EFFECT OF A SUBSURFACE PLASTIC FILM INSERTION SYSTEM ON SOIL MOISTURE REGIME

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ABSTRACT

Systems that enhance water retention in soils have the potential to increase agricultural production and mitigate the effects of droughts. In the present study, the effect of a Subsurface Plastic Film Insertion System (SPFIS) on soil water retention was evaluated. Four plots were established using the plastic film, applied through subsoiling at a depth of 40 cm. Tensiometers were installed at soil depths of 0-10 cm, 10-20 cm, 20-30 cm, and 30-40 cm, and tension was recorded weekly. The results indicated lower soil water matric potential values in the plots with the plastic film compared to the control plots (without the film). These result can be attributed to the increased water retention and concentration around the films, which also resulted in a longer duration of elevated soil moisture content, even during periods of no rainfall. The SPFIS contributed to increased soil moisture, with the potential to enhance agricultural productivity.

Keywords: stress resistance; soil management; soil characteristic curve; crop yield

INTRODUCTION

In many regions of the world, water acts as the main limiting factor for agricultural production (Kavdir *et al.*, 2014; Nkurunziza *et al.*, 2019). Water stress caused by drought can lead to significant losses in crop productivity due to dehydration during critical stages of plant development (Dietz *et al.*, 2021). In this context, in the current climate change scenario, the increased frequency of extreme drought and heatwave events can act as strong stressors on plant growth (Xu *et al.*, 2019; Flach *et al.*, 2021), thereby contributing to the reduction of food security (FAO, 2015).

One way to tackle the limitations that water imposes on agricultural production is by increasing soil moisture through various technologies, such as: irrigation, soil cover, raising the organic matter content in the soil's surface horizon, developing and adopting more water use efficient genotypes, and installing physical barriers that prevent water percolation to depths beyond the root zone. In the latter case, such systems have been termed subsurface water retention systems (Pari *et al.*, 2022) and have been developed to keep water in the arable layer for a longer period, with the potential to increase water use efficiency.

Subsurface water retention technologies have been used in arid regions of Africa and the Middle East for a long time (Kavdir *et al.*, 2014). Initially, clay pots were buried in the soil (ibid). However, with technological advancements, other materials such as asphalt (Gupta and Aggarwal, 1980), clay, and various forms of plastics (Pari *et al.*, 2022) have been tested in the field. These technologies are highly relevant with regards to enhancing water retention in soils to support food production, particularly in arid regions where water scarcity limits food production (Nkurunziza *et al.*, 2019).

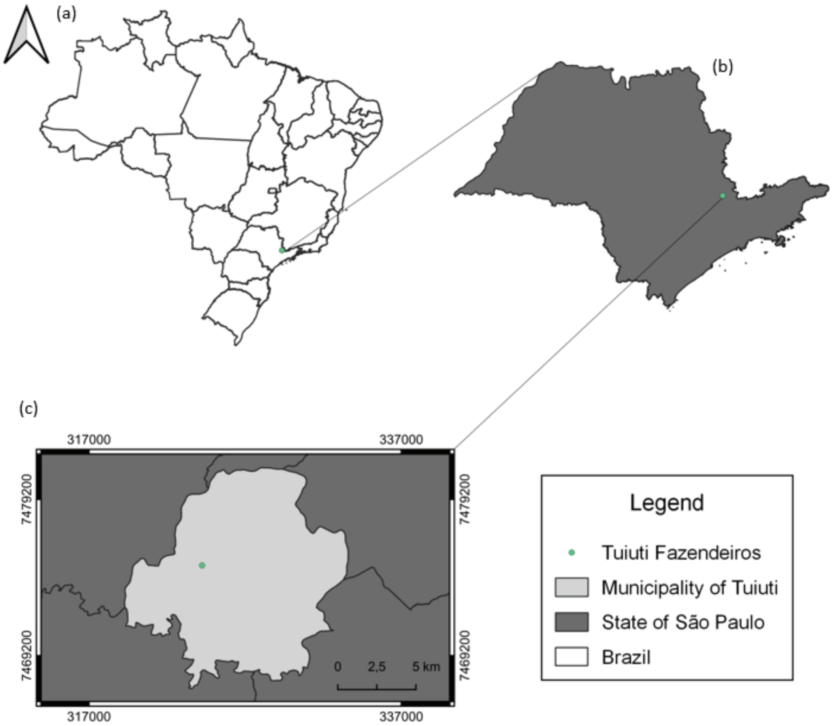
To contribute to the existing body of knowledge, the present study evaluated the effect of a subsurface plastic film (installed at a depth of 40 cm) on soil water regime. Given that previous studies with similar technologies indicated an increase in soil moisture content over time (e.g., Gupta and Aggarwal, 1980; Guber *et al.*, 2015), it was expected that soil with the plastic film would maintain higher moisture content over time compared to soil without it.

METHODS

Study area

The study was conducted at Tuiuti Fazendeiros farm, located in the municipality of Tuiuti, State of São Paulo, Brazil (Figure 1).

Figure 1. Location of the study area in the municipality of Tuiuti (a), State of São Paulo (b), Brazil (c).



The climate of the region is classified as Cfb (Alvarez *et al.*, 2013), which is characterized by a humid subtropical climate with moderately warm summers and mild winters, with temperatures in the hottest month up to 35°C and precipitation well-distributed throughout the year.

Metamorphic rocks (predominantly gneisses) dominate the region. The soil in the experimental area is classified as Red Latosol with a clayey texture (Rossi, 2017). The terrain of this soil type features a gently undulating relief with a slope of approximately 6%.

Variables and Sampling Design

A field experiment was conducted from July to September 2011 to evaluate the impact of plastic film on soil moisture retention. Four experimental plots (0.36 m × 60 m) were established. In each plot, a plastic film (recycled polyethylene) was buried at a depth of 43 cm using a subsoiler. In each plot, a set of tensiometers was installed at depths of 0–10 cm, 10–20 cm, 20–30 cm, and 30–40 cm to measure soil water potential on a weekly basis. A total of four plots with plastic film and four control plots without plastic film were established. Throughout the experiment, all plots were kept bare of vegetation.

Precipitation was measured on a daily basis using a vertical-walled bucket equipped with a ruler.

Figure 2. Subsoiler introducing the plastic film in the soil.

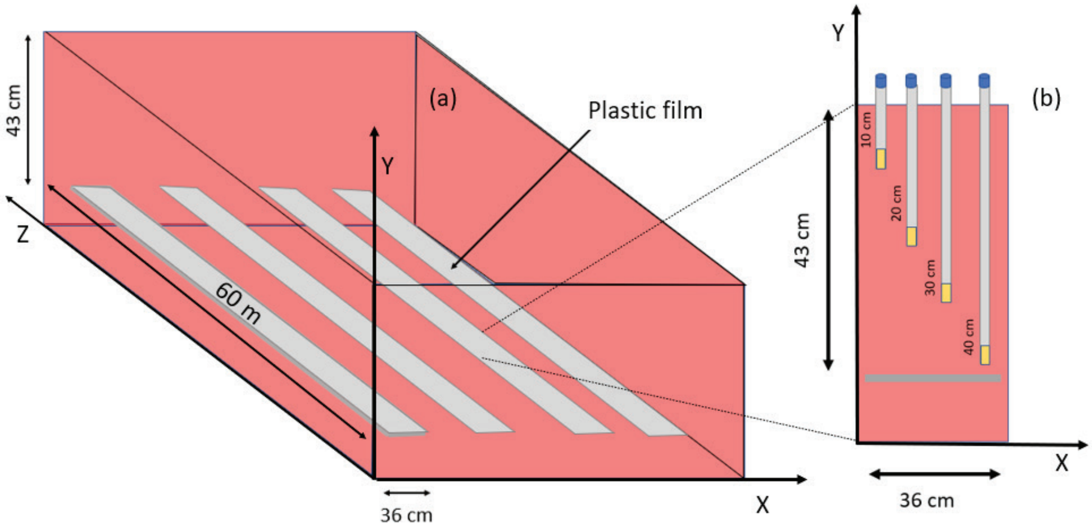


Figure 3. Sampling design showing 4 replicates of soil that had the plastic film installed (a). Tensiometers were installed at depths of 0–10 cm, 10–20 cm, 20–30 cm, and 30–40 cm in each of the four replicates (b) and their respective controls (not shown for simplicity). Scheme not scaled.

Statistics

Normality of residuals and homoscedasticity were examined using the Shapiro-Wilk and Levene tests, respectively. The results indicated normal residuals and homogeneity of variances (Table 1). Therefore, a repeated measures analysis of variance was performed. All analyses were conducted using the Past software (version 4.04) at a significance level of $p < 0.05$.

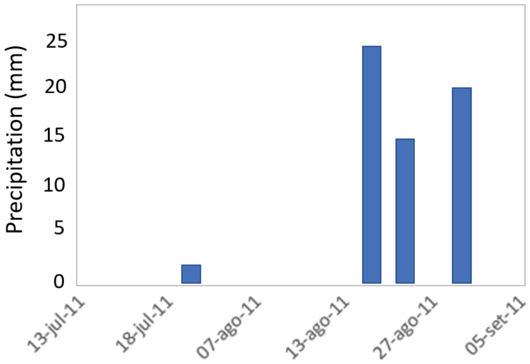
Table 1. Values of parameters of the normality (Shapiro-Wilk) and homocedasticty (Levene) tests

	Normality		Homocedasticity
Depth (cm)	W	p	p
10	0.88	0.21	0.35
20	0.93	0.58	0.29
30	0.98	0.97	0.57
40	0.88	0.21	0.09

RESULTS

A total of 63 mm of rainfall was recorded throughout the experiment, concentrated in just 4 days (Figure 4). In the period prior to the experiment, 96 mm of rainfall was recorded over 4 days (not shown). There was no evidence of surface runoff in either treatment (with or without the plastic film).

Figure 4. Daily precipitation during the study period.

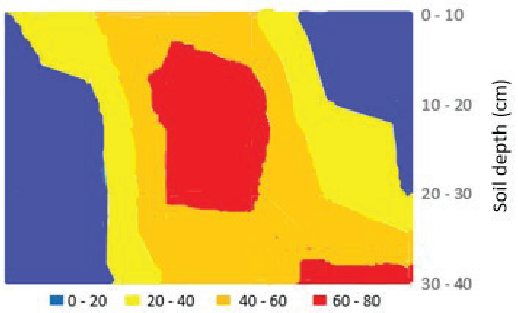


At the onset of the observation period, the soil water remained most of the time with a lower matric potential in the soil with the film compared to the soil without it (Figure 4) We attributed such initial soil moisture content difference to the rainfall (96 mm) which occurred prior to the beginning of the experiment. The control showed a longer period in the higher matric potential range (60 to 80 kPa) compared to the soil with the film (Figure 5).

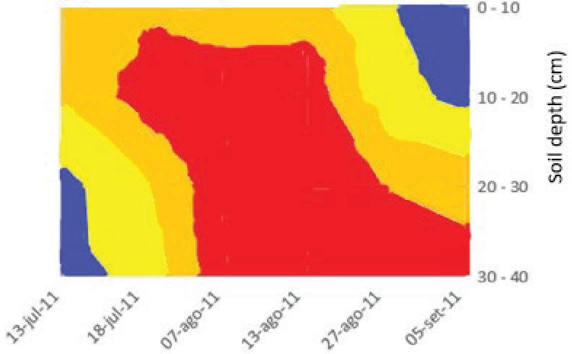
The median soil water matric potential was lower in the soil with the film compared to the soil without it at all depths, except in the 10 to 20 cm layer (Figure 6). There was a significant difference between treatments at all depths studied depths, except at 10–20 cm (Figure 6). Although no significant differences in matric potential were observed at 10 – 20 cm layer when analyzing the data globally (Figure 6), daily analysis revealed significant differences at this layer as well as the others (Figure 7). We find no apparent explanation for the absence of differences in the 10 – 20 cm layer.

Figure 5. Temporal variation of soil water matric potential (ψ) in soil with (a) and without plastic film (b).

(a) Soil with plastic film



(b) Soil without plastic film



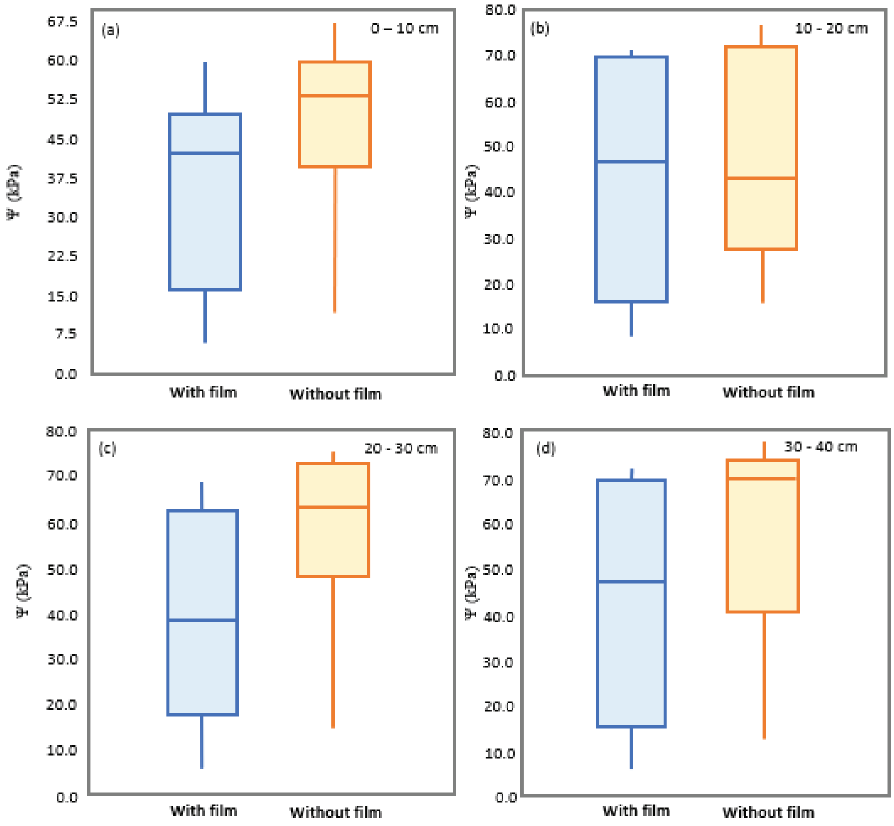


Figure 6. Box plots of soil water matric potential (ψ) in the 0–10 cm (a), 10–20 cm (b), 20–30 cm (c), and 30–40 cm (d) soil layers, with (blue) and without (yellow) plastic film, over the entire study period (n = 12 per soil depth and treatment).

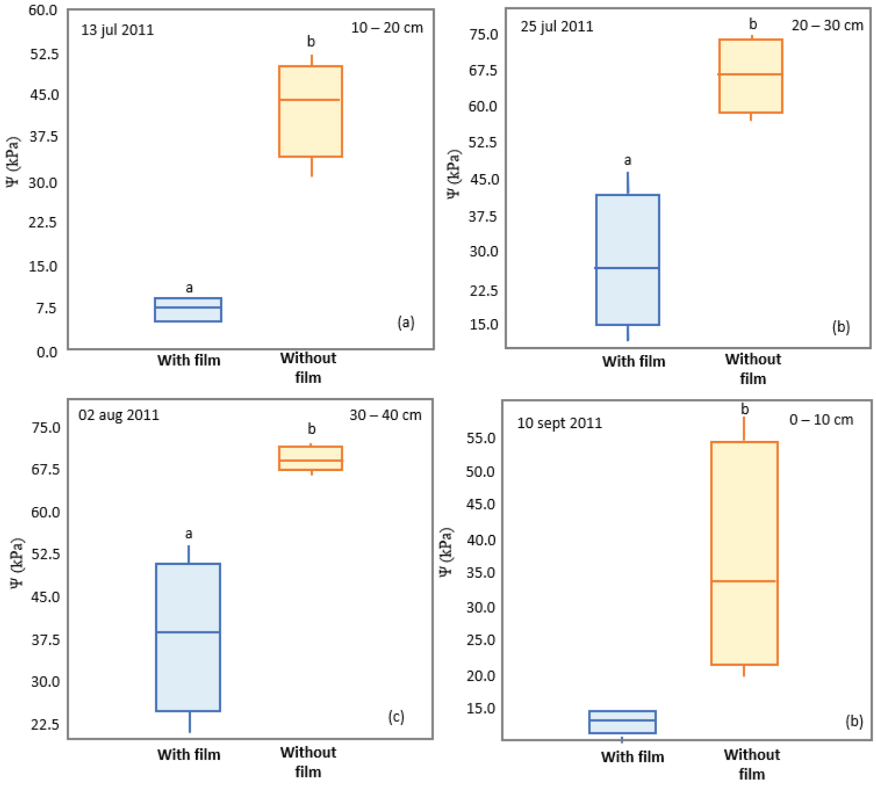


Figure 7. Box plot of soil water matric potential (ψ) in the 0 – 10 (a), 10 – 20 (b), 20 a 30 (c) and 30 - 40 (d) layers in the soil with (blue) and without (yellow) the plastic film. Different letters indicate significant differences between treatments.

DISCUSSION

In the present study, it was demonstrated that the soil subjected to the insertion of a plastic film through subsoiling had higher moisture levels (inferred from the soil water matric potential) compared to the soil without the film. The higher moisture content can be attributed to two related factors: (1) the formation of macropores through the furrow created during subsoiling and (2) the potential prevention of water percolation beyond 40 cm due to the presence of the plastic film. Since there was no surface runoff, the amount of water that infiltrated the soils with and without the film did not differ. However, the passage of the subsoiler contributed to the formation of macropores (aeration pores) (Ning *et al.*, 2022; Figure 7), which become preferential water pathways in the soil with the film. This condition can affect the distribution of the wetting front, allowing water to more easily penetrate deeper soil layers in the soil with the film (which underwent subsoiling) compared to the soil without it.

Figure 8. Furrows (which act as macropores) formed after the insertion of the plastic film through the passage of the subsoiler. Water infiltration is highly favored by these furrows.

Overall, the median soil water matric potential was lower when comparing the soil with the film to that without it. Observations from both global and daily data confirmed the effect of subsoiling with the film insertion.

Numerous studies have used plastic on the soil surface ('mulch'), thereby maintaining moisture for a longer period and reducing evaporation (e.g., Saglam *et al.*, 2017; Ma *et al.*, 2024). Similarly, studies on subsurface water retention systems have been conducted with various types of materials and designs (see Pari *et al.*, 2022). Many of these studies have demonstrated the potential of these technologies to increase the productivity of various agricultural crops (Roy *et al.*, 2019). For example, subsurface barriers promoted increased yields in rice (Rao *et al.*, 1972), soybeans (Kavdir *et al.*, 2014), and corn (Nkurunziza *et al.*, 2019). Therefore, given the higher frequency of low soil water matric potential values in the soil with the film, it is likely that, like studies have previously demonstrated for other forms of subsurface water retention technologies, the technology presented here will also positively influence productivity. Further studies are needed to evaluate the effect of increased soil water content on crop yields.

Future studies could also examine, in addition to the effect of the film on crop productivity, the differentiation between the effects of subsoiling from the plastic film. This could be evaluated by creating an additional treatment in which only the passage of the subsoiler is performed. By comparing subsoiled soil with subsoiled soil + plastic film, the effect of the cover itself could be isolated. Furthermore, the effect of adding contiguous films to create a wider subsurface barrier (potentially with a greater moisture retention effect) could be tested. Therefore, given the above, more studies are needed to enhance the understanding of this technology.

Given that climate change has led to an increased frequency of extreme events, including severe droughts and heatwaves (Xu *et al.*, 2019), technologies such as the one presented here have the potential to serve, either alone or in combination with others (e.g., irrigation, no-till farming, increasing soil organic matter, application of biochar, among others), as means to enhance water retention and, consequently, mitigate the impact of droughts on crops.

The use of plastic films in agriculture, such as mulching and subsurface films, offers benefits but also poses significant environmental impacts (Steinmetz *et al.*, 2016). On the one hand, these films help conserve soil moisture, reduce erosion, and control weeds, enhancing agricultural efficiency (ibid). However, improper disposal or accumulation of plastic films in the soil can lead to plastic pollution, negatively affecting soil quality and microbial diversity (Sun *et al.*, 2022). Additionally, degradable plastics may release microplastics, contaminating terrestrial and aquatic ecosystems (Lei *et al.*, 2024) and potentially entering the food chain (Eze *et al.*, 2024). Finally, given the widespread presence of microplastics in various ecosystem compartments, the use of plastic films in agriculture should be accompanied by an assessment of their impacts on soil, nutrient absorption in plants (Mészáros *et al.*, 2022), and efforts should be directed towards the development of more environmentally friendly plastic sources or substitutes.

CONCLUSION

Subsoiling with the insertion of a plastic film in the soil subsurface led to a change in the soil water regime. This change was reflected in the higher frequency which the soil with the film exhibited lower matric potentials and, therefore, higher moisture over time. Thus, it is concluded that the technology presented in this study may increase water retention and, consequently, it has the potential to increase crop yields.

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