



## The role of used disposable diapers for improving the growth and survival of *Eucalyptus alaticaulis* seedling under drought conditions

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[Received: November 05, 2021 Accepted: February 28, 2022 Published Online: May 30, 2022]

### Abstract

The potential of afforestation in Egypt is high due to land availability. However, available lands for afforestation are light-textured soils with low water holding capacity (WHC). Besides, the process of used disposable diapers (UDDs) represents a big challenge, particularly in developing countries. Such UDDs contain significant amounts of super absorbent polymers (SAPs). Thus, when incorporated into the soil, could increase soil WHC. This study investigates the potential of recovered-SAPs (R-SAPs) from UDDs to enhance soil hydraulic properties and aid the survival of *Eucalyptus alaticaulis* seedling under drought stress. R-SAPs were mixed with the soils (in 20-L pots) at three concentrations, i.e., 0.0, 0.75, or 1.5%. Under glasshouse conditions, seedling were irrigated for 4-months to ensure seedling' establishment, then subjected to drought by terminating irrigation. The pots were weighed daily for monitoring daily evapotranspiration until the seedling' death. R-SAPs addition increased WHC, plant available water, and prolonged seedling' survival. The seedling survived for 14, 17, and 23 days for 0.0, 0.75, and 1.5%, respectively. R-SAPs at 1.5% increased the total dry weight by 10.8%. The soil moisture at the seedling' death in R-SAPs-amended soils was higher than the control, indicating that not all the water retained by R-SAPs was available for plant absorption. R-SAPs addition increased soil salinity and  $\text{Na}^+$  concentration. The reuse of UDDs for afforestation purposes could represent a novel process for UDDs and support afforestation programs. Future research should focus on the effect of R-SAPs' addition on soil quality parameters, in particular those related to  $\text{Na}^+$  accumulation.

**Keywords:** SAPs; diapers waste; plant available water; afforestation; evapotranspiration

### Introduction

The potential for large-scale afforestation in Egypt is high due to the availability of sufficient desert land (over 950,000 km<sup>2</sup>) and sewage water (more than 6 billion m<sup>3</sup> annually) (Zalesny *et al.*, 2011; Subandi *et al.*, 2019). Consequently, Egypt has the potential to afforest over 650,000 ha and annually sequestra about 25 million tons of atmospheric CO<sub>2</sub> in the soil (Elkateb and Mosandl, 2012). Besides, the huge benefits of afforestation, large-scale afforestation in arid regions could stimulate cloud formation and may result in rainfall that is urgently needed (Zalesny *et al.*, 2011; Subandi *et al.*, 2019). High growth rates of the plantation forests in desert lands of Egypt have been observed (Zalesny *et al.*, 2011; Elkateb and Mosandl, 2012; Subandi *et al.*, 2019). Nevertheless, grounds intended for afforestation in Egypt are desert light-textured lands, with a low ability to retain irrigation water (low water holding capacity; WHC) and a lack of alimentary substances

(Abdallah, 2019; Salim *et al.*, 2021). In these soils, excessive water loss by percolation could lead to underdevelopment and decay of afforestation, and lower water use efficiency (Boczoń *et al.*, 2009). In such arid/semi-arid ecosystems, water deficit after seedling' transplanting could lead to mortality of the seedling after planting (Chirino *et al.*, 2011). Interestingly, the used disposable diapers (UDDs) contain a significant quantity of super absorbent polymers (SAPs), which are the primary agent for water absorption and retention (Ng *et al.*, 2013). Therefore, the use of UDDs as a soil conditioner for conserving soil moisture could bring several environmental benefits, i.e., mitigating the accumulation of UDDs and enhancing soil hydraulic properties for supporting afforestation projects.

The management of UDDs represents a big challenge, in particular in developing countries (Ojeda-Benítez *et al.*, 2008; Sánchez -Orozco *et al.*, 2017). It is estimated that about 20 billion UDDs are discarded in landfills annually, generating nearly 3.5 million tons of diaper-waste (about

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**Cite This Paper:** Zekry, M., H. Salim, I. Nassar and A. Abdallah. 2022. The role of used disposable diapers for improving the growth and survival of *Eucalyptus alaticaulis* seedlings under drought conditions. *Soil Environ.* 41(1): xx-xx.

4% of municipal solid waste), that needs about 500 years to decay (Khoo *et al.*, 2019). The problem of diaper-waste is expected to be aggravated due to the high birth rate, especially in developing countries (Khoo *et al.*, 2019). Several attempts for disposable diapers' reusing, i.e., anaerobic digestion (Forkes, 2007), composting (Espinosa-Valdemar *et al.*, 2014b), biodegradability (Colón *et al.*, 2013, 2011) have been undertaken. However, a small portion of UDDs is recycled, due to the difficulties in UDDs separation and collection, the lack of waste recycling facilities, and the high cost of available methods for diapers' recycling (Arena *et al.*, 2016). Besides the high cost, UDDs' recycling requires high technology, complex facilities, and equipment (Arena *et al.*, 2016), which are not available in developing countries. Nevertheless, the disposable diapers contain SAPs of 20 to 30% (w/w) (Qu and de Varennes, 2010). Such SAPs are Na<sup>+</sup> polyacrylate (Ng *et al.*, 2013; Khoo *et al.*, 2019). The Recovered SAPs (R-SAPs) from UDDs showed the ability to absorb and retain about 311-530 g of water for each g R-SAPs (Qu and de Varennes, 2010; Zekry *et al.*, 2020). Therefore, the potential of reuse of the UDDs to enhance soil hydraulic properties for afforestation purposes could represent a novel process to reuse UDDs.

SAPs are cross-linked polymers, non-water dissolved, and able to absorb, retain and release a significant amount of water. Therefore, SAPs in the soil could mitigate water stress and decrease the water- footprint (Beniwal *et al.*, 2010; Han *et al.*, 2013; Saha *et al.*, 2020). It is widely known that SAPs application enhances the hydraulic properties of light-textured soils, in particular, the WHC (Cao *et al.*, 2017; Yu *et al.*, 2017), reducing the saturated hydraulic conductivity (Bhardwaj *et al.*, 2007; Abdallah, 2019;), reducing water loss by evaporation (Yang *et al.*, 2015; Zhao *et al.*, 2019) and by deep percolation (Banedjschafie, and Durner, 2015; Montesano *et al.*, 2015; Liao *et al.*, 2016; Lejcuš *et al.*, 2018; Elshafie and Camele, 2021). Therefore, SAPs addition boost plant performance during germination and establishment stages (Zhang *et al.*, 2006; Yang *et al.*, 2014; El-Asmar *et al.*, 2017) and decrease the death possibility of newly-transplanted seedling (Wu and Liu, 2008; Oriquiriza *et al.*, 2013). More importantly, SAPs application was found to aid the growth and survival of various seedling species under drought stress, i.e., *Pinus* (HuÈttermann *et al.*, 1999; Ptach *et al.*, 2009; El-Asmar *et al.*, 2017;), *Scots pine* (Sarvaš *et al.*, 2007; Boczoń *et al.*, 2009; Ptach *et al.*, 2009), *Populus popularis* (Shi *et al.*, 2010), *buttonwood* (Al-Humaid and Mofteh, 2007), *Cork oak* (Chirino *et al.*, 2011) and a wide range of tested species (Agaba *et al.*, 2010; Oriquiriza *et al.*, 2013). Although there are many types of SAPs developed at

a laboratory scale, few types reached the market, due to economic reasons and/or the high sensitivity to soil- and water salinity (Guilherme *et al.*, 2015). Besides the high absorption rate and absorption capacity, the availability at a low price is the utmost required property of a certain SAPs type "for afforestation purposes". The high absorption rate, absorption capacity, and availability of R-SAPs from UDDs (Al-Jabari *et al.*, 2019; Zekry *et al.*, 2020), increase the potential of the use of UDDs for afforestation purposes.

In Egypt, more than 42 million UDDs are used daily, producing about 8400 tons of diaper-waste (Zekry *et al.*, 2020). Currently, UDDs in Egypt are burned or placed in landfills. The use of R-SAPs from UDDs for improving the WHC of the soil has been investigated (Qu and de Varennes, 2010; Al-Jabari *et al.*, 2019; Zekry *et al.*, 2020). Nevertheless, the beneficial effect of R-SAPs from UDDs on seedling' growth and survival for afforestation purposes has not yet been investigated. The ongoing afforestation projects in Egypt showed that *Eucalyptus sp.* has a great potential for afforestation in light-textured soils. Elkateb and Mosandl (2012) evaluated the growth of 18 species in three different governorates representing northern and southern Egypt, to identify the most promising species for sustainable forestry. *Eucalyptus sp.* was among the top four species that showed the highest growth rate over the three locations. *Eucalyptus sp.* is a drought-tolerant evergreen tree that showed fast growth, and was found to be suitable for salina-sodic soil (Zalesny *et al.*, 2011; Elkateb and Mosandl, 2012; Subandi *et al.*, 2019). In the present study, the performance of R-SAPs from UDDs was valorized to quantify the usefulness of the use of wasted UDDs for the afforestation of *Eucalyptus alaticaulis*. We investigated the effect of amending the soil using R-SAPs from UDDs for enhancing soil hydraulic properties, growth, and survival of *Eucalyptus alaticaulis* seedling subjected to drought as well as R-SAPs' effects on soil chemical properties. The results of this study could support the development of the afforestation program in Egypt in decision-making regarding boosting seedling' growth conditions after the success of the selection of appropriate tree species.

## Materials and Methods

### Used soil, SAPs recovery and preparation

Surface soil samples (0-30 cm) were collected from the experimental field site of Damanhour University, El-Behira governorate, Egypt (30°46'46" N, 30°82'32" E). The soil contained 70.0, 5.0, and 25% of clay, silt, and sand, respectively. The soil was sandy clay loam in texture (supporting information; Table S1). After air-drying, the



collected samples were ground, sieved through a 2 mm sieve, and the fine-earth “soil particles less than 2 mm” were used in the lab experiments. For the pot experiment, air-dried non-sieved soil samples were used.

The UDDs were collected from a private nursery-house (Damanhour, Egypt). For investigating the effect of the R-SAPs on soil hydraulic conductivity, the dry SAPs were extracted. To eliminate pathogens, the collected diapers were heated in an autoclave for 15 minutes at 125°C, then the UDDs were sliced up and the components were separated. The polymers “SAPs” blended in cellulose fibers were oven-dried for 24.0 hr at 60.0°C (Sánchez -Orozco *et al.*, 2017). The cellulose fibers were shaken in a plastic container to obtain the dried R-SAPs. The R-SAPs is a white powder with a particle size of ~300 µm and a bulk density of 600–750 Mg m<sup>-3</sup>. Swollen R-SAPs were used for the greenhouse experiments. Swollen R-SAPs were obtained by immersing the UDDs “overnight” in tap water, then the swollen R-SAPs were extracted.

### Saturated hydraulic conductivity (Ks)

The Ks was determined using the constant-head method (Moutier *et al.*, 2000). Air-dried soil (passed through a 2 mm sieve) was amended with 0.0, 0.5, and 1.0 % (w/w) of the R-SAPs, backed into PVC cylinders, and all treatments were compressed to a bulk density of 1.46 Mg m<sup>-3</sup> to simulate the bulk density of the field. The R-SAPs amended soil was saturated using upward flow, after which the direction of the water flow was overturned, and a constant pressure head (5 cm) was applied. The amount of percolated water during a certain time was determined. This process was repeated until a constant value was observed, then the Ks was calculated using Darcy’s Law.

### Greenhouse experiment

#### Experimental design and conditions

*Eucalyptus sp.* was chosen due to its high adaptability to Egyptian conditions. Based on the results of Elkateb and Mosandl (2012), *Eucalyptus sp.* has a high potential for afforestation under hot-dry conditions in Egypt. Among 18 tree species, across three locations “governates” representing northern and southern Egypt, *Eucalyptus Sp.* was among the top four species that showed fast growth, evergreen, drought-tolerant, ease of propagation, suitable for saline-sodic soil, with economic uses.

For determining the effect of R-SAPs from UDDs on seedling’ growth, water relations, and survival, the collected UDDs were soaked in tap water, then the swollen R-SAPs were recovered and mixed with the air-dried soil to give two different concentrations 7.5 and 15% (w/w), in addition to

the control (without SAPs). Swollen samples were collected, and the corresponding concentration based on the R-SAPs dry weight was calculated, i.e., 0.75 and 1.5%, respectively. One-year-old *Eucalyptus alaticaulis* seedling (100 cm-high) were potted on April 1<sup>st</sup>, 2019, in 20 L pots (r = 15.2 cm, height = 28 cm) filled with the soil with no amendment (control), with R-SAPs at 0.75%, or 1.5% using five replicates for each treatment. The seedling were placed in the greenhouse (T of 28.0±2°C and RH of 70.0±5%) and arranged in a completely randomized design. To minimize the micro-climate variability, the pots were rotated inside the glasshouse every week keeping the completely randomized arrangement. During the first four months, the seedling were irrigated twice every week using 3 L per pot, to ensure the successful establishment of the seedling, which was demonstrated by the growth of some new leaves (Agaba *et al.*, 2010; Abdallah, 2019). After that, seedling were exposed to drought by ceasing irrigation.

After irrigation ceasing, the pots’ growth weight was determined to calculate the initial soil water content (the changes in plant weights were ignored). The gross weight for a pot was recorded daily to follow the soil water status and daily evapotranspiration (ET) (Agaba *et al.*, 2010; Abdallah, 2019). The seedling were monitored to identify when they showed permanent wilting (died). The seedling were deemed dead when all leaves went brown and began to fall off, and the branches became brittle (verified by breaking a sample from the seedling that appeared dry) (Agaba *et al.*, 2010). Shoot height was measured at wilting of the seedling. For determining the total dry weight of a seedling, the wilted seedling were harvested and then dried at 70°C. Soil samples were collected after the experiment termination for chemical characterization.

The survival time (day) was calculated as the total time to reach the permanent wilting stage (seedling death) (Agaba *et al.*, 2010). Plant available water (PAW; mm) or cumulative ET (mm) was determined as the differences between the whole pot weights after ceasing irrigation and seedling’ death (Hüttermann *et al.*, 1999; Abedi-koupai and Asadkazemi, 2006; Agaba *et al.*, 2010). The overall average ET rate (mm d<sup>-1</sup>) was obtained by dividing the PAW (mm) by the survival duration (days) (Hüttermann *et al.*, 1999). The pattern of daily ET was measured as the daily loss in the whole pot weight (Abdallah, 2019). The measurement of ET by weighing the pot was widely used (Hüttermann *et al.*, 1999; Abedi-koupai and Asadkazemi, 2006; El-Asmar *et al.*, 2017; Page *et al.*, 2019; Abdallah *et al.*, 2021).



## Soil analysis

Immediately after harvesting the seedling, a soil sample representing each pot was collected and some chemical parameters were determined. The total organic matter was determined according to Walkley-Black (1934). Soil pH was determined in a 1:2.5 soil-water suspension, whereas electrical conductivity (EC), soluble  $\text{Ca}^{+2}$ , and soluble  $\text{Na}^{+}$  were measured in 1:5 soil water extract (Jackson, 1973). Soluble  $\text{Ca}^{+2}$  was determined by titration methods, while soluble  $\text{Na}^{+}$  was measured by the flame photometer (Jackson, 1973).

## Analysis of measurements

Data were analyzed based on the nonlinear regression analysis. A third-degree polynomial function was used for explaining water loss from pots as a function of time,

$$P(x) = ax^3 + bx^2 + cx + d$$

where  $P(x)$  is the polynomial value at a certain time ( $x$ ) and  $a$ ,  $b$ ,  $c$  and  $d$  are polynomial coefficients.

## Statistical analysis

The data were analyzed as a completely randomized design using SAS 9.4 (SAS, 2013. Inc., Cary, NC, 2013). The significance of differences among means was determined at a significance level of 5% ( $p \leq 0.05$ ) and means were compared according to Tukey's test.

## Results

### Saturated hydraulic conductivity (Ks)

The addition of R-SAPs decreased the Ks significantly ( $p \leq 0.05$ ) in comparison with the control (without R-SAPs) (Figure 1). The Ks value of the control was 2.5 folds with respect to R-SAPs-amended soil (1.0%).

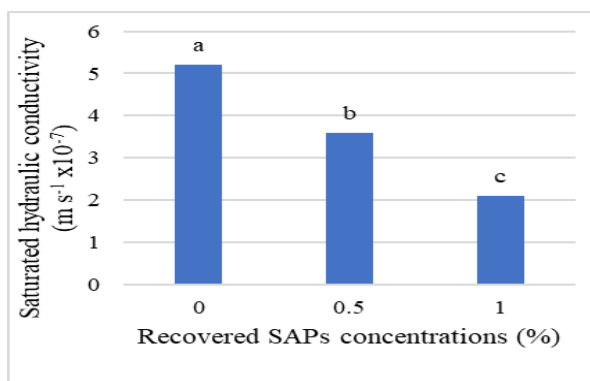


Figure 1. The saturated hydraulic conductivity (Ks) in R-SAPs-amended soil with different concentrations, i.e., 0.0, 0.5 and 1.0%

### *Eucalyptus alaticaulis* growth and survival

Seedling' shoot height, survival time, and total dry weight as a function of R-SAPs levels at the permanent wilting time are presented in Figure (2). The shoot height did not differ significantly due to R-SAPs application (Figure 2a). In contrast, the presence of R-SAPs from UDDs significantly prolonged the survival time of *Eucalyptus alaticaulis*. The highest survival time was recorded at the high concentration of R-SAPs. The addition of R-SAPs increased the survival time of the seedling by 21.4 and 64.5% for R-SAPs-amended soil at 0.75% and 1.5%, respectively, (Figure 2b). Furthermore, total dry weight of the seedling increased significantly only at 1.5% concentration, while R-SAPs at 0.75% had no effect. The total dry weight was higher than the control treatment by 9.25%.

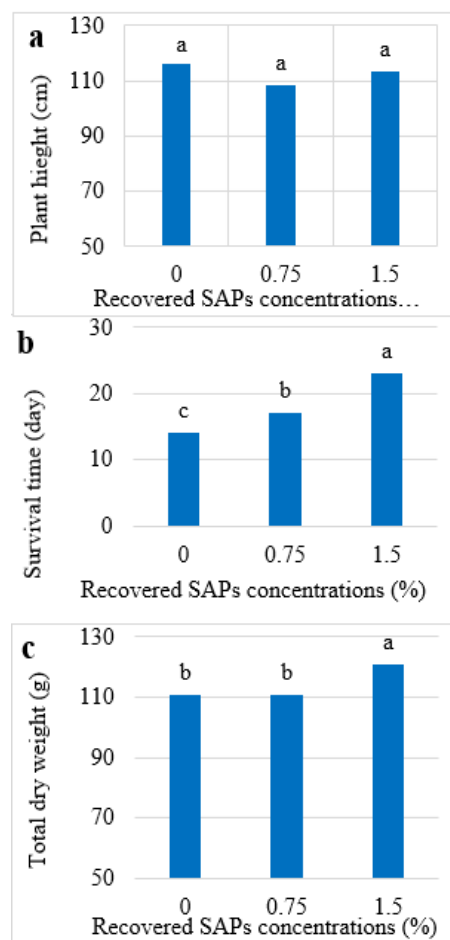


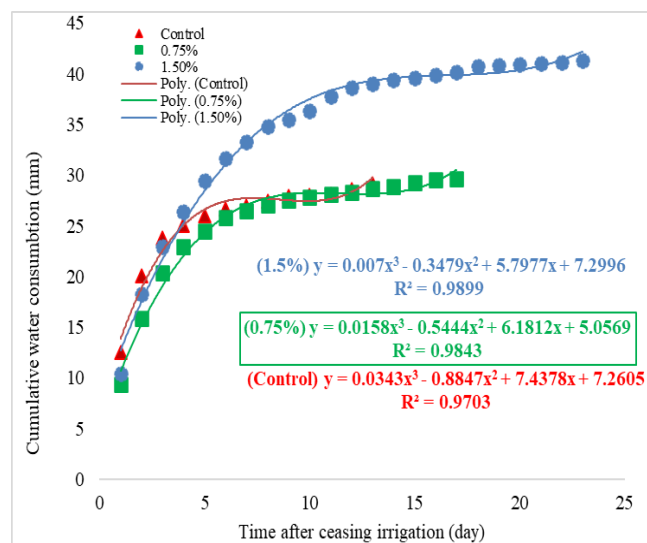
Figure 2. Effect of different levels of R-SAPs, i.e., 0.0, 0.75, and 1.5%, on shoot height (a), survival time (b) and total dry weight (c) of *Eucalyptus alaticaulis* seedling at wilting point



## *Eucalyptus alaticaulis* - R-SAPs water relations

### Cumulative evapotranspiration (ET)

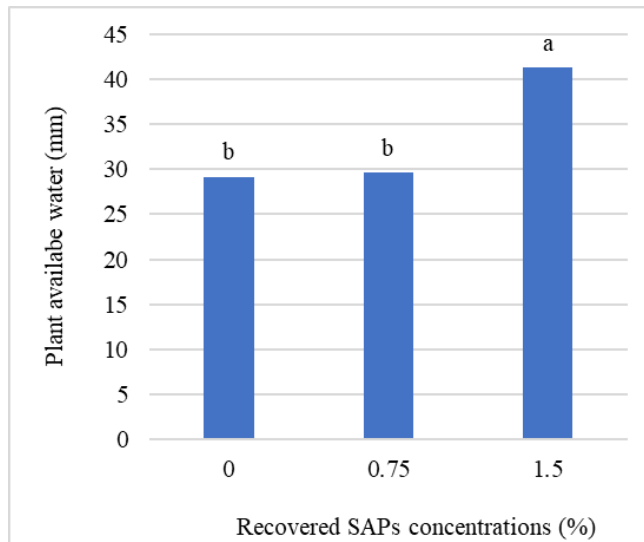
Figure (3) presents the cumulative ET as a function of time for *Eucalyptus alaticaulis* seedling as affected by the additive R-SAPs from UDDs. The cumulative ET was described using the third-degree polynomial function. The calculated ET and measured values are compatible well because of their strong coefficient of determination ( $R^2$  greater than 0.97). The ET pattern followed the order of  $1.5\% > 0.75\% > \text{control}$ . The ET showed two distinguished stages: greatly and slightly increasing stages. The first stage comprised the first five days after drought initiation, while the second ET stage took place with further time. In particular, after the 5<sup>th</sup> day, a higher cumulative ET was observed for the highest concentration (1.5%).



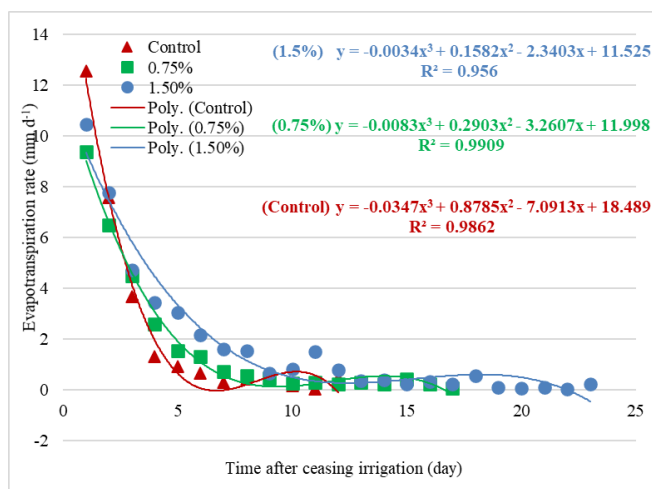
**Figure 3.** The cumulative evapotranspiration (ET; mm) as a function of time for *Eucalyptus alaticaulis* seedling as affected by the additive R-SAPs at different levels, i.e., 0.0, 0.75, and 1.5%

### Plant available water (comprehensive total evapotranspiration)

Figure (4) shows the PAW (comprehensive total ET) under the treatments used. The ET represents the difference between the gross weight of the pot (pot + plant) at the time of drought initiation and the weight at the wilting time of the plant. As compared to the control, the PAW (total water losses by ET) was 45% higher than the control for the 1.5% R-SAPs treatment, while R-SAPs at the low concentration of 0.75% showed no effect.



**Figure 4.** The effect of different R-SAPs levels, i.e., 0.0, 0.75, and 1.5%, on plant available water (total evapotranspiration) of *Eucalyptus alaticaulis* seedling



**Figure 5.** The daily evapotranspiration (ET; mm d<sup>-1</sup>) of *Eucalyptus alaticaulis* seedling as a function of time after ceasing irrigation as affected by R-SAPs levels, i.e., 0.0, 0.75, and 1.5%

### Daily evapotranspiration and its pattern

The calculated daily ET rates along with measured values are presented in Figure (5). Both the calculated and measured rates are in good agreement. Similar to the cumulative ET, the pattern of daily ET rates showed two decreasing stages (fast and gradual ones). The ET rates of the three treatments differed among the treatments. The 1.5% R-SAPs concentration possessed the greatest ET rate while the control possessed the lowest value for rates. These

rates are a function of time as the cumulative ET. The first derivative of the function is calculated at 5 and 10 days after the drought initiations. The calculated ET rates after 5 days were 1.16, 1.92, and 2.84 mm d<sup>-1</sup> for 0.0, 0.75, and 1.5%, respectively. The measured values after 5 days were 0.93, 1.53 and 3.07 mm day<sup>-1</sup> for 0.0, 0.75, and 1.5%, respectively. It is obvious that as further time increased the rate is eventually reduced (Figure 5). For example, the daily ET after ten days after ceasing irrigation, ET rates were 0.042, 0.23, and 0.78 mm d<sup>-1</sup>. The reduction was more pronounced for the control treatment. Therefore, the presence of R-SAPs boosted both the water supply-demand for ET and the water transport coefficients compared to the control treatment.

**Overall average evapotranspiration**

The overall average ET rates were shown in Figure (6). These rates were obtained by dividing the total ET by the survival period of a plant. The average ET rate was significantly higher than SAP-amended soil at the two tested concentrations. The R-SAPs addition decreased the average evapotranspiration rate (mm d<sup>-1</sup>) by 20.7 and 17.3% for 0.75% and 1.5% treatments, respectively.

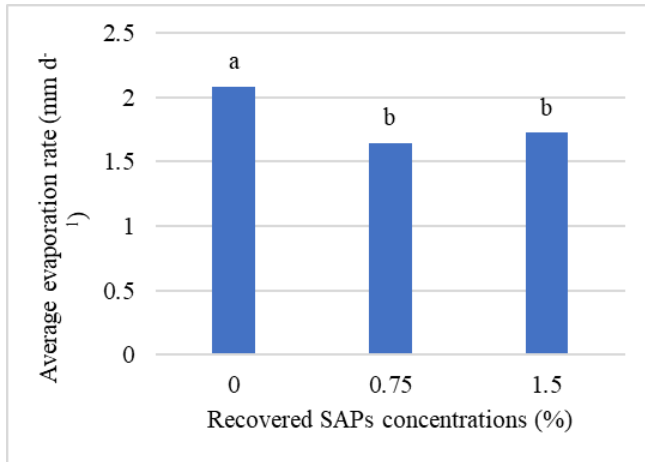


Figure 6. Effect of R-SAPs level (0.0, 0.75, and 1.5%) on the average evapotranspiration rates of *Eucalyptus alaticaulis* seedling

**Water holding capacity and water content at wilting point**

Figure (7) presents the daily whole weight (pot + plant). These weights are a function of retained water in soil and increases in biomass through the drought period. The distributions of daily weights are described using a third-degree polynomial function. The function described the observed weights well because the determination coefficients (R<sup>2</sup>) for all treatments were approximately unity using the

function. The retained water is affected positively by the additive R-SAPs levels, in which the R-SAPs enhanced the storage capacity of the soil (Figure 7). The retained water decreased greatly during the first five days of drought stress followed by a slight decrease as time increased. However, not all the retained water in the soil due to R-SAPs addition was available for plant uptake. This has been indicated by the pot weights- and the gravimetric soil water content at seedling wilting (death) (Figure 8). The wilting point was significantly increased as the R-SAPs concentration increased. The wilting point was 5.0 and 8.3 times higher than the control for 0.75 and 1.5% treatments, respectively.

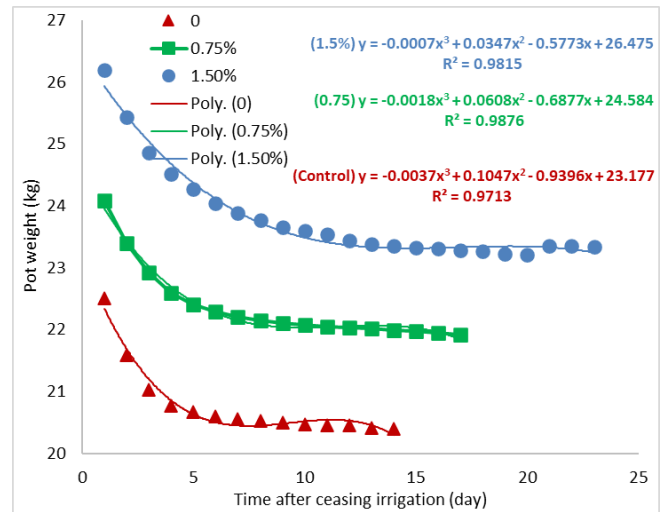


Figure 7. Observed daily weight of the whole pot (including the seedling) as affected by R-SAPs levels, i.e., 0.0, 0.75, and 1.5%

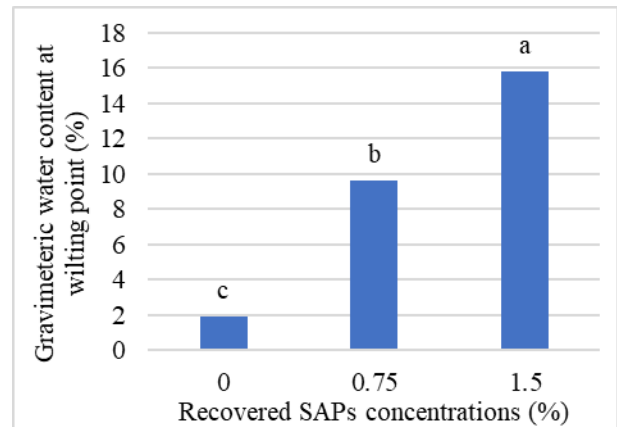


Figure 8. The gravimetric soil water contents of wilting point of *Eucalyptus alaticaulis* for the different SAPs (0.0, 0.75, and 1.5%) recovered from used diapers



## Soil chemical analysis

After harvesting seedling<sup>7</sup>, soil samples were collected for determining some chemical parameters, i.e., total organic matter, pH, EC and calcium and sodium concentrations. Figure (9) show the pH, EC and total organic matter under different R-SAPs levels. The addition of R-SAPs significantly ( $p \leq 0.05$ ) affected the pH values. The pH decreased as the R-SAPs level increased (Figure 9a). The pH ranged from 8.30 (1.5% SAP) to 8.78 (control). The EC was significantly increased by additives R-SAPs (Figure 9b). The ECs were 0.26, 0.48, and 0.46 dS  $m^{-1}$  for the 0.0, 0.75, and 1.5% of R-SAPs, respectively. The organic matter contents differed significantly among the treatments. The soil organic matter increased with increasing the level of R-SAPs (Figure 9c). Organic matter increased by 4.25 and 6.4% for 0.75 and 1.5% of R-SAPs, respectively.

$Ca^{2+}$  and  $Na^{+}$  concentrations in the soil under the R-SAPs treatments are presented in Figure (10). The differences in the means of calcium concentrations were

significantly lower at R-SAPs of 1.5%, while R-SAPs at low concentrations had no effect (Figure 10a). However, the sodium concentrations were highly affected by the addition of R-SAPs (Figure 10b). The sodium increased under the 0.75 and 1.5% R-SAPs levels in comparison to the control. R-SAPs additions increased  $Na^{+}$  by two folds with respect to the control.

## Discussion

In developing countries, the management of the UDDs is a big challenge. Huge amounts of diaper waste are produced daily. However, the UDDs contain nearly 30% (w/w) SAPs, which are capable of absorbing and retaining a marked amount of water. Our previous work (Zekry *et al.*, 2020) showed the high water absorption capacity and high swelling rate of R-SAPs from UDDs, as well as its significant positive effect on the WHC of the soil. The R-SAPs from UDDs were able to retain 311.0 g water  $g^{-1}$  R-SAPs, thus, increasing soil WHC by 2.6 folds (Zekry *et al.*, 2020). Therefore, the potential reuse of the UDDs as a soil amendment represents a novel process to decrease the

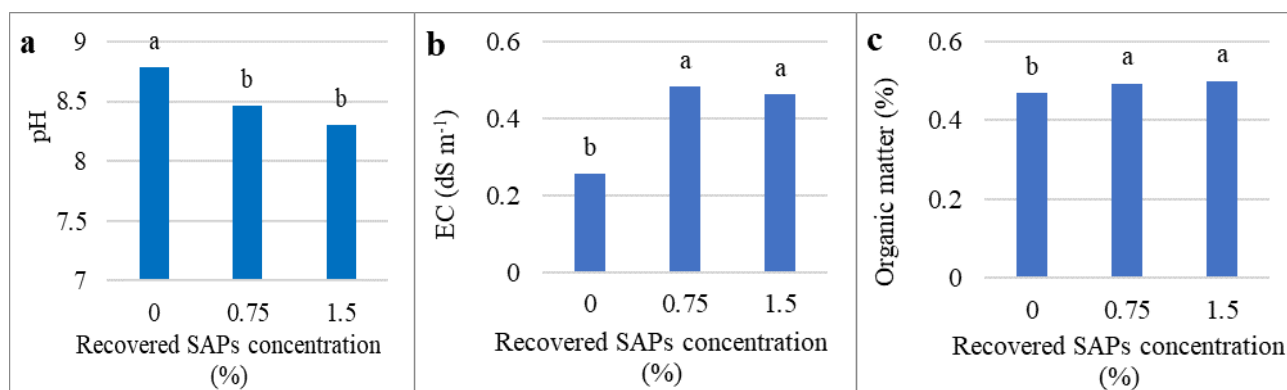


Figure 9. The pH (a), soil salinity (b) and total organic matter (c) after seedlings harvest as affected by different levels of R-SAPs, i.e., 0.0, 0.75, and 1.5%

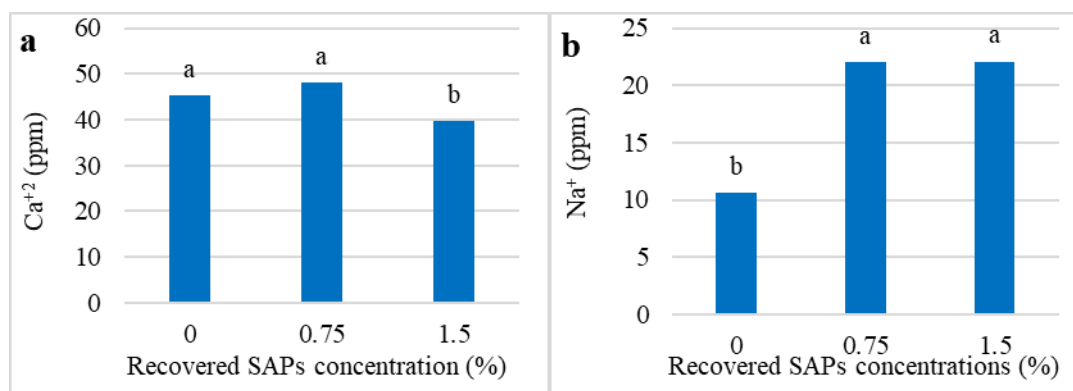


Figure 10:  $Ca^{2+}$  and  $Na^{+}$  concentrations in the soil after seedlings harvest as affected by different levels of R-SAPs, i.e., 0.0, 0.75, and 1.5%

accumulation of the UDDs in the environment. In Egypt, the available lands for the ongoing afforestation program are desert lands with low WHC. The current study introduces information about the potentiality of the reuse of the UDDs for enhancing the growth, water relations, and survival of *Eucalyptus alaticaulis* seedling subjected to drought stress. This study would help avoid such environmental pollution by these UDDs and support the afforestation program in Egypt. In this study, the impact of R-SAPs on saturated hydraulic conductivity was investigated. After that, the impact of R-SAPs' level on the growth and the survival of *Eucalyptus alaticaulis* seedling and chemical properties of soil was assessed.

### Effect of R-SAPs on saturated hydraulic conductivity

The observed significant reduction in Ks, due to R-SAPs addition has been widely reported on different soil types (Bhardwaj *et al.*, 2007; Andry *et al.*, 2009; Morsy *et al.*, 2021). However, this is the first study that investigates the effect of SAPs recovered from UDDs on the Ks. The high water absorption capacity and swelling rate of the R-SAPs (Qu and de Varennes, 2010; Zekry *et al.*, 2020) could explain the marked reduction in the Ks of R-SAPs amended soil. The swollen SAPs enlarged the pores that are the main paths for water transfer. The high SAPs swelling eventually led to a decline in pore space and pore blockage (Levy *et al.*, 2005; Han *et al.*, 2013; Abdallah *et al.*, 2021). The reduction in Ks causes a decrease in water percolation, which boosts soil WHC, water use efficiency (Abdallah, 2019).

### *Eucalyptus alaticaulis* growth and survival

The increase in seedling' survival due to R-SAPs addition could be attributed to the increased soil water availability that supports the growth of the seedling. As the SAPs concentration increases, the total retained- and available water for plant uptake increases, delaying seedling' wilting, and extending seedling' survival, dry matter accumulating (El-rehim *et al.*, 2004; Abdallah, 2019). These data of dry weight are compatible with the survival time. When the soil starts to dry, the swollen SAPs gradually release their water to the nearby dry soil, which becomes available for plant uptake (HuËttermann *et al.*, 1999; Ptach *et al.*, 2009; El-Asmar *et al.*, 2017). Therefore, during the drought period, a higher amount of water was released to the seedling' roots in R-SAPs' treatments (HuËttermann *et al.*, 1999; Orikiriza *et al.*, 2013; Abdallah, 2019; Abdallah *et al.*, 2021). The results of *Eucalyptus alaticaulis* survival support those of *Pinus* trees grown under water stress on SAPs-amended soils (HuËttermann *et*

*al.*, 1999; Andry *et al.*, 2009). For example, in sandy clay loam, El-Asmar *et al.*, (2017) found that hydrogel at 0.4% prolongs the survival of *pine* seedling' by 90%. The results of seedling' growth are in agreement with the findings of Qu and de Varennes, (2010) in which they found that amending the soil with SAPs recovered from diapers led to the greatest growth and biomass of *Spergularia purpurea*, as compared with the control.

### Effect of R-SAPs on *Eucalyptus alaticaulis* seedling's water relations

The increases in biomass with time especially during drought stress might be trivial (El-Asmar *et al.*, 2017; Elbasyoni *et al.*, 2019; HuËttermann *et al.*, 1999). Therefore, the behaviors of the daily weights in the present studies are concomitant with retained water in soils. The higher daily- and cumulative ET of seedling grown in R-SAPs-amended soil could be due to the increase in soil WHC and PAW (Han *et al.*, 2013; Orikiriza *et al.*, 2013). The soil amended with R-SAPs was able to retain more water throughout the irrigation period compared with the non-amended soils. Therefore, the SAPs-amended soil could offer to lose more water "through ET" and yet preserve more water than the non-amended soil. The presence of R-SAPs enhanced the cumulative ET that concomitance with soil WHC as presented in our previous work (Zekry *et al.*, 2020) and other studies (Sánchez-orocho *et al.*, 2017; Al-Jabari *et al.*, 2019). As further time increased "after ceasing irrigation" the ET rate is eventually reduced. There are three fundamental factors for evaporation to occur: available water, available energy, and a vertical moisture gradient. As a result, the actual evaporation is governed by external vaporability or the soil's ability to supply water. If the top-soil layer is wet, as at beginning of the drought period (first stage), the water evaporation from the soil surface gradually decreases soil moisture, thus increasing the matric potential at the soil surface. As a result, the soil water in the sub-surface soil layers is drawn upward, given that the sub-surface layers are adequately wet (Hillel, 1980). With further water loss "the second stage", the supply of soil water for evaporation is declined because of the low soil isothermal and thermal water diffusivity for the upper soil layer. Therefore, the water losses during the second stage might be dominated by transpiration via the *Eucalyptus alaticaulis* leaves. A similar pattern of ET was obtained by HuËttermann *et al.* (1999) and Abdallah (2019). Similarly, Agaba *et al.* (2010) concluded that SAPs addition decreased plant ET. In the present study, the overall average ET rates (comprehensive ET/survival time) are in contradiction with the comprehensive ET and the daily ET rates. These discrepancies might be due to the differences in the survival



times among the treatments used. The longer the survival time is the lower the overall average ET is. Agaba *et al.* (2010) concluded that SAPs decreased the average ET for different forestry seedling in different soil types.

Despite R-SAPs increased seedling' survival time, cumulative ET, and PAW due to increasing the amount of water retained in the soil, a portion of this stored water was not available for plant uptake when required (Since seedling in the control died at soil moisture of 1.9%, while the seedlings in R-SAPs-amended died at soil moisture of 15.8%). The higher soil moisture at PWP of R-SAPs treatment implies that not all the water retained by the SAPs is available for plant uptake. The results support those of HuËttermann *et al.* (1999), who found that *Pinus halepensis* seedling died at a water content of 0.6% and 10.7% for control and hydrogel-amended soils, respectively. Yang *et al.* (2013) found that about 11% of the water retained by SAPs was not available to plant uptake whereas the percentage increased to 24% as reported by Abdallah (2019). Such changes in the percentage of non-available water could be attributed to the variation in the cultivated plant, soil texture, and SAPs type, concentration and particle size.

### Soil chemical analysis

The observed reduction in soil pH due to the addition of R-SAPs from UDDs could be attributed to the presence of the uric acid in the UDDs when first used. Such reduction in soil pH suggests that the degradation of diaper SAPs could enhance plant nutrient availability. Contrary to our results, Qu and de Varennes (2010) found that SAPs from UDDs increased the soil pH, which the pH increased from 4.7 to 6.6. The conflict results could be attributed to the extreme differences in the soil pH, where the soil in our study is slightly alkaline, whereas the soil in the experiment conducted by Qu and de Varennes (2010) is highly acidic. It is noteworthy that, in the two studies, the recovered SAPs from UDDs positively adjusted the soil reaction. The observed increases in the EC could be due to the release of some salt, by R-SAPs. SAPs in diapers are responsible for absorbing and retaining the urine, which ultimately contains significant amounts of different salts. In addition to some salts that can be released from the SAPs itself. Gómez *et al.* (2015) found an increase in soil salinity by adding SAPs in which the soil salinity was 93.57 and 124.9  $\mu\text{S cm}^{-1}$  for 0.0 and 0.4% SAP, respectively. Therefore, the increases in soil salinity that result from using R-SAPs from UDDs must be considered as an agricultural policy for future uses of diapers. More importantly, the significant increase in  $\text{Na}^+$  in the soil is mainly attributed to R-SAPs addition. SAPs used in UDDs are usually  $\text{Na}^+$  polyacrylate (Al-Jabari *et al.*

2019); for instance SAPs from diapers contain 136  $\text{mg g}^{-1}$  dry polymer, (Qu and de Varennes, 2010). The slight reduction in  $\text{Ca}^{+2}$  in the soil could be explained by that some calcium might be tightening to the SAPs. The divalent cations ( $\text{Mg}^{2+}$  and  $\text{Ca}^{2+}$ ) are particularly bound to the carboxylic acid groups of acrylic acid, resulting in insoluble complexes (Spagnol *et al.*, 2012b; Zhou *et al.*, 2012). The observed increase in soil salinity and  $\text{Na}^+$  content and the reduction in  $\text{Ca}^{+2}$  could lead to chemical degradation of the soil by increasing the exchangeable sodium percentage, which ultimately will lead to physical soil degradation. Therefore, careful soil management must be considered when reusing R-SAPs from UDDs as a soil amendment, for example by adding gypsum as a  $\text{Ca}^{+2}$  source to minimize  $\text{Na}^+$  accumulation. The present study demonstrated the viability of using R-SAPs from UDDs for enhancing the growth conditions of *Eucalyptus alaticaulis* under drought conditions. The results of the study could serve as an appropriate implementation of the afforestation in the desert lands of Egypt to help mitigate climate change and to mitigate the accumulation of UDDs in the environment. However, in developing countries, the separation, gathering and management of the UDDs as well as the recovery of SAPs from UDDs, represents another challenge for the reuse of UDDs as soil amendments in afforestation.

### Conclusions

The results of this study addressed the usefulness of UDDs as a soil conditioner and avoiding such environmental pollution by a kind of diaper. The reuse of the UDDs to enhance soil hydraulic properties for afforestation purposes could represent a promising process to reuse UDDs and support the afforestation program of Egypt by enhancing the growth conditions after the success of the selection of appropriate tree species. Careful soil management must be considered when reusing R-SAPs from UDDs to avoid possible soil salinization and sodification. Further studies are required to investigate the effect of the reuse of UDDs on soil quality in the long term.

### Acknowledgements

This research has been supported by the Faculty of Agriculture, Damanhour University, Egypt. The authors introduce their sincere thanks to Mr. Muhammad Ahmad for the linguistic revision of the manuscript.

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