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HYDRO-PHYSICAL CHARACTERIZATIONS OF COMPOST FOR OPTIMAL CONCEPTION OF GROWTH SUBSTRATES IN FOREST NURSERIES

M'SADAK Y., EL HICHRI N.

Department of Horticultural Engineering Systems and Natural Environment, University of Sousse/Higher Institute of Agronomy of Chott Mariem/Chott Mariem, Sousse, Tunisia

msadak.youssef@yahoo.fr

ABSTRACT

Several research studies have shown the importance of using compost for containers seedlings production. In this context, the present study attempts to hydro-physically optimize growing media formed of Acacia cyanophylla crude compost mixed with olive oil and livestock manures wastes Co-compost. The contribution of co-compost was carried out according to different proportions to determine mixtures that have the best physical characteristics (total porosity, aeration and retention porosity, dry bulk density) and moisture content (pF curves, water availability and time of rewetting) for optimum forest seedling growth. The results have shown that the incorporation of 20% rabbit manures Co-compost, 50% olive wastes Co-compost, 50% ovine manures Co-compost and 50% cattle manures Co-compost with Acacia cyanophylla compost have shown relatively better results. The raw Acacia cyanophylla compost has showed good air content and insufficient moisture content. Mixed with Olive wastes Co-compost, he has proved an unsatisfactory air content, but water availability was good.

Keywords: Forest nurseries, Acacia cyanophylla compost, Co-compost, Porosities, Hydro-physical behavior.

RESUME

Plusieurs études ont montré l'importance de l'utilisation du compost pour la production de plants en conteneurs. Dans ce contexte, la présente étude tente d'optimiser les milieux hydro- physiques de culture, constitués par le compost brut d'Acacia cyanophylla, mélangé avec le Co-compost oléicole ou le Co-compost de fumier. L'apport de Co- compost a été réalisé selon diverses proportions pour déterminer les mélanges qui ont les meilleures caractéristiques physiques (porosité totale, porosités d'aération et de rétention, masse volumique sèche) et une teneur convenable en humidité (courbes pF, disponibilité en eau et temps de remouillage) pour la croissance optimale des plants forestiers. Les résultats ont dévoilé que les incorporations de 20 % de Co – compost cunicole, 50 % de Co - compost oléicole, 50 % de Co – compost de fumier ovin et 50% de Co - compost de fumier bovin avec le compost d'Acacia cyanophylla étaient relativement les meilleures. Le compost brut d'Acacia cyanophylla a révélé une bonne teneur en air et une rétention en eau insuffisante. Mélangé à un Co - compost oléicole, il a prouvé une teneur en air insuffisante, mais la disponibilité en eau était bonne.

Mots-clés : Pépinières forestières, Compost d'Acacia cyanophylla, Co-compost, Porosités, Comportement Hydro- physique.

INTRODUCTION

As part of the modernization of forest nurseries in Tunisia, the first challenge was to find an alternative to peat utilization to improve farming practices and seedlings quality production in forest nurseries. To avoid the use of imported substrates (peat, vermiculite ...), particular attention was paid to the composting of forest biomass (pine bark, branches of acacia and scrub) for their use in forest nurseries (Ammari and al., 2003). The uses of composted forest and agricultural wastes have shown excellent results in terms of growth substrates manufacturing for the production of aboveground horticulture and forest seedlings (Lemaire and al., 1989, Landis and Growing media, 1990, Miller and Jones, 1995, Rose and al., 1995; Fitzpatrick, 2001). In addition, composting allows biological decomposition and stabilization of organic substrates (Mustin, 1987, Haug, 1993; Stoffella and Kahn, 2001). Good knowledge of the physico-chemical characteristics and hydrological proprieties of growing media can explain and predict the transfer of mineral elements between solid phase and nutritive solution, especially when the medium is physico-chemically active (Lemaire and al., 1989). In forest nurseries, physical properties of growth substrates are very important for good biological quality of forest seedlings plants (Andre, 1987; Gras, 1987). Given the difficulty of their modification after installation of forest seedlings, it's difficult to modify physicals proprieties of

substrates; that's why, these characteristics are more important than chemical properties. Physicals proprieties directly affect root plants functions, including the absorption of water and nutrients (Landis and al., 1990).
In this perspective, this work attempts to develop a suitable growth substrate, based on a mixture of *Acacia cyanophylla* compost, plant biomass and animal manures based Co-compost. As these substrates are made for the production of forest seedlings in containers, physical and hydrological characterization are necessary to evaluate their suitability.

MATERIALS AND METHODS

Substrates being tested

Table 1: Composition of raw compost being tested

Substrates	Substrate Name	Substrate formulation
RACC	Raw *Acacia cyanophylla* compost	100% *Acacia cyanophylla*
RMCC	Rabbit manures Co-compost	70% rabbit manures + 30% crushed olive branches
OWCC	Olive Wastes Co-compost	70% crushed olive branches + 30% rabbit manures.
SMCC	Sheep manures Co-compost	75% sheep manures + 25% crushed branches of *Ficus nitida*.
CMCC	Cattle manures Co-compost	75% cattle manures + 25% grinded palms of *Washingtonia filifera*

In the forest nursery of Chott Mariem, Tunisia, composted branches of *Acacia cyanophylla* are the main component used in the composition of current growth substrates for the production of forest seedlings. Raw materials used for the conception of compost included animals manures (rabbit, sheep and cattle) and plants wastes (olive, *Ficus nitida* and *Washingtonia filifera* crushed branches). Windrow piles, 1.5 m high by 10 m long, were constructed using shredded materials. Forced aeration was used for the first eight weeks (bio-oxidative phase), followed by a six-month maturation period during which the piles were turned periodically to maintain adequate O_2 levels. During the maturation phase, the pile was turned every 15 days in order to improve both the O_2 level inside the pile and the homogeneity of the material. Ammonium nitrate was added to windows to ensure Carbon-Nitrogen (C/N) nutritional balance. Pile moisture was controlled weekly by adding enough water to obtain a moisture content of

not less than 50%. The experiment was carried out to introduce components of different compositions mixed with *Acacia cyanophylla* compost (considered as control compost) to develop a suitable growing medium for forest seedlings. Raw compost being used and their composition are given in the Table 1.
Taking into account *Acacia cyanophylla* compost characteristics, it was mixed with rabbit manure Co-compost (RMCC), olive wastes Co-compost (OWCC), sheep manures Co-compost (SMCC) and cattle manures Co-compost (CMCC) at different ratio, in order to prepare suitable growth media for forest nursery. (Table 2) shows the volumetric formulations of the different media used in this study.

Table 2: Growing media used in the study

Mixtures	Mixture Composition	Mixture Formulation
M1	80% RACC + 20% RMCC	
M2	70% RACC + 30% RMCC	RACC + RMCC
M3	60% RACC + 40% RMCC	
M4	50% RACC + 50% RMCC	
M5	80% RACC + 20% OWCC	RACC + OWCC
M6	70% RACC + 30% OWCC	
M7	60% RACC + 40% OWCC	
M8	50% RACC + 50% OWCC	
M9	80% RACC + 20% SMCC	RACC + SMCC
M10	70% RACC + 30% SMCC	
M11	60% RACC + 40% SMCC	
M12	50% RACC + 50% SMCC	
M13	80% RACC + 20% CMCC	CSB + CMCC
M14	70% RACC + 30% CMCC	
M15	60% RACC + 40% CMCC	
M16	50% RACC + 50% CMCC	

Physical characterization of substrates

Physical characterization has affected the following parameters: total porosity, aeration porosity, retention porosity and dry bulk density.

Standard test of porosity

To determine the different porosities of a substrate, we use the method described below. We take a container, which we blocked its drainage hole, and we fill it with water (WV is the volume of water in the container). We remove water and fill the container with the substrate. We add water very slowly into the entire surface of the container until the water appears on the surface. The volume of water added (VWA) represents the volume of air and water in the substrate. We obstruct drainage holes and we collect water that drains (VCW) for 10 minutes (VCW or volume of water collected is the volume of air in the substrate).
Porosities of substrate (total porosity, aeration porosity and retention porosity) were calculated according to formulas below.
Total porosity (TP) = (VWA / WV) x 100 (%)
Aeration Porosity (AP) = (VCW / WV) x 100 (%)
Retention Porosity (RP) = TP - AP (%)

The optimum ranges of porosities are given below: TP $\geq$ 50%, AP $\geq$ 20% and RP $\geq$ 30%. Those ranges were inspired from Canadian Standards (CPVQ, 1993).

Dry bulk density

Dry bulk density measurement was performed to substrates as well as for mixtures selected from the standard test of porosity. Substrates samples were put in an oven at a temperature of 105 °C for 24 hours to determine dry mass. The dry bulk density (DBD) was expressed according to the following formula.

DBD = (MDS - DM) / V (g cm^{-3})
DMS = Mass of dry sample in g
DM = mass of the empty dish in g
V = Capsule Volume: 100 cc

According to (Clauzel, 1997), the optimum range for dry bulk density is 0.08 as lower limit and 0.4 as upper limit.
0.08 < DBD (g cm^{-3}) < 0.40

Hydrological characterization of substrates

Hydrological characterization of substrates was focused on the following parameters: pF curves, water availability and rewetting time.

pF curves

To determine pF curves, it is necessary to know some principles. Drying samples that was previously brought to full saturation was subjected to a suction corresponding to the selected value (Table 3) by using a suction table. Water in excess with respect to this pressure value is discharged through a medium (sand layer) whose characteristics correspond to an air pressure in the medium greater than the saturated pressure. When equilibrium is reached, the water content of the sample is determined by weigh. pF curve is a specific indicator of hydraulic properties of a substrate (Lemaire and al., 1990). Most technical analysis uses the concept of the pF curve for a hydrological characterization of substrate (Mongondry, 1996).

Table 3: pF and suction values established according to suction table

pF values	Suction values (mbar)
0.0	-1.0
0.4	-2.5
1.0	-10.0
1.5	-31.6
1.7	-50.0
2.0	-100.0

To determine the pF curves and estimate the total porosity from bulk density, samples were placed in the suction table. They were brought into contact with a column of water through a layer of water-saturated sand. The water potential of the test sample starts in equilibrium with the hydrostatic pressure of the water column. Such a technique is physically limited to 100 mbar (pF2). The experiment was performed on 9 substrates: 5 raw substrates (RACC, RMCC, OWCC, SMCC and CMCC) and 4 mixtures having satisfactory physical proprieties retained from the standard test of porosity. The trial was conducted in capsules of 100 cc.

To determine pF curve, we use the method described below. We weigh an empty capsules and we fill it with the substrate and we weigh the whole; we Place the capsule in the suction table and we put the suction pressure regulator at pF 0; we open the cylinder valve to supply water until the water level in suction table reached 1 cm height; we close the cylinder valve of the suction table and we wait for the saturation of the samples; after saturation and drainage through the valve on the suction table, we weigh at 0.4 pF, 1.0 pF, 1.5 pF, 1.7 pF and 2.0 pF. We put the pressure regulator at the wanted pF. After 24 hours, weigh each time the masses of capsules for each pF.

To determine pF curve, we use the following equation:

Volume of water for every pF = ((MSPF - ME - MDS) / V) x 100
MSPF = Sample mass for each pF
ME = mass of the empty capsule
MDS = mass of dry sample after drying at 105 °C for 24 hours
V = Volume of the capsule: 100 cc

Total porosity (TP)
The total porosity (TP) was determined according to (Gras and Agius, 1983) formula
TP (%) = 95.83 - 32.43 DBD
DBD = Dry Bulk Density

Air content at pF1 (AP)
AP (%) = TP - RP
TP = Total porosity
RP = Water content at pF 1

Water availability
Water availability (WA) is expressed by the equation below.
WA = (pF 1 - pF 2) x 100
pF 1: humidity close to container capacity
pF 2: value at which irrigation was initiated
It should be noted that a preliminary attempt was also made to determine the needed dose for irrigation and water holding capacities of some substrates. Assessing water availability has concerned control substrate (RACC) and four mixtures (M1, M8, M12 and M16).

Rewetting time

The technique chosen for measuring rewetting time of substrate consist in quantifying the penetration time of a water drop (Water Drop Penetration Time: WDPT). Rewetting time is evaluated for five raw substrates (RACC, RMCC, OWCC, SMCC and RMCC) and four mixtures (M1, M8, M12 and M16). The measurement was made on 6 cavities for each substrate.

Statistical analyzes

Hydro-physical parameters of substrates were evaluated with analysis of variance (ANOVA) and Duncan multiple range test ($p < 0.05$) using the SPSS (13.0) System. Differences were considered significant at the 5% level (means followed by different letters).

RESULTS AND DISCUSSION

Direct evaluation of porosity

Raw Compost

Figure 1 shows the variation of total porosity, aeration porosity and retention porosity of raw compost.
The results obtained showed that all these substrates have a satisfactory total porosity (TP > 50%) with a slight rise in Raw *Acacia cyanophylla* compost (74%). However, aeration porosity is different and is out of optimum range (AP < 20%) for RMCC, OWCC, SMCC and CMCC. Aeration porosity is below the standards (AP < 20%) because of the presence of large proportions of fine particles. This is true for RMCC compost which has very low aeration porosity (6.8%). Thus, available air in the substrate is very low and there will be danger of plant suffocation. Retention porosity is linked to the aeration porosity; any increase in air content causes a lowering in the water content. It is interesting to incorporate an adequate proportions of Co-compost (having high water holding capacity) with raw *Acacia cyanophylla* compost (having high air capacity) to obtain a final substrate that takes into account plants requirement. It should be noted that each studied porosity presented significant differences which appear clearly in the Figure 1.

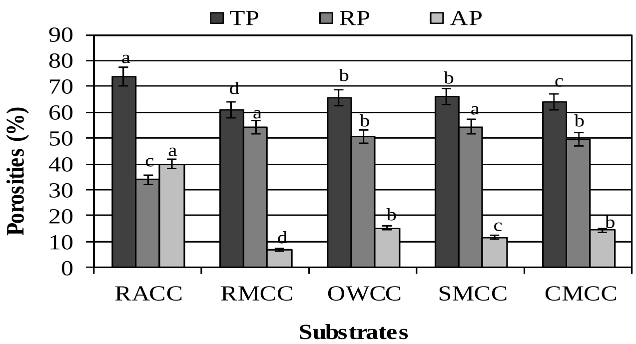

Figure 1: Porosities of raw compost

(RACC + RMCC) Mixture

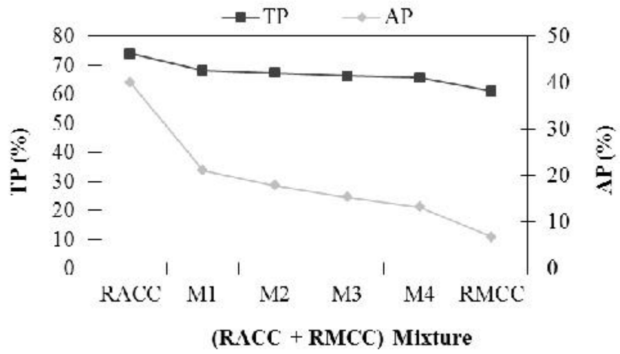

Figure 2: Variation in total porosity and aeration porosity of substrates resulting from mixture of Raw Acacia cyanophylla compost (RACC) with rabbit manures Co-compost (RMCC)

Figure 2 shows the variation in total porosity and aeration porosity of Raw *Acacia cyanophylla* compost (RACC) in mixture with rabbit manures Co-compost (RMCC). These results reveal that it is advantageous to incorporate RMCC at 20% ratio with RACC. Indeed, M1 mixture (80% RACC + 20% RMCC) presented acceptable total porosity and aeration porosity. In contrast, there was a decrease in aeration porosity below the standards in other mixtures (M2, M3 and M4).

(RACC + OWCC) Mixture

Figure 3 describes the variation in total porosity and aeration porosity of *Acacia cyanophylla* compost in mixture with olive waste Co-compost (OWCC). We note that when OWCC percentage in mixture increases, aeration porosity became satisfactory (22%) for the M8 (50% RACC + 50% OWCC) mixture. The same results were observed for total porosity, which has become equal to 67%.

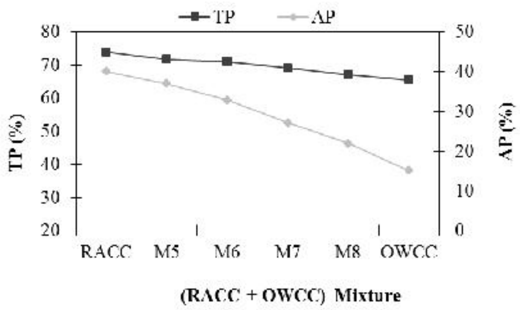

Figure 3: Variation in total porosity and aeration porosity of substrates resulting from mixtures of Raw *Acacia cyanophylla* compost (RACC) with olive waste Co-compost (OWCC)

(RACC + SMCC) Mixture

Figure 4 describes the variation in total porosity and aeration porosity of raw *Acacia cyanophylla* compost (RACC) in mixture with sheep manures Co-compost (SMCC).

At a ratio of 20% to 30% of SMCC, we note an improvement of aeration porosity for M9 and M10 mixtures, which are in the optimum range of aeration porosity (AP > 20%). When SMCC ratio is beyond 40%, aeration porosity of M11 and M12 mixtures decreased and are below the optimum range. Taking into account the interesting chemical properties of SMCC, an incorporation of 50% SMCC can be beneficial for growing forest species in nurseries. However, M12 mixture (50% RACC + 50% SMCC) was selected as the best substrate according to its optimal porosities (total porosity and aeration porosity) in this case.

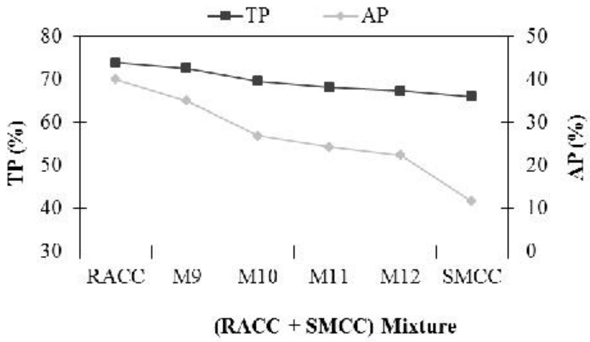

Figure 4: Variation in total porosity and aeration porosity of substrates resulting from mixtures of Raw *Acacia cyanophylla* compost (RACC) with sheep manures Co-compost (SMCC)

(RACC + CMCC) Mixture

Figure 5 shows the variation in total porosity and aeration porosity of *Acacia cyanophylla* compost in mixture with cattle manures Co-compost (CMCC). The results obtained showed that M16 mixture (50% RACC + 50% CMCC) gives the best result for aeration porosity (22%). For other mixtures, aeration porosity was above the norm.

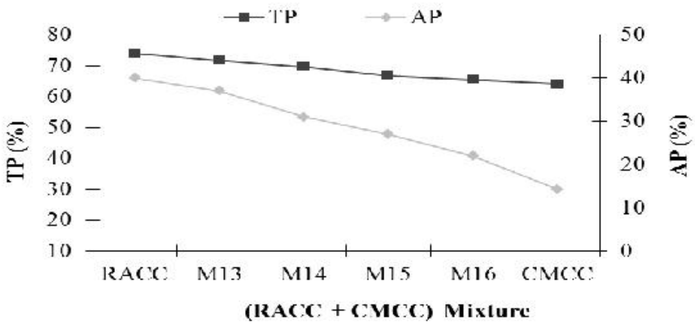

Figure 5: Variation in total porosity and aeration porosity of substrates resulting from mixtures of Raw Acacia cyanophylla compost (RACC) with cattle manures Co-compost (CMCC)

Evaluation of dry bulk density (DBD)

Table 4: Dry bulk density (DBD) of different substrates

Substrates	DBD (g cm^{-3})
RACC	0.24^{ef}
RMCC	0.44^{a}
OWCC	0.33^{c}
SMCC	0.40^{b}
CMCC	0.42^{ab}
M1	0.23^{f}
M8	0.25^{e}
M12	0.24^{ef}
M16	0.27^{d}

Results presented in Table 4 show that RACC has the lowest bulk density (DBD), which means that RACC compost has the lowest particles sizes. On other hand, bulk density is relatively high for Co-composts (RMCC, OWCC, SMCC and CMCC). The highest DBD was noted for the RMCC (exceeding the upper limit of 0.4 g/cm^3); this substrate is characterized by a high degree of compaction and can affect roots development. DBD is within the norm for other mixtures. This observation can be attributed to an interaction between Co-compost and RACC, which helped to increase mixture porosity, and therefore make easy the spread of roots in the container. (Clauzel, 1997) reported that the more DBD is lower; the more porosity is higher, which is entirely consistent with our results. According to (Lamhamedi, 1997), DBD increases the mechanical strength of the substrate. Such resistance has direct consequences on growth and root morphology.

Evaluation of porosity

The results disclosed in Table 5 show hydro-physical characteristics of nine substrates. pF curves represent for each suction the distribution of air and water in the substrate. Interpretation of these curves is based on the value of air and water content at pF1, as it approaches the water availability, which is the difference of soil moisture between pF1 and pF2.

Table 5: Hydro-physical proprieties of tested substrates

Substrates	Total porosity (%)	Air content at pF1 (%)	Water content at pF2 (%)	Water Availability (%)
RACC	88.0	23.1	64.9	18.1
RMCC	81.5	16.7	64.8	16.3
OWCC	85.0	11.3	73.7	24.1
SMCC	83.0	11.3	71.7	7.2
CMCC	82.2	10.8	71.4	10.6
M1	88.4	22.7	65.7	21.8
M8	87.7	15.1	72.6	27.8
M12	88.0	20.3	67.7	22.3
M16	87.0	21.0	66.1	20.8

Table 5 summarizes the hydro- physical characteristics of substrates. These results were derived from each pF curves established for each substrate. Morel (2000) stated the optimal characteristics of a growth substrate.

• Total porosity > 88%
• Air porosity at pF1 = 20 - 30%
• Water holding capacity at pF1 = 55 - 70%
• Available Water (pF1-PF2) = 20 - 30%

According to the norm stated below, the best substrates selected for evaluation of porosity are:
M1: 80% RACC + 20% RMCC
M8: 50% RACC + 50% OWCC
M12: 50% RACC + 50% SMCC
M16: 50% RACC + 50% CMCC

From Table 5, we note that the growing media have porosity parameters close to normal, except for M1 substrate which is in the range value. However, only four substrates are within the norm for air porosity at pF1 and water holding capacity at pF1. M1, M12 and M16 mixtures have a high water and air content as well as acceptable water availability. Indeed, M1 mixture is within the range of hydro-physical characteristics. Although RACC has an air and a water holding capacities within the optimum range, respectively 23.1% and 64.9%, water availability is relatively low (18.1%). According to the physical characteristics of Co-compost, they are far from being used separately as growth substrate because they have low air content (10.8% for CMCC) and low water availability (7.2% for SMCC), but rather a high water content. According to hydro-physical results, we can say that M8 mixture (50% RACC + 50% OWCC) is not recommended because of a lack of air content, while other three mixtures (M1, M12 and M16) were satisfactory and deserves further consideration for the production of forest seedlings. Control substrate (RACC) was the best; however, its low value of water availability means that its use in raw state is not recommended.

Irrigation dose and water holding capacities of substrates

According to previous results, we can calculate the dose and the irrigation time for each substrate to ensure optimal water supply to plants. Given the difficulty of having accurate knowledge of the reference limits, we tried to determine orders of magnitude that can be useful for reasoning irrigation. The work done in the nursery of National Centre of Horticulture Chambourcy in France, have shown that it is appropriate to adopt an irrigation dose corresponding to one-third of water availability (WA). This dose, called strict irrigation, allows to properly exploit the water reservoir of the substrate and to keep a line of water content when needed, without the risk of hindering the growth of the plant. Watering plants in the forest nursery of Chott Mariem is provided by sprinkler irrigation with a square pattern (8m x 8m), operating with a flow rate of 5 l/min/Sprinkler and having a uniformity coefficient UC = 75%, measured during the experiment. Initially, the strictly irrigation dose (SID) should be determined for a liter of substrate. Subsequently, this dose will be calculated per m^2.

SID per m^2 = (Number of cavities/m^2) x Volume of cavities x SID.
Number of cavities m^{-2} = 225

Volume of cavity = 345 ml $cavity^{-1}$

Table 6: Irrigation dose and spray time in substrates

Substrates	Strict irrigation dose (ml l^{-1}) of substrate	Strict irrigation dose per m^2 (l m^{-2})	Required spray time
M1	72.7	5.6	4 h 58 min
M8	92.7	7.2	6 h 24 min
M12	74.4	5.8	5 h 9 min
M16	69.4	5.4	4 h 48 min
RACC	60.4	4.7	4 h 10 min

In a second step, to actually bring substrate to the strict irrigation dose calculated as described above, this will require that the amount of spread water over the growing area is equal to the coefficient dose of table culture collection which corresponds to the UC estimated at 75% (Table 6). Ultimately, the management of watering is to bring to the substrate the strict irrigation dose. The frequency of contributions is generally determined by taking into account plants consumption.

Rewetting time of substrates

Raw Substrates

Table 7: Rewetting time of raw substrates

Raw substrates	Rewetting time (s)
RACC	90
RMCC	145
OWCC	120
SMCC	160
CMCC	100

Table 7 shows rewetting time of substrates. The rewetting time of these substrates is quite different. For RACC, it was noted that the penetration of water is relatively short compared to other substrates because particles sizes was large, so that the compost will have good water content. For Co-composts (M1, M8, M12 and M16), rewetting time is relatively long, especially SMCC Co-compost.

(RACC + Co-compost) Mixture

Table 8: Rewetting time of (RACC + Co-compost) Mixture

Mixtures	Rewetting time (s)
M1	90
M8	145
M12	120
M16	160

Table 8 highlights rewetting time of substrates containing mixture of Raw *Acacia cyanophylla* compost with Co-composts. Rewetting time of mixtures was higher than of raw substrates, due to the strong influence of surface heterogeneity of the materials used. (RACC + RMCC) mixture takes longer time to moisten than other mixtures; therefore, irrigation time should be more important to reach container capacity.

CONCLUSION

Forest wastes composting is an alternative way to substitute peat. According to the findings of this study, it appear that the incorporation of 20% rabbit manures Co-composts, 50% olive wastes Co-compost, 50% sheep manures Co-compost and 50% cattle manures Co-compost to Raw *Acacia cyanophylla* compost improves hydro-physical properties of substrate. We can say that there are complementarities between RACC and each incorporated Co-compost into the prepared mixture in terms of physical quality, since we noted an improvement of porosities in mixtures. Moreover, it should be noted that the mixture of RACC with the Co-compost in equal proportions (50%- 50%) could be hydro-physically interesting. Furthermore, it should be noted that the variation of total porosity and aeration porosity is almost similar in all four cases of mixture between RACC with Co-compost. Moreover, analyses of hydro-physical characteristic of substrates allows us to identify the best mixtures in terms of total porosity, air contents and water holding capacity at pF1 and water availability, which are: M1 (80% RACC + 20% RMCC), M12 (50% RACC + 50% SMCC) and M16 (50% RACC + 50% CMCC).

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