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# Characterisation of different substrates for possible use as casing in mushroom cultivation

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## Abstract

In this study we describe the principal physical, chemical and biological characteristics of different materials and mixtures for possible use as casing in mushroom cultivation. Besides the base of mineral soil used for the preparation of the mixtures, we have analysed different substrates for use as structural correctors and as water holding agents. Of possible alternative materials to the traditionally used peat, coconut fibre is confirmed as the best because of its high porosity and water holding capacity. As regards the mixtures, their characteristics are in accordance with the components included and conditioned by the characteristics of the soil used. Subsequent evaluation of these mixtures for mushroom cultivation would be of great interest.

***Key words***: *Agaricus bisporus*, fructification, casing materials, analysis.

## Introduction

The initiation and development of the carpophores of *Agaricus bisporus* (Lange) Imbach depend not only on the genetic capacity of the mycelium to fructify but also on physical, environmental, chemical, nutritional and microbiological factors[1-3]. In commercial cultivation, fructification occurs in the casing used to cover the compost normally after a germination phase to induce the transition from vegetative to reproductive growth. The ecological modification which implies the beginning of this fructification takes place in this layer and represents the basis of the interest in mushroom as a commercial crop. The casing layer fulfils several functions[4-7]: it constitutes the physical support of the emerging carpophores and contributes to the maintenance of a moist microclimate to help feed the mycelium and support the formation of primordia; it acts as a suitable medium for the development of bacteria which stimulate fructification; it provides water for the growth and development of mushrooms, supplementing the water provided by the compost; it provides the mycelium with a suitably aerated environment, permitting gas interchange; and finally, it provides an environment of low osmotic value unlike compost, whose osmotic value is too high for mushrooms. For these ends the casing material must fulfil certain conditions[5,6,8-10]. For example, it must be sufficiently resistant and deep enough to provide adequate support for mushroom growth, have a high capacity to absorb and release water, be able to withstand frequent irrigation without losing its structure and possess a structure which permits good permeability for water and gases ($O_2$ and $CO_2$). It should have a low nutritional value and sufficiently low salt concentration to minimise any water deficit which would be unfavourable to the initiation of growth, be of neutral or slightly alkaline pH, contain calcium carbonate (mainly for its buffering effect against changes in pH), have a high cationic exchange capacity, have a low magnesium content and low levels of other toxic elements. Finally, it should be free of parasites and competitors. Among the numerous materials which have been used alone or in combination as mushroom casing both at the experimental and commercial level are materials of a mineral origin (natural or heat treated and industrial wastes), of vegetal origin (natural or transformed) and even synthetic materials[11]. Of these, peat is the most widely used throughout the world because of its water holding capacity and structural properties[12]. The main problem associated with its use is its decreasing availability and the alteration of ecosystems[13]. In the search for alternatives, quality, availability and price are determining factors, and peat will only be replaced after much experimental investigation. The most widely used casing in Spain at the present time is mineral soil, to which different kinds of peat are added as structural correctors or water holding agents[11]. In this paper we physically, chemically and biologically characterise the different substrates which are normally used in the casing for mushroom cultivation in Castilla-La Mancha, Spain (mainly mineral soil and different types of peat) along with other possible alternatives, such as composted pine bark, coconut fibre, wood fibre and composted vine shoots. Binary mixtures are also characterised, using the usual mineral soil as base and 200 mL $L^{-1}$ of each of the above mentioned materials as structural corrector and water retainer. We also examine the casing used in La Rioja, another important mushroom producing region in Spain.

## Experimental

***Substrates:***

***Soil**:* The soil used as base material (mineral subsoil) was taken from a depth of 3-4 metres in La Cerrasa, Villanueva de la Jara (Cuenca, Spain) and provided by Oviedo Soler Hnos. S.L. It had a slightly clayey texture (sand 470 g $kg^{-1}$, silt 270 g $kg^{-1}$, clay 260 g $kg^{-1}$).

***Sphagnum peat**:* This type of peat comes from oligotrophic peat bogs formed by permanent anaerobiosis of undemanding species such as *Sphagnum* spp. moss developed in cold, wet climatic conditions of low evaporation, little solar radiation and low winter temperatures[14]. Because of frequent leaching due to the high rainfall, the resulting peat contains low levels of nutritive elements and is of acidic pH. The most appreciated quality is its high water holding capacity[14]. The German peat used showed different degrees of decomposition (H3-H5 according to Von Post´s scale) and acidic pH. It is sold in 300 litre bales under the commercial name of Protorf (Projar, S.A., Valencia, Spain).

***Black peat***: The black peat used came from the coastal peat formations southeast of Torreblanca (Castellón, Spain), which lie parallel to the coast, occupying a belt 8 km long x 1 km wide (800 ha). The peat was taken from a mean depth of 4 m and the reserves are estimated at 5 million tons[15,16]. $^{14}C$ dating assigns an age of 6280 years to the deepest peat at 4 metres, 4120 years at 2.5 metres and 1670 years at l m[15], which implies a growth rate of about 6.4 m per century. The coastal belt plays a primordial function during the genesis of these outcrops since it provides relative protection against salt waters and permits the establishment of a marsh vegetation, especially *Carex* spp., *Juncus* spp., *Phragmites* spp. and *Typha* spp. The residues of these plants have been transformed over the years in anaerobic conditions, resulting in substantial masses of black peat with a high degree of decomposition (H7-H8 according to Van Post´s scale). These were subsequently covered by a loamy material, up to 1 m thick in places. The well structured peat results from allowing the raw material to drain on the surface of the bog for some months, favouring the formation of granular aggregates[16].

***Composted pine bark***: A residue of the wood industry, which can be used directly after a long process of natural or controlled aerobic fermentation[17]. The product has a mean organic matter content of 700 g $kg^{-1}$.[17] The material used was provided by Masecor S.L. of Motilla del Palancar (Cuenca, Spain) after natural fermentation lasting two years.

***Coconut fibre pith***: Coconut fibre is a golden brown material which forms a dense fibrous mass surrounding the hard shell of the mature coconut, *Cocus nucifera* L. After extraction of the essential part of the fibres (mainly to make rigging ropes) a powdery fibrous material remains with a high air content and stable structure. Sometimes called "ecological peat" since it shares most of peat's characteristics, it may well become more important because of growing concern for environmental protection [18]. The material comes in compressed bricks weighing about 650 g (8-10 L after rehydration) and is known commercially as Cocopeat R (Projar, S.A., Valencia, Spain).

***Wood fibre***: A lignocellulosic material from the wood industry, known commercially as Hortifibra (Projar, S.A., Valencia, Spain), it is made from fibres of *Pinus pinaster* Soland and *Pinus sylvestris* L. separated by a patented mechanical and thermal process which provides thick or thin fibres with no added chemicals[19]. The wood is cut into shavings which are treated by steam before passing between two metal plates. The resulting material is dried before being stored. The product consists of golden fibres of varying lengths depending on the wood used[19].

***Composted vine shoots***: The process used to obtain this material is based on those described by Lacasta *et al.*[20] for composting vine shoots in the open air and by Lobo[21] for the biodegradation and humification of the same material in the laboratory. The starting material, vine shoots of *Vitis vinifera* L. cv. Bobal, had an initial humidity content of 165 g $kg^{-1}$, a nitrogen content of 6.7 g $kg^{-1}$ and 961.7 g $kg^{-1}$ organic matter. This was first finely chopped to a size of < 2.5 cm and then soaked for 24 hours. Urea was then added to achieve a C/N ratio of 30, a value considered optimum for materials which are to be fermented. The mixture was fermented in 100 kg piles for five months in a covered warehouse, and stirred every two weeks. To maintain optimal humidity levels (500-600 g $kg^{-1}$) variable quantities of water were added every 2-3 days according to the results of the analyses of the humidity content. At the end of the process the material was ground in a mill and sieved through a 0.5 cm sieve in order to obtain a material of uniform texture which would be easy to mix with other materials.

***La Rioja type casing***: The casing used in La Rioja (Spain) consists of a mixture of a very fine limestone gravel from a quarry and sphagnum peat[22]. The material used in this study was provided by Gohercu, S.L., Quel (La Rioja, Spain), the gravel comings from Burgos (Spain) and the sphagnum peat from Denmark (Pindstrup Sphagnum, Scandinavian moss peat, Kongerslev, Denmark) mixed in a proportion of 600 L peat/ 1000 kg gravel.

***Mixtures***: The mineral soil, the individual additives and the casing used in La Rioja were characterised, as where binary mixtures using the mineral soil as base and 200 mL $L^{-1}$ of each of the above described materials as structural corrector and water-holding agent: sphagnum peat, black peat, composted pine bask, coconut fibre, wood fibre and composted vine shoots.

**Analytical Methods:**

***Bulk density***: Bulk density was determined by measuring the weight of material contained in a 1 L cylinder after submitting the sample to a force of 650 g [23]. Using the resulting value and the moisture content of the sample previously determined by measuring the loss of weight after desiccation at 105ºC [24], the results were expressed in terms of dry matter.

***Particle real density***: Particle real density was determined using the pycnometer method, which consists of determining the weight of the particles and calculating the volume from the mass and density of the water, which is displaced by the sample[24].

***Total porosity***: Calculated from the bulk and particle real density values obtained.

***Water-holding capacity***: Calculated by desiccating the material contained in plastic cylinders after saturating and draining the contents three times[23,24].

***Hydraulic conductivity and permeability***: These were determined using a glass cylinder of known area and height, the base of which is covered by a nylon cloth by means of a rubber band[25]. The cylinder was filled carefully to a height of 10 cm with uncompacted material and then placed in water overnight to attain saturation *per ascensum*. Distilled water was then added gradually to a height of 15 cm to obtain a water level 5 cm above the material. This height was maintained throughout the process. Once dripping was constant, the volume of water which percolated in a given time was measured in a test tube. Hydraulic conductivity (in cm $h^{-1}$) was calculated as the product of the water percolated ($cm^3$) and the height of the cylinder (10 cm), divided by the product of time (hours) and area of the base of the cylinder used (8042 $cm^2$), and the height of the water column. Bearing in mind the density of water (d= 0.99823 g $cm^{-3}$ at 20ºC), its viscosity (ç =1.002 cp a 20ºC) and the acceleration of gravity (g= 9.80665 m $s^{-2}$), it was possible to calculate the permeability (in $cm^2$) by multiplying the hydraulic conductivity (cm $h^{-1}$) by 2.84 x $10^{-9}$.

***Granulometric analysis/particle size***: The method used consists of breaking the aggregates of the air-dried sample by mechanical pressure, sieving and calculating the rate corresponding to each particle size. This was done with a battery of circular sieves (20 cm diameter x 5 cm high) of decreasing mesh size (25, 10, 5, 4 and 1 mm) using a mechanical siever for approximately 10 minutes[23,24].

***Water-release curves***: The device used was designed by De Boodt *et al.*[26]. It consists of a glass funnel with a porous plate connected by a three-way tap to a system of intercommunicating glasses where the different suctions can be applied[27]. The procedure for determining the curve[28] involves applying increasing suctions (0, 10, 50 and 100 cm of water, each for 24 hours) to the saturated material and weighing the funnel at the end of each suction. From the different volumes of moisture, the volume of air in each suction can be calculated, as can the difference between porosity and the volume of moisture for a given suction. The air capacity corresponds to the volume of air in the material for a suction of 10 cm. The water retained in a material for suctions of 10-50 cm is considered "easily usable". The water contained between 50 and 100 cm is usually termed "compensatory water capacity" or "water reserve", while the total of both is known as "useful water". The water retained at suctions greater than 100 cm is called "difficult to use water" and needs a great deal of applied energy for its extraction. From the water-release curves the parameter, R, was determined for each material to express the pressure at which the air and water contents are equal[23].

***pH and electrical conductivity***: The pH was measured directly in the suspension resulting from stirring a given volume of material in six times its volume of water. Electrical conductivity was measured directly in a filtered extract by introducing the measuring cell of a conductimeter[23]. To determine the potential pH (pH-KCL) a solution was prepared using 0.1 M potassium chloride instead of water[24].

***Buffering capacity***: The method used to establish the titration curves and buffering capacity is based on measuring the changing pH of equal volumes of fresh material mixed with distilled water (100 mL) to which 1 mL aliquots of 0.1 N HCl are added. The mixture was allowed to rest for 5 minutes before noting the pH [10]. After obtaining the titration curve, the buffering capacity is expressed as the meq $H^+$ needed to lower the pH of 1 L of material by 1 unit.

***Cationic exchange capacity***: In the case of the organic residues, the method involved displacement of the exchangeable cations of the sample with dilute hydrochloric acid and subsequent displacement of the $H^+$ ions by the $Ba^{2+}$ ion of a solution of barium acetate, calculating the protons released with NaOH [29]. To calculate the CEC in soils and casing mixtures the barium chloride-triethanol-amine method was used[30,31].

***Carbonates***: A Bernard calcimeter was used to measure the volume of $CO_2$ released after heating the carbonates with chlorhydric acid[24].

***Active lime***: By gasometric dosification of the $CO_2$ of the ammonium carbonate formed when the active calcium carbonate reacts with ammonium oxalate in solution[24].

***Organic matter content***: By difference in the ash content[23]. To analyse the content of the ashes the samples were calcined at 540ºC [24]. For soils, Walkley and Black's method was used, determining the organic matter which is oxidised with potassium dichromate in the presence of sulphuric acid[31].

***Total nitrogen***: Kjeldahl's method[24,32].

***Total elements***: Potassium, calcium, sodium, magnesium, iron, manganese, zinc, copper, boron, phosphorus and molybdenum were determined by digestion of the sample with a nitric-perchloric acid solution and plasma emission spectrophotometry[28].

***Nematodes***: The preliminary search for nematodes used the method described by Bloom[33]. Phytopathogenic nematodes were extracted and counted using the centrifugation in sugar method[34] and identified from their morphological characteristics[35].

***Mites***: Mites were extracted using a bank of Berlèse-Tüllgren funnels[36], in which 50 g of sample were placed; 25 W lamps; exposure 24 h; collection on 50% methanol. Solomon's method was used to estimate mite numbers[37], while their identification was based on morphological characteristics[38,39].

## Results and Discussion

***Physical characterisation***: Tables 1-3 summarises the physical properties of the materials studied (bulk density, particle real density, total porosity, water-holding capacity, hydraulic conductivity, permeability, particle size and water-release curve parameters). The soil was characterised by its high percentage of particles measuring less than 1mm (616 g $kg^{-1}$), high bulk density (1.106 g $cm^{-3}$), high particle real density (2.727 g $cm^{-3}$), low porosity (595 mL $L^{-1}$), low water holding capacity (0.40 kg $kg^{-1}$) and low hydraulic conductivity (17 cm $h^{-1}$) (Tables 1 and 2). The water-release curve (Table 3) showed this material's low air capacity and low capacity to hold "useful water". The high R value (>100 cm) indicated that this material will not provide sufficient aeration. The principal characteristics of the sphagnum peat were its low bulk density (0.075 g $cm^{-3}$), high degree of porosity (951 mL $L^{-1}$), high water-holding capacity (10.51 kg $kg^{-1}$) and high hydraulic conductivity (947 cm $h^{-1}$) (Table 4). The water-release curve (Table 3) showed this material's high air capacity (550 mL $L^{-1}$), while the "easily usable water" value was relatively low (160 mL $L^{-1}$). The low R value (5 cm) reflected the high air capacity and low availability of "easily usable water". The black peat was characterised by its high porosity (863 mL $L^{-1}$) and relatively low water-holding capacity (2.16 kg $kg^{-1}$), which was below that of sphagnum peat because of the greater degree of mineralisation (Table 1). It had a high air capacity (270 mL $L^{-1}$) and rather low percentage of "easy usable water" (180 mL

L$^{-1}$), as reflected by its high R value (42 cm). Similarly to black peat, composted pine bark showed a high porosity value (874 mL L$^{-1}$) and relatively low water-holding capacity (2.72 kg kg$^{-1}$), while its hydraulic conductivity was substantially higher (379 as opposed to 86 cm h$^{-1}$) (Table 1). It had a high air capacity (450 mL L$^{-1}$) and low rate of easily usable water (140 mL L$^{-1}$) (Table 3). The low R value (8 cm) reflected its sufficient air capacity. The coconut fibre, the same as sphagnum peat, showed a low bulk density (0.074 g cm$^{-3}$) and high porosity (953 mL L$^{-1}$), water-holding capacity (10.67 kg kg$^{-1}$) and hydraulic conductivity values (1126 cm h$^{-1}$) but had a better structure and more uniform particle size (776 g kg$^{-1}$ less than 1 mm) (Tables 1 and 2). A well balanced air (300 mL L$^{-1}$) and "easily usable water" (270 mL L$^{-1}$) capacity with an R of 26 cm completed its characterization. Wood fibre had a low bulk density (0.038 g cm$^{-3}$) and high porosity (972 mL L$^{-1}$), water-holding capacity (11.66 kg kg$^{-1}$) and hydraulic conductivity (2713 cm h$^{-1}$). However, it had a high proportion of particles between 5 and 10 mm (35.6 g kg$^{-1}$) which were difficult to break up and a low proportion of particles smaller than 1 mm (21.1 g kg$^{-1}$) (Tables 1 and 2). It had a very high air capacity (760 mL L$^{-1}$) an low percentage of "easily usable water"(140 mL L$^{-1}$) and "reserve water" (10 mL L$^{-1}$), with a very low R value (2 cm).

The bulk density of grapevine shoots was low (0.096 g cm$^{-3}$, while the porosity was high (938 mL L$^{-1}$); good water-holding capacity (6.37 kg kg$^{-1}$), intermediate hydraulic conductivity (538 cm h$^{-1}$) and uniform particle size (Tables 1 and 2), high air capacity (580 mL L$^{-1}$) and low "easily usable water" (100 mL L$^{-1}$) and "reserve water" (10 mL L$^{-1}$) percentages and very low R (3 cm). The most commonly used casing in La Rioja showed a high bulk density (0.677 g cm$^{-3}$), low porosity (742 mL L$^{-1}$), low water-holding capacity (0.69 kg kg$^{-1}$), low hydraulic conductivity (85 cm h$^{-1}$) and uniform granulometry (Tables 1 and 2). It had a balanced air (310 mL L$^{-1}$) and "easily usable water (210 mL L$^{-1}$) capacity. The R value (17 cm) indicated the sufficient availability of air and "easily usable water". The mixtures of soil and correctors (sphagnum peat, black peat, composted pine bark, coconut fibre, wood fibre and composted vine shoots) showed high bulk density values (0.691 to 0.730 g cm$^{-3}$), low porosity (730 to 745 mL L$^{-1}$), low water-holding capacity (0.47 to 0.54 kg kg$^{-1}$), low hydraulic conductivity (102 to 191 cm h$^{-1}$) and a high rate of particles of less than 1 mm (612 to 618 g kg$^{-1}$) (Tables 1 and 2). All were characterised by a high air capacity (410 to 470 mL L$^{-1}$) and low rates of "easily usable water" (40 to 80 mL L$^{-1}$) and "reserve water" (10 to 30 mL L$^{-1}$). The low R values (2 to 5 cm) reflected the sufficient air capacity but poor availability of "easily usable water".

***Chemical characterisation***: Tables 4 and 5 show the results obtained for the chemical parameters studied (pH-$H_2O$, pH-KCL, electrical conductivity, pH buffering capacity, cationic exchange capacity, total carbonates, active lime, organic matter and total elements concentration). The soil had an alkaline pH (8.09), a good buffering capacity against changes in pH (27.9 meq $H^+$ L$^{-1}$), low electrical conductivity (158µS cm$^{-1}$), a low cationic exchange capacity (16.2 $cmol_c$ kg$^{-1}$), low organic matter content (5.6 g kg$^{-1}$) and high percentages of total carbonates (648 g kg$^{-1}$) and active lime (231 g kg$^{-1}$) (Table 4).

The principal characteristics of sphagnum peat were its acid pH (3.97), low electrical conductivity (57 µS cm$^{-1}$), high cationic exchange capacity (135.6 $cmol_c$ kg$^{-1}$) due to the high number of carboxylic groups[14], high organic matter content (988.7 g kg$^{-1}$) and low total elements content (Tables 4 and 5).

The black peat was characterised by its slightly alkaline pH (7.68), high buffering capacity (70.8 meq $H^+$ L$^{-1}$) and high electrical conductivity (1746 µS cm$^{-1}$). The high degree of salinity is a result of salt water seaping into the peat deposits through the coastal belts[16]. The material had a high cationic exchange capacity (102.2 $cmol_c$ kg$^{-1}$), a low organic matter content (469.9 g kg$^{-1}$), as is to be expected in a highly decomposed peat (Table 4) and a high content of elements, particularly calcium, magnesium, sodium, iron and boron (Table 5).

Composted pine bark showed slightly acid pH values (6.88), a low buffering capacity (4.6 meq $H^+$ L$^{-1}$), low electrical conductivity (188µS cm$^{-1}$), high cationic exchange capacity (91.7 $cmol_c$ kg$^{-1}$), a relatively low organic matter content (728.7 g kg$^{-1}$) (Table 4) and an intermediate total elements content (Table 5).

The main characteristics of the coconut fibre were its acid pH (5.86), low buffering capacity (2.2 meq $H^+$ L$^{-1}$) and high organic matter content (902.7 g kg$^{-1}$) (Table 4), while, among the elements, the high potassium content was of note (5025 mg kg$^{-1}$) (Table 5).

Wood fibre had an acidic pH (5.99) and a very low buffering capacity (1.0 meq $H^+$ L$^{-1}$), EC (38 µS cm$^{-1}$) and cationic exchange capacity (15.7 $cmol_c$ kg$^{-1}$). It had the highest organic matter content (995.8 g kg$^{-1}$) (Table 4) and low total elements content (Table 5).

The composted vine shoots were characterised by their slightly alkaline pH (7.69) and noticeably high cationic exchange capacity (124.8 $cmol_c$ kg$^{-1}$). They also had a high total elements content, particularly of nitrogen, phosphorus, potassium and zinc (Tables 4 and 5).

The casing from La Rioja had an alkaline pH (7.82), low cationic exchange capacity (15.0 $cmol_c$ kg$^{-1}$), high carbonate (890 g kg$^{-1}$) and active lime (224 g kg$^{-1}$) content and a low organic matter content (59.0 g kg$^{-1}$) (Table 4). It had low nitrogen, phosphorus, potassium and sodium levels and a high calcium content (Table 5).

The mixtures of soil with sphagnum peat, black peat, composted bark, coconut fibre, wood fibre and composted vine shoots showed chemical characteristics in accordance with the individual components and strongly conditioned by the characteristics of the soil. The most noteworthy aspects were the low buffering capacity of the mixture using wood fibre (14.4 meq $H^+$ L$^{-1}$) and the high electrical conductivity (456 µS cm$^{-1}$) and sodium content (888 mg kg$^{-1}$) of the mixture using black peat (Tables 4 and 5).

***Biological characterisation***: The search for phytopathogenic nematodes and mites (Table 6) showed only the presence of the latter (identified as *Histiostoma* spp.) in the composted vine shoots. Some of these mites, which are occasionally found on mushrooms, have been associated with small pits in the caps and stipes of mushrooms, which then often suffer from bacterial decomposition. It is not clear, however, whether the mites cause the damage, or merely exacerbate an existing bacterial attack. These mites may also feed on the mycelium and have been shown to have a limited capacity to spread the spores of *Verticillium*, probably the most common and serious fungal disease of the mushroom crop[40].

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**Table 1**: Physical properties of materials

| Material | Bulk density (g cm$^{-3}$) | Particle real density (g cm$^{-3}$) | Total pore space (mL L$^{-1}$) | Water-holding capacity (kg kg$^{-1}$) | Hydraulic conductivity (cm h$^{-1}$) | Permeability (cm$^{2}$) |
|---|---|---|---|---|---|---|
| S | 1.106 | 2.729 | 595 | 0.40 | 17 | $4.83\ 10^{-8}$ |
| SP | 0.075 | 1.517 | 951 | 10.51 | 947 | $2.69\ 10^{-6}$ |
| BP | 0.288 | 2.107 | 863 | 2.16 | 86 | $2.44\ 10^{-7}$ |
| CB | 0.205 | 1.624 | 874 | 2.72 | 379 | $1.08\ 10^{-6}$ |
| CF | 0.074 | 1.568 | 953 | 10.67 | 1126 | $3.20\ 10^{-6}$ |
| WF | 0.038 | 1.364 | 972 | 11.66 | 2713 | $7.70\ 10^{-6}$ |
| CV | 0.096 | 1.537 | 938 | 6.37 | 538 | $1.53\ 10^{-6}$ |
| RI | 0.677 | 2.626 | 742 | 0.69 | 85 | $2.41\ 10^{-7}$ |
| S+SP | 0.714 | 2.709 | 736 | 0.54 | 172 | $4.88\ 10^{-7}$ |
| S+BP | 0.726 | 2.692 | 730 | 0.51 | 102 | $2.90\ 10^{-7}$ |
| S+CB | 0.722 | 2.681 | 731 | 0.51 | 126 | $3.58\ 10^{-7}$ |
| S+CF | 0.691 | 2.710 | 745 | 0.54 | 188 | $5.34\ 10^{-7}$ |
| S+WF | 0.730 | 2.717 | 731 | 0.47 | 191 | $5.42\ 10^{-7}$ |
| S+CV | 0.713 | 2.704 | 736 | 0.50 | 139 | $3.95\ 10^{-7}$ |

S: soil; SP: sphagnum peat; BP: black peat; CB: composted pine bark; CF: coconut fibre pith; WF: wood fibre; CV: composted vine shoots; RI: La Rioja type casing; S+SP: soil-sphagnum peat mixture (4:1, v/v); S+BP: soil-black peat mixture (4:1, v/v); S+CB: soil-composted pine bark mixture (4:1, v/v); S+CF: soil-coconut fibre pith mixture (4:1, v/v); S+WF: soil-wood fibre mixture (4:1, v/v); S+CV: soil-composted vine shoots mixture (4:1, v/v).

**Table 2**: Physical properties of materials (cont.): particle size (g kg$^{-1}$)

| Material | >25 mm | 25-10 mm | 10-5 mm | 5-4 mm | 4-1 mm | <1 mm |
|---|---|---|---|---|---|---|
| S | 0 | 0 | 52 | 25 | 308 | 616 |
| SP | 0 | 34 | 146 | 35 | 282 | 502 |
| BP | 0 | 0 | 54 | 35 | 356 | 555 |
| CB | 0 | 0 | 17 | 17 | 417 | 548 |
| CF | 0 | 0 | 4 | 12 | 208 | 776 |
| WF | 0 | 107 | 356 | 19 | 307 | 211 |
| CV | 0 | 0 | 1 | 11 | 527 | 461 |
| RI | 0 | 0 | 5 | 9 | 519 | 467 |
| S+SP | 0 | 1 | 53 | 25 | 308 | 613 |
| S+BP | 0 | 0 | 52 | 25 | 311 | 612 |
| S+CB | 0 | 0 | 50 | 24 | 313 | 613 |
| S+CF | 0 | 0 | 51 | 24 | 306 | 618 |
| S+WF | 0 | 1 | 54 | 25 | 308 | 612 |
| S+CV | 0 | 0 | 50 | 24 | 313 | 613 |

S: soil; SP: sphagnum peat; BP: black peat; CB: composted pine bark; CF: coconut fibre pith; WF: wood fibre; CV: composted vine shoots; RI: La Rioja type casing; S+SP: soil-*sphagnum* peat mixture (4:1, v/v); S+BP: soil-black peat mixture (4:1, v/v); S+CB: soil-composted pine bark mixture (4:1, v/v); S+CF: soil-coconut fibre pith mixture (4:1, v/v); S+WF: soil-wood fibre mixture (4:1, v/v); S+CV: soil-composted vine shoots mixture (4:1, v/v).

**Table 3**: Physical properties of materials (cont.): water release curve parameters

| Material | Easily available water (mL $L^{-1}$) | Air capacity (mL $L^{-1}$) | Water buffering capacity (mL $L^{-1}$) | Hardly available water(mL $L^{-1}$) | R parameter (cm) |
|---|---|---|---|---|---|
| S | 100 | 160 | 20 | 310 | >100 |
| SP | 160 | 550 | 40 | 200 | 5 |
| BP | 180 | 270 | 40 | 370 | 42 |
| CB | 140 | 450 | 30 | 250 | 8 |
| CF | 270 | 300 | 50 | 330 | 26 |
| WF | 140 | 760 | 10 | 60 | 2 |
| CV | 100 | 580 | 10 | 250 | 3 |
| RI | 210 | 310 | 40 | 180 | 17 |
| S+SP | 80 | 420 | 20 | 220 | 5 |
| S+BP | 80 | 410 | 10 | 230 | 4 |
| S+CB | 40 | 460 | 10 | 220 | 2 |
| S+CF | 70 | 440 | 30 | 210 | 4 |
| S+WF | 60 | 470 | 20 | 180 | 2 |
| S+CV | 60 | 450 | 20 | 210 | 3 |

S: soil; SP: sphagnum peat; BP: black peat; CB: composted pine bark; CF: coconut fibre pith; WF: wood fibre; CV: composted vine shoots; RI: La Rioja type casing; S+SP: soil-sphagnum peat mixture (4:1, v/v); S+BP: soil-black peat mixture (4:1, v/v); S+CB: soil-composted pine bark mixture (4:1, v/v); S+CF: soil-coconut fibre pith mixture (4:1, v/v); S+WF: soil-wood fibre mixture (4:1, v/v); S+CV: soil-composted vine shoots mixture (4:1, v/v).

**Table 4**: Chemical properties of materials

| Material | pH-$H_2O$ | pH-KCl | Electrical conductivity (μS $cm^{-1}$) | pH buffering capacity (meq $H+L^{-1}$) | Cation exchange capacity (cmolc $kg^{-1}$) | Total carbonates (g $kg^{-1}$) | Active lime (g $kg^{-1}$) | Organic matter (g kg-1) |
|---|---|---|---|---|---|---|---|---|
| S | 8.09 | 8.05 | 158 | 27.9 | 16.2 | 648 | 231 | 5.6 |
| SP | 3.97 | 3.11 | 57 | 8.7 | 135.6 | 0 | 0 | 988.7 |
| BP | 7.68 | 7.62 | 1746 | 70.8 | 102.2 | 267 | 134 | 469.9 |
| CB | 6.88 | 6.65 | 188 | 4.6 | 91.7 | 6 | 2 | 728.7 |
| CF | 5.86 | 5.23 | 218 | 2.2 | 86.8 | 0 | 0 | 902.7 |
| WF | 5.99 | 4.77 | 38 | 1.0 | 15.7 | 0 | 0 | 995.8 |
| CV | 7.69 | 7.46 | 424 | 6.4 | 124.8 | 22 | 8 | 872.8 |
| RI | 7.82 | 8.27 | 161 | 23.8 | 15.0 | 890 | 224 | 59.0 |
| S+SP | 8.03 | 7.97 | 157 | 25.0 | 18.1 | 637 | 227 | 21.4 |
| S+BP | 8.05 | 8.02 | 456 | 30.2 | 21.2 | 625 | 225 | 30.0 |
| S+CB | 8.00 | 7.99 | 170 | 27.4 | 19.4 | 620 | 221 | 35.2 |
| S+CF | 8.03 | 8.00 | 191 | 26.2 | 17.9 | 638 | 227 | 20.2 |
| S+WF | 8.08 | 8.02 | 157 | 14.4 | 17.1 | 643 | 229 | 16.0 |
| S+CV | 8.06 | 8.04 | 193 | 25.3 | 17.9 | 635 | 226 | 23.4 |

S: soil; SP: sphagnum peat; BP: black peat; CB: composted pine bark; CF: coconut fibre pith; WF: wood fibre; CV: composted vine shoots; RI: La Rioja type casing; S+SP: soil-sphagnum peat mixture (4:1, v/v); S+BP: soil-black peat mixture (4:1, v/v); S+CB: soil-composted pine bark mixture (4:1, v/v); S+CF: soil-coconut fibre pith mixture (4:1, v/v); S+WF: soil-wood fibre mixture (4:1, v/v); S+CV: soil-composted vine shoots mixture (4:1, v/v).

**Table 5**: Chemical properties of materials (cont.): concentration of total elements

| Material | N (g kg$^{-1}$) | P (mg kg$^{-1}$) | K (mg kg$^{-1}$) | Ca (mg kg$^{-1}$) | Mg (mg kg$^{-1}$) | Na (mg kg$^{-1}$) | Fe (mg kg$^{-1}$) | Zn (mg kg$^{-1}$) | Cu (mg kg$^{-1}$) | Mn (mg kg$^{-1}$) | B (mg kg$^{-1}$) | Mo (µg kg$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S | 0.8 | 130 | 2135 | 225250 | 2732 | 380 | 10900 | 17.5 | 3.0 | 67.0 | 9.0 | < 4.0 |
| SP | 7.0 | 100 | 50 | 1760 | 503 | 135 | 309 | 7.0 | 3.0 | 2.5 | 3.0 | < 4.0 |
| BP | 11.7 | 580 | 2065 | 136250 | 6420 | 8750 | 3305 | 24.0 | 3.0 | 74.5 | 50.5 | < 4.0 |
| CB | 4.3 | 250 | 725 | 17900 | 2338 | 310 | 2880 | 36.0 | 3.0 | 73.5 | 11.5 | < 4.0 |
| CF | 5.1 | 140 | 5025 | 1385 | 1122 | 1865 | 535 | 14.0 | 3.0 | 24.5 | 19.5 | < 4.0 |
| WF | 0.9 | 70 | 50 | 735 | 164 | 70 | 57 | 9.0 | 3.0 | 53.0 | 3.0 | < 4.0 |
| CV | 29.3 | 1445 | 6600 | 33400 | 2693 | 760 | 545 | 66.0 | 3.0 | 68.5 | 32.0 | < 4.0 |
| RI | 0.5 | 35 | 50 | 302000 | 3112 | 60 | 545 | 18.5 | 7.5 | 23.5 | 3.0 | < 4.0 |
| S+SP | 0.9 | 129 | 2099 | 221421 | 2694 | 376 | 10718 | 17.3 | 3.0 | 65.9 | 8.9 | < 4.0 |
| S+BP | 1.5 | 157 | 2131 | 219844 | 2956 | 888 | 10439 | 17.9 | 3.0 | 67.5 | 11.5 | < 4.0 |
| S+CB | 1.0 | 135 | 2073 | 216179 | 2715 | 377 | 10549 | 18.3 | 3.0 | 67.3 | 9.1 | < 4.0 |
| S+CF | 0.9 | 130 | 2182 | 221602 | 2706 | 404 | 10731 | 17.4 | 3.0 | 66.3 | 9.2 | < 4.0 |
| S+WF | 0.8 | 129 | 2117 | 223352 | 2710 | 377 | 10808 | 17.4 | 3.0 | 66.9 | 8.9 | < 4.0 |
| S+CV | 1.4 | 158 | 2229 | 221228 | 2731 | 388 | 10683 | 18.5 | 3.0 | 67.0 | 9.5 | < 4.0 |

S: soil; SP: sphagnum peat; BP: black peat; CB: composted pine bark; CF: coconut fibre pith; WF: wood fibre; CV: composted vine shoots; RI: La Rioja type casing; S+SP: soil-sphagnum peat mixture (4:1, v/v); S+BP: soil-black peat mixture (4:1, v/v); S+CB: soil-composted pine bark mixture (4:1, v/v); S+CF: soil-coconut fibre pith mixture (4:1, v/v); S+WF: soil-wood fibre mixture (4:1, v/v); S+CV: soil-composted vine shoots mixture (4:1, v/v).

**Table 6.** Exploration of individual materials by pathogen nematodes and mites

| Material | Pathogen nematodes | Mites (count per 100g) |
|---|---|---|
| S | Absence | Absence |
| SP | Absence | Absence |
| BP | Absence | Absence |
| CB | Absence | Absence |
| CF | Absence | Absence |
| WF | Absence | Absence |
| CV | Absence | 189 (*Histiostoma spp.*) |
| RI | Absence | Absence |

S: soil; SP: sphagnum peat; BP: black peat; CB: composted pine bark; CF: coconut fibre pith; WF: wood fibre; CV: composted vine shoots; RI: La Rioja type casing.