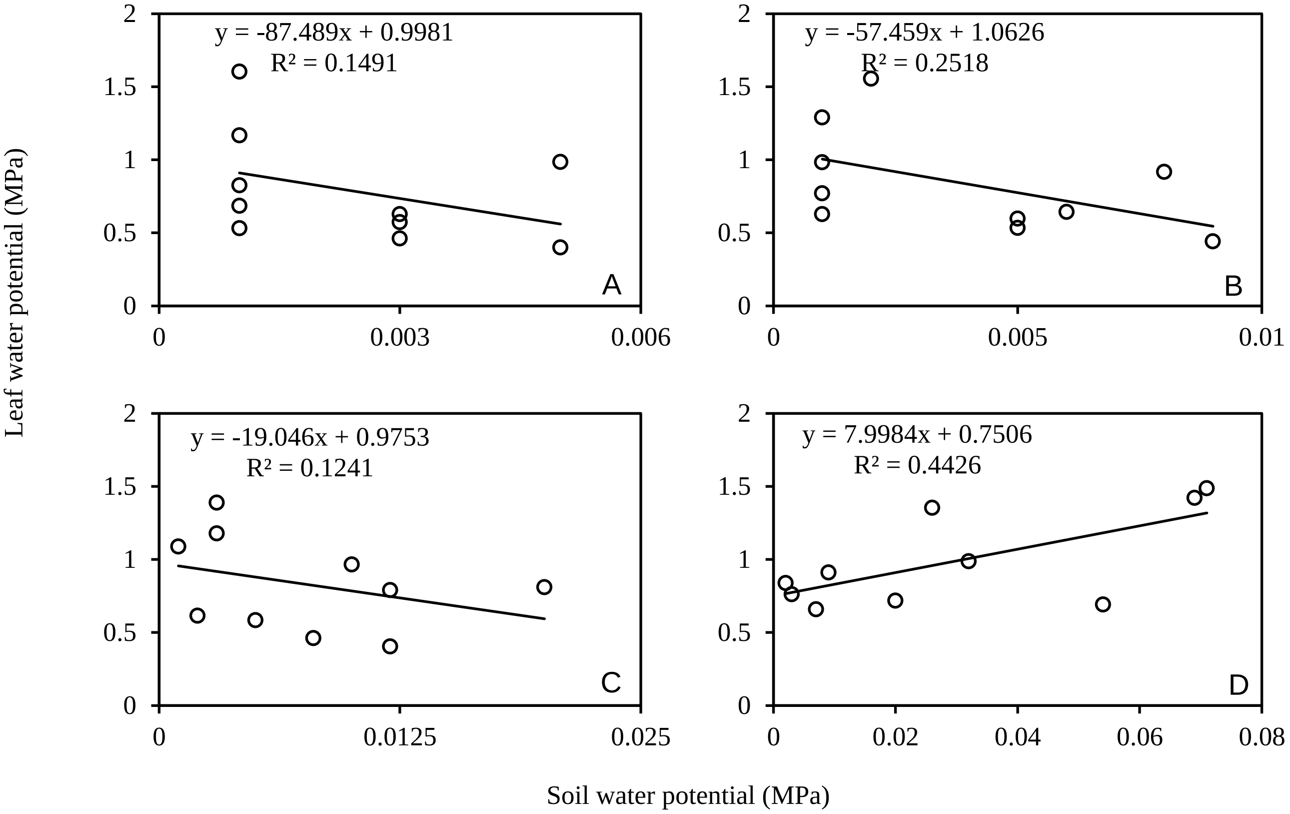

Figure 4. Dynamics of the leaf water potential as a function of the soil water potential in Esmeralda grass subjected to five days of irrigation withholding. A, 10 cm of soil profile; B, 20 cm of soil profile; C, 30 cm of soil profile; and D, 40 cm of soil profile.

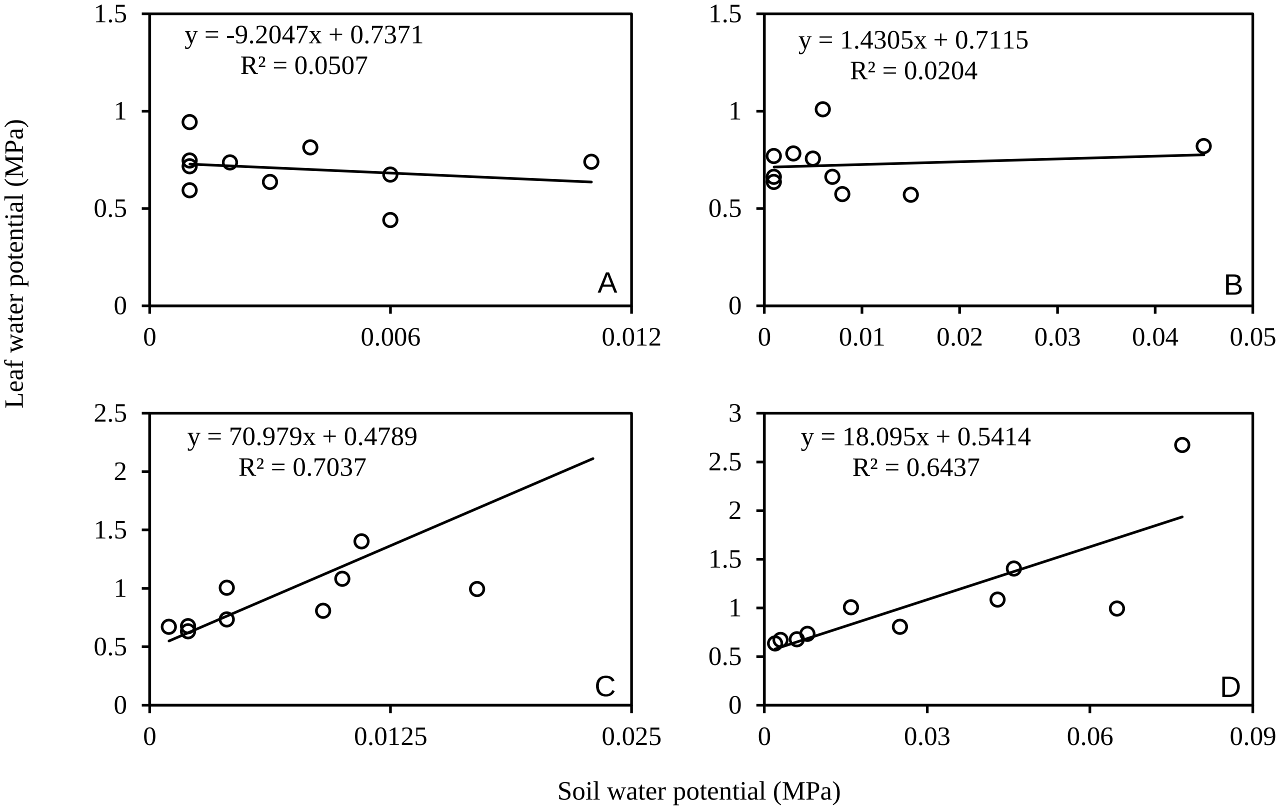

Figure 5. Dynamics of the leaf water potential as a function of the soil water potential in Santo Agostinho grass subjected to five days of irrigation withholding. A, 10 cm of soil profile; B, 20 cm of soil profile; C, 30 cm of soil profile; and D, 40 cm of soil profile.

In general, all analyzed species showed a similar relationship between leaf water potential and soil water potential for the deeper soil profile tested (reasonable R²), whereas there was a weak R² between leaf water potential and soil water potential in the shallow soil profile (Figure 6). In addition, Esmeralda grass tended to stress less under irrigation withholding at the four soil depths tested compared to Tanzania grass. According to Kørup et al. (2018) plants exhibit a series of characteristics and mechanisms to deal with limited water availability, including many physiological and morphological responses. Esmeralda grass probably developed drought-tolerant characteristics to cope with drought conditions and thus could be a viable option in water-scarce regions.

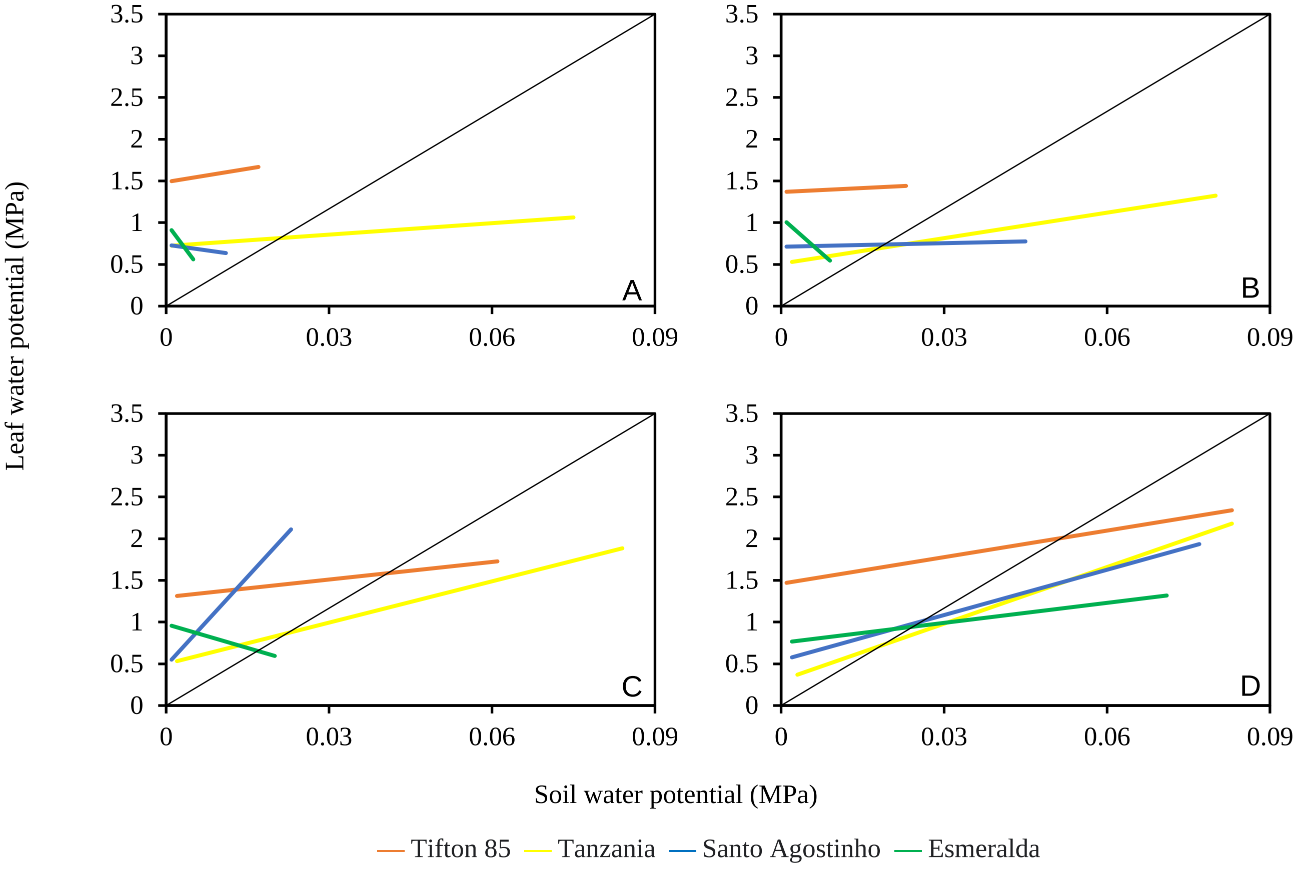

Figure 6. Comparison of the linear relationship between leaf water potential and soil water potential of the four tested grasses. A, 10 cm of soil profile; B, 20 cm of soil profile; C, 30 cm of soil profile; and D, 40 cm of soil profile.

Conclusions

Weak correlations for shallow soil profiles suggest that not only soil moisture should be studied, but also the relationships with variables that reflect the water status conditions in the plants.

The strongest correlations between leaf water potential and soil water potential were found in treatments with soil depth of 40 cm. The shallow soil profiles (10 and 20 cm) contributed to reducing the water stress for the four grass species, highlighting that Santo Agostinho and Esmeralda grasses that completely cover the soil tend to conserve soil moisture and consequently achieve the lowest leaf water potential.

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