Evaluation of Substrate Hydraulic Properties Amended by Urea–formaldehyde Resin Foam

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Abstract. Urea–formaldehyde resin foam has been introduced as a synthetic organic soil amendment and is used in hydroponic systems, soilless cultures, production of container-grown plants, roof gardens, and sports fields. To evaluate whether urea–formaldehyde resin foam can improve physical properties (water retention capacity and aeration) of horticultural substrates, an organic substrate (coir) and an inorganic soil (loam soil) were selected and amended with urea–formaldehyde resin foam (Fytocell). Water retention curves, $\theta(h)$, saturated hydraulic conductivity, K_s , and the relationship between unsaturated hydraulic conductivity and volumetric water content, $K(\theta)$, were determined for Fytocell, coir, loam soil, mixtures of coir/Fytocell (60/40 v/v), and loam soil/Fytocell (60/40 v/v). Water retention curves indicated that the addition of Fytocell in loam soil and coir mixtures increased and decreased, respectively, the water retention capacity. The K_s of loam soil and coir mixtures were decreased and increased, respectively, by the addition of Fytocell. In all substrates studied, $K(\theta)$ decreased sharply when θ decreased from 0.80 to 0.20 $\text{m}^3\cdot\text{m}^{-3}$. However, the coir/Fytocell mix had the highest values of $K(\theta)$ when θ was below 0.40 $\text{m}^3\cdot\text{m}^{-3}$. Moreover, the comparison between estimated $K(\theta)$ values obtained using the experimental outflow method of Valiantzas (1989) and predicted values using the van Genuchten–Mualem model showed a satisfactory agreement ($0.937 \leq R^2 \leq 0.996$) for the substrates examined.

Recently, urea–formaldehyde resin foam (UFRF) has been introduced as a synthetic organic soil amendment and is used as a substrate in the propagation and growth of plants in hydroponic systems, soilless cultures, and substrates used in production of container-grown plants, in roof gardens, and sports fields. Urea–formaldehyde resin foam and its effect on plant growth has been the subject of study as an amendment for soils and organic substrates for several researchers (Chan and Joyce, 2007; Mooney and Baker, 1999; Nektarios et al., 2003, 2004; Nguyen et al., 2009; Nikolopoulou and Nektarios, 2004; Nikolopoulou et al., 2004). Urea–formaldehyde resin foam is environmentally friendly, lightweight (18–30 $\text{kg}\cdot\text{m}^{-3}$), slowly biodegradable over a period of 20 years, sterile, and has a high water retention capacity (57% v/v) (Werminghausen, 1972). Furthermore, UFRF has been found to increase air-filled porosity and water infiltration of fine texture soils and water retention of coarse texture soils (Baader, 1999). In this article, a UFRF with the brand name Fytocell was studied (Fig. 1). Over the past 10-year introduction period, Fytocell has provided such

results that could characterize it as a “unique and promising” substrate for the soilless culture sector (Welleman, 2005). This compound has a spongy structure and could be used either in the form of slabs or flakes as a component of organic and inorganic mixtures.

Previous research using UFRF has mainly focused on the study of the physical properties of UFRF-amended soils and organic substrates (Chan and Joyce, 2007; Mooney and Baker, 1999; Nektarios et al., 2003, 2004; Nguyen et al., 2009). Mooney and Baker (1999) determined the K_s of UFRF-amended sandy soils and Nektarios et al. (2003, 2004) determined the $\theta(h)$ of UFRF-amended soils and substrates.

However, the knowledge of both main hydraulic properties of UFRF-amended substrates such as $\theta(h)$ and the relationship between unsaturated hydraulic conductivity and volumetric water content, $K(\theta)$, is necessary for the selection of substrates for plant growth and the proper management of irrigation. Although $\theta(h)$ for substrates is easily determined in the laboratory, the direct experimental determination of $K(\theta)$ is usually difficult, time-consuming, and requires specialized laboratory equipment (Londra, 2010). Many researchers have used mathematical models to calculate $\theta(h)$ and $K(\theta)$ for substrates (Fonteno et al., 1981; Karlovich and Fonteno, 1986; Londra, 2001; Londra and Valiantzas, 2011; Milks et al., 1989; Valiantzas et al., 2007; Wallach et al., 1992). However, large fluctua-

tions in hydraulic conductivity (K) between different substrates limit the predictive value of these models.

An indirect experimental procedure for estimating $K(\theta)$ is the one-step outflow method. This procedure is one of the most widely used laboratory methods for determining $K(\theta)$ (if water retention data are available) and the soil water diffusivity, D , as a function of the volumetric water content θ [$D(\theta)$] on porous material samples of small height. In the one-step outflow method, a short soil or substrate sample of height L , with initial water content θ_i , is suddenly subjected to a large increment of pressure and the outflow volume, V , is recorded with time, t , until the water content reaches the final equilibrium value θ_f (Gardner, 1962; Gupta et al., 1974; Passioura, 1976; Valiantzas, 1989; Valiantzas et al., 1988, 2007).

Compared with other methods, the one-step outflow method requires little time for the calculation of K but cannot be applied in the first outflow stage, in which the flow is practically determined by the resistance of the porous plate (Passioura, 1976; Valiantzas, 1990). Therefore, the method cannot be used for the calculation of K near saturation.

In this study, laboratory experiments were conducted for determining the $\theta(h)$ in substrate samples of Fytocell, loam soil/Fytocell (60/40 v/v), coir/Fytocell (60/40 v/v), coir, and loam soil. In the same substrate samples under the same experimental apparatus, one-step outflow experiments were also carried out to estimate the relations of $D(\theta)$ and consequently $K(\theta)$. Therefore, the $K(\theta)$ values were compared with the values predicted by the most popular closed-form analytical hydraulic model of van Genuchten–Mualem. Furthermore, the K_s was determined experimentally.

The main aim of this study was to evaluate the effect of UFRF on the hydraulic behavior of its mixtures with a soil and an organic substrate. Contrary to previously reported research (Chan and Joyce, 2007; Mooney and Baker, 1999; Nektarios et al., 2003, 2004; Nguyen et al., 2009), in this study, both basic hydraulic properties, the water retention curve and the relationship between unsaturated hydraulic conductivity and volumetric water content, of the UFRF and its mixtures were determined using a fast and easy methodology in the same substrate sample for a range of water contents of vital importance for the plant growth.

Materials and Methods

Substrates. The substrates studied were: 1) a UFRF (Fytocell; Resins Agro B.V., The Netherlands), which was used in the form of foam flakes both as a pure substrate and as a component of substrate mixtures; 2) coir, which is a byproduct of coconut husk fiber treatment (van der Knaap, The Netherlands). Coir has a compressed form (bricks) with dimensions 30 cm $\times$ 30 cm $\times$ 15 cm for easy transportation; 3) a loam soil composed of 50.16% sand, 33.82% silt, and 16.02% clay; 4) a mixture of loam soil and Fytocell in

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Fig. 1. Fytocell in the form of flakes.

a proportion 60/40 v/v loam soil/Fytocell; and 5) a mixture of coir and Fytocell in a proportion 60/40 v/v coir/Fytocell.

Experimental procedure. Water retention curve measurements and one-step outflow laboratory experiments were performed on a tension plate apparatus in a Haines-type assembly (Haines, 1930), in which negative pressure steps were applied through the saturated tension plate. Initially, the $\theta(h)$ were measured followed by the one-step outflow experiment in the same substrate sample in the same apparatus to avoid the effect of sample variability in the obtained results by the two experimental methods. Three replications per substrate were conducted ($n = 3$).

Water retention curves. To achieve a satisfactory packing of the substrate samples, small amounts of substrate were gradually put on the tension plate apparatus in a Haines-type assembly with simultaneous vibration of the latter. The samples were less than 3 cm in height and 9.2 cm in diameter. The air-entry value of the tension plate was -180 cm of the water column. The UFRF flakes and coir were pre-wetted before using. The samples were allowed to wet gradually from the bottom of the plate until saturation (for 48 h). After that, the samples were subjected to a drying–wetting cycle. The drying and wetting branches of the retention curves were obtained by measuring the water content at different pressure heads.

One-step outflow experiment. Once the water retention curves were determined, at the end of wetting, and although the samples were saturated, the one-step outflow procedure began. A large negative pressure step, h_f , was suddenly applied at the bottom of the samples and the cumulative outflow volume was recorded with time until the water content reached the final equilibrium value, θ_f . The h_f value applied was equal to the highest negative pressure head used in the determination of the retention curve. The experimental one-step outflow procedure gave a series of measured outflow volumes, V_i , in the relevant times, t_i ($i = 1, 2, 3 \dots N$). The experimental data obtained were converted in mean values of water content $\bar{\theta}_i$, as $\bar{\theta}_i = \theta_{in} - V_i/V_o$, where θ_{in} is the uniform initial volumetric water content and V_o is the sample volume.

Soil water diffusivity as a function of mean volumetric water content $[D(\bar{\theta})]$ was calculated from the one-step outflow data using the Valiantzas (1989) equation:

Fig. 2. Experimental water retention curves during drying and wetting for the substrates: 1) coir and Fytocell mixture at a proportion of 60/40 (v/v) coir/Fytocell (A); 2) loam soil and Fytocell mixture at a proportion of 60/40 (v/v) loam soil/Fytocell (B); and 3) Fytocell (C). Values are the means of three replications and bars represent $\pm$ SE.

Fig. 3. Comparative presentation of the experimental water retention curves during drying among the substrates: 1) coir and its mixture with Fytocell at a proportion of 60/40 (v/v) coir/Fytocell (A); 2) loam soil and its mixture with Fytocell at a proportion of 60/40 (v/v) loam soil/Fytocell (B); and 3) loam soil, coir, and Fytocell (C). Values are the means of three replications and bars represent $\pm$ SE.

$$D(\bar{\theta}) = -\frac{2L^2}{\pi^2} \left(\frac{dq}{d\bar{\theta}} + \frac{q}{\bar{\theta} - \theta_f} \right) \quad [1]$$

where L is the length of the sample, q is the rate of outflow ($q = d\bar{\theta}/dt$), and θ_f is the final volumetric water content.

The proposed equation is validated for various types of soils (Valiantzas, 1989; Valiantzas and Salsalou, 1991) and substrates (Valiantzas et al., 2007).

From the plot of the measured cumulative outflow volume, V , against the square root of time, $\sqrt{t}$, the nonlinear portion of the curve (Stage III; Fig. 3), in which the effect of impedance of the porous plate becomes negligible, was identified (Passioura, 1976; Valiantzas, 1990). The derivatives $q = d\bar{\theta}/dt$ and $dq/d\bar{\theta}$ are calculated using a finite differences scheme from the outflow data $V_i(t_i)$ ($i = 1, 2, \dots, N$) collected at this stage.

The three stages of outflow (Passioura, 1976) are clearly identifiable in all curves. In the first stage, corresponding to the initial part of the curve before the outflow becomes linear with $\sqrt{t}$, the plate impedance determines the outflow rate. In the second stage, during which the outflow varies linearly with $\sqrt{t}$, the effect of plate impedance is still significant. The third stage, corresponding to the portion of the curve where cumulative outflow ceases to be linear with $\sqrt{t}$, the effect of plate impedance is minimal.

Therefore, the overall procedure to determine $D(\bar{\theta})$ was:

- 1) Perform the one-step outflow experiment (as described previously) and record V vs. t .
- 2) Plot V vs. $\sqrt{t}$ and identify the portion of the curve where V ceases to be linear with respect to $\sqrt{t}$ (Stage III).
- 3) Determine $D(\bar{\theta})$ function using Eq. [1].

Volumetric water content calculation. The $K(\bar{\theta})$ relationship was calculated using $K(\bar{\theta}) = D(\bar{\theta})d\bar{\theta}/dh$ (Childs and Collis-George, 1950). The slope $d\bar{\theta}/dh$ was calculated from the experimental water retention curves.

Saturated hydraulic conductivity. The K_s was determined independently by the constant-head method (Klute and Dirksen, 1986). Each sample was subjected to a wetting-drying cycle before the measurement.

Estimation of volumetric water content using the van Genuchten-Mualem model. The hydraulic conductivity was calculated using the pore-size distribution model of Mualem (1976) combined with the Van Genuchten (1980) water retention function and was expressed as a function of the water content:

$$K = K_s \cdot \left(\frac{\theta - \theta_r}{\theta_s - \theta_r} \right)^{1/2} \cdot \left[1 - \left(1 - \left(\frac{\theta - \theta_r}{\theta_s - \theta_r} \right)^{1/m} \right)^m \right]^2 \quad [2]$$

where θ is the volumetric water content, θ_s and θ_r are the saturated and residual water

content, respectively, K_s is the saturated hydraulic conductivity, and m is a fitting parameter, where $0 < m < 1$.

Statistical analysis. Three replications per substrate were conducted for water retention curve, saturated and unsaturated hydraulic conductivity. The analysis of variance was performed using STATGRAPHICS Centurion XV statistical software (StatPoint, Inc., U.S.), and treatment means were compared using Tukey's honestly significant difference at a probability of $P = 0.01$.

The goodness of fit of the $K(\theta)$ predictions obtained by the van Genuchten–Mualem model to the $K(\theta)$ predictions obtained from experimental outflow data using the Valiantzas (1989) equation was evaluated from the coefficient of determination R^2 . The coefficient R^2 was calculated using the equation:

$$R^2 = 1 - \frac{\sum (\log(K^E) - \log(K^P))^2}{\sum \left(\log(K^E) - \frac{\sum \log(K^E)}{N} \right)^2} \quad [3]$$

where K^P and K^E are the hydraulic conductivity values obtained using the van Genuchten–Mualem model and the Valiantzas (1989) equation, respectively, and N is the number of values.

Results and Discussion

The experimental drying and wetting branches of the water retention curves of Fytocell and its mixtures with coir and loam soil showed hysteresis for all the substrates studied (Fig. 2A–C). Hysteresis was most pronounced in the Fytocell (Fig. 2C). The maximum hysteretic difference (between drying and wetting curves having the same value of pressure head) relative to the value on the wetting curve is $\approx 68\%$ for Fytocell (Fig. 2C), 26% for coir/Fytocell (Fig. 2A), and 13% for loam soil/Fytocell (Fig. 2B).

The water retention curves of the substrates studied provide data for the range of pressure heads between 0 and -170 cm. The substrate properties provided from these retention curves, i.e., water retention capacity and air–water balance, highlight the importance of accounting for these properties when selecting plants for growing in the substrates studied and especially when plants are known to be sensitive to inadequate root aeration or anoxic root environments.

To assess the effect of Fytocell on hydraulic behavior of the coir/Fytocell and loam soil/Fytocell mixtures, the retention curves of the latter were compared with those of pure coir and loam soil (Fig. 3A–B). The comparison showed that the addition of Fytocell in the 60/40 coir/Fytocell and 60/40 loam soil/Fytocell substrates led to the decrease (Fig. 3A) and increase (Fig. 3B) of the water retention capacity, respectively. Specifically, the total porosity (water content in 0-cm pressure head) and the water contents at -50 and -100 cm of the coir/Fytocell were significantly decreased by 0.117 , 0.056 , and 0.029 $\text{m}^3\cdot\text{m}^{-3}$, respectively, compared with the pure coir (Table 1). In contrast, comparing the loam soil/Fytocell with the pure loam soil, the total porosity and water contents at -50 and -100 cm of the loam soil/Fytocell were significantly increased by 0.098 , 0.073 , and 0.040 $\text{m}^3\cdot\text{m}^{-3}$, respectively, compared with the pure loam soil (Table 1).

The easily available water (the amount of water released between -10 and -50 cm) and the air-filled porosity at -50 cm for coir/Fytocell were significantly decreased compared with pure coir (Table 1). Contrary, in the case of loam soil/Fytocell, these values were not significantly increased by the addition of Fytocell compared with loam soil (Table 1). Comparative presentation of the retention curves among the Fytocell, coir, and loam soil substrates (Fig. 3C) showed that the Fytocell has a lower total porosity and water retention capacity than the coir and higher total porosity and water retention capacity up to ≈ -20 -cm pressure head than the loam soil.

Overall, the addition of Fytocell had an opposite effect on the water retention capacity in the coir/Fytocell (Fig. 3A) than in loam soil/Fytocell (Fig. 3B) mixtures. This difference in hydraulic effect of Fytocell on the two substrates could be related to the water retention capacity of the Fytocell [it is higher than the loam soil (up to -20 cm) and lower than the coir] (Fig. 3C). It is also possible that there were differences in pore size distribution between the mixtures that resulted from structural differences between the Fytocell flakes and fibrous coir or granular loam soil.

The outflow data used to calculate $D(\theta)$ were collected from Stage III, which was identified from the nonlinear portion of the cumulative outflow volume vs. time (Fig. 4A–E).

The $K(\theta)$ values (Fig. 5A–C) indicated a rapid decrease in unsaturated hydraulic

conductivity over a range of water contents, which are of vital importance to plant growth (De Boodt and Verdonck, 1972). The hydraulic conductivity of the 60/40 coir/Fytocell substrate decreased by approximately seven orders of magnitude, from 10.2 (K_s) to 1.1×10^{-6} $\text{cm}\cdot\text{min}^{-1}$ over a range of water contents varying between 80% and 25% (Fig. 5A), although for pure coir, the hydraulic conductivity values decreased from 7.8 (K_s) to 1.3×10^{-5} $\text{cm}\cdot\text{min}^{-1}$ (value shown in Fig. 6B) over a range of water contents varying between 92% and 40% . In the case of 60/40 loam soil/Fytocell, the decrease was approximately five orders of magnitude, from 0.34 (K_s) to 8×10^{-6} $\text{cm}\cdot\text{min}^{-1}$, for water contents between 61% and 39% (Fig. 5B), although for loam soil, the hydraulic conductivity values decreased from 0.5 (K_s) to 1.5×10^{-5} $\text{cm}\cdot\text{min}^{-1}$ (value shown in Fig. 6A) over a range of water contents varying between 51% and 36% . Also, the hydraulic conductivity of the Fytocell decreased by approximately five orders of magnitude, from 3.17 (K_s) to 9.5×10^{-5} $\text{cm}\cdot\text{min}^{-1}$ over a range of water contents varying between 59% and 20% , (Fig. 5C).

Saturated hydraulic conductivity values were high for all substrates examined (Table 1). The addition of Fytocell in the 60/40 coir/Fytocell increased significantly the saturated hydraulic conductivity compared with pure coir. On the other hand, the saturated hydraulic conductivity of the 60/40 loam soil/Fytocell was not significantly decreased by the addition of Fytocell compared with loam soil (Table 1).

Furthermore, the unsaturated hydraulic conductivity values of Fytocell (Fig. 5C) were the greatest for water contents lower than 0.40 $\text{m}^3\cdot\text{m}^{-3}$ compared with the coir/Fytocell (Fig. 5A) and loam soil/Fytocell (Fig. 5B) mixtures. This is of fundamental importance; because the rate of evapotranspiration is directly correlated to hydraulic conductivity, the water flow rate of Fytocell has a great capacity to replace water loss caused by evapotranspiration. This should be taken into account to create growing mixtures based on Fytocell according to crop needs. The comparison of the two mixtures with Fytocell showed that the 60/40 coir/Fytocell mixture has a greater capacity (≈ 40 -fold) of replacing water losses caused by evapotranspiration than the 60/40 loam soil/Fytocell mixture (Fig. 5A–B).

In addition, the $K(\theta)$ values obtained from the experimental outflow data using the

Table 1. Physical–hydraulic characteristics of the substrates: 1) coir; 2) coir and Fytocell mixture at a proportion of 60/40 (v/v) coir/Fytocell; 3) loam soil; 4) loam soil and Fytocell mixture at a proportion of 60/40 (v/v) loam soil/Fytocell; and 5) Fytocell.^a

Substrate	Total porosity ^b ($\text{m}^3\cdot\text{m}^{-3}$)	Water content at -50 cm ($\text{m}^3\cdot\text{m}^{-3}$)	Water content at -100 cm ($\text{m}^3\cdot\text{m}^{-3}$)	Easily available water ^c ($\text{m}^3\cdot\text{m}^{-3}$)	Air-filled porosity at -50 cm ($\text{m}^3\cdot\text{m}^{-3}$)	K_s^w ($\text{cm}\cdot\text{min}^{-1}$)
Coir	0.918 a	0.391 b	0.310 c	0.328 a	0.527 a	7.80 b
60/40 coir/Fytocell	0.801 b	0.335 c	0.281 d	0.276 b	0.466 b	10.2 a
Loam soil	0.510 d	0.400 b	0.361 b	0.070 d	0.110 d	0.50 d
60/40 loam soil/Fytocell	0.608 c	0.473 a	0.401 a	0.105 d	0.135 d	0.34 d
Fytocell	0.592 c	0.275 d	0.158 e	0.217 c	0.316 c	3.17 c

^aValues are the means of three replications ($n = 3$). Means that differ significantly using Tukey's honestly significant difference at a probability level of 0.01 are noted with different letters.

^bThe water content at 0 cm pressure head (saturation).

^cThe amount of water released between pressure heads of -10 and -50 cm.

^wThe value of hydraulic conductivity at saturation.

Fig. 4. Cumulative outflow volume against the square root of time and presentation of Stage III, in which the effect of porous plate impedance becomes negligible, from one-step outflow experiments, for the substrates: 1) coir (A); 2) coir and Fytocell mixture at a proportion of 60/40 (v/v) coir/Fytocell (B); 3) loam soil (C); 4) loam soil and Fytocell mixture at a proportion of 60/40 (v/v) loam soil/Fytocell (D); and 5) Fytocell (E). Values are the means of three replications and bars represent $\pm$ SE.

Valiantzas (1989) equation were compared with the $K(\theta)$ predictions obtained by the van Genuchten–Mualem model using as input data the experimental water retention data and the K_s value (Fig. 5A–C). The van Genuchten–Mualem model parameters, m and θ_r , and the correlation coefficient R^2 of the fitted curve are given in Table 2. The comparison indicated that there is a satisfactory agreement of the results ($0.937 \leq R^2 \leq 0.996$) and showed

the flexibility of the van Genuchten–Mualem model describing the relationship between unsaturated hydraulic conductivity and water content (Fig. 5A–C).

To assess the effect of the Fytocell addition in the alteration of the unsaturated hydraulic conductivity of its mixtures, the $K(\theta)$ relations of the 60/40 coir/Fytocell and 60/40 loam soil/Fytocell were compared with those of pure coir and loam soil (Fig. 6A–B).

The addition of 40% Fytocell in the loam soil contributed to a significant reduction of the unsaturated hydraulic conductivity values compared with loam soil for a range of water contents, which are critical for plant growth (the difference between K values at 0.40 $\text{m}^3\cdot\text{m}^{-3}$ water content is ≈ 10 -fold) (Fig. 6A). In contrast, the 40% Fytocell addition in the coir substrate significantly improved the K values compared with pure coir (the difference

Fig. 5. Hydraulic conductivity as a function of water content for the substrates: 1) coir and its mixture with Fytocell at a proportion of 60/40 (v/v) coir/Fytocell (A); 2) 60/40 (v/v) loam soil/Fytocell (B); and 3) Fytocell (C) obtained using outflow data and the Valiantzas equation and the van Genuchten–Mualem model. Values are the means of three replications and bars represent $\pm$ SE.

Fig. 6. Comparative presentation of the hydraulic conductivity as a function of water content, obtained using outflow data and the Valiantzas equation, among the substrates: 1) loam soil and its mixture with Fytocell at a proportion of 60/40 (v/v) loam soil/Fytocell (A); and 2) coir and its mixture with Fytocell at a proportion of 60/40 (v/v) coir/Fytocell (B). Values are means of three replications and bars represent $\pm$ SE.

Table 2. van Genuchten–Mualem model parameters of $K(\theta)$ fitting parameter (m) and residual volumetric water content (θ_r).²

Substrate	m	θ_r ($\text{m}^3 \text{m}^{-3}$)	R^2
60/40 coir/Fytocell	0.251	0.105	0.996
60/40 loam soil/Fytocell	0.119	0.00	0.937
Fytocell	0.507	0.138	0.994

² R^2 is the coefficient of determination of the $K(\theta)$ fitted curves of the substrates: 1) coir and Fytocell mixture at a proportion of 60/40 coir/Fytocell (v/v); 2) loam soil and Fytocell mixture at a proportion of 60/40 loam soil/Fytocell (v/v); and 3) Fytocell.

between K values at 0.40 $\text{m}^3 \text{m}^{-3}$ water content is ≈ 30 -fold) (Fig. 6B) classifying the 60/40 coir/Fytocell mixture as the most suitable substrate to meet plant water demand during periods of high evapotranspiration. These results are in line with the water retention curve observations.

To conclude, addition of 40% Fytocell to an organic coir substrate decreased water retention capacity and increased saturated and unsaturated hydraulic conductivity compared with 100% coir. In contrast, addition of 40%

Fytocell to an inorganic loam soil increased water retention capacity and decreased saturated and unsaturated hydraulic conductivity compared with 100% loam soil. Moreover, the comparison of $K(\theta)$ values between coir and loam soil mixtures with Fytocell showed that the 60/40 coir/Fytocell substrate is more suitable than the 60/40 loam soil/Fytocell to meet plant water demands during periods of high evapotranspiration.

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