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Mixing Sorghum Distillery Residue Biochar with Old Corrugated Cardboard and Cattle Manure to Develop Degradable Biochar Plug

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This study developed Old Corrugated Cardboard (OCC), cattle manure, and different percent weight of Sorghum Distillery Residue Biochar (SDRBC) into Degradable Biochar Plugs (DBCP), and the fertility index and feasibility of the time–dependent degradation of DBCP were evaluated. The pH value of DBCP was slightly alkaline at 7.56–7.65; the electrical conductivity was lower than 1.00 mS/cm; the cation exchange capacity was 22.19–31.56 cmole/kg. According to the fertility index, the total nitrogen, effective phosphorus, and exchangeable potassium ion contents in DBCP increased significantly with the addition percent weight of SDRBC. The case with addition was 1.97–3.06 times of that without addition. After degradation, the increase of the biochar addition percent weight was helpful for fertilizer retention. The dry strength of DBCP was 120.3–141.3 N, the wet strength was 14.2–18.0 N. The case with SDRBC was able to enhance the dry/wet strength, which were 1.16 and 1.22 times of that without the addition. The winter degradability results showed that the overground/underground percent weight (%) of DBCP decreased with time, and 28 days later the difference between the cases without addition and with addition of SDRBC was 6.11–29.83%. For the spring degradability, after 45 days the percent weight of the overground case without the addition of SDRBC decreased 38.20%, and that with the addition decreased 19.91–32.10%, and for the underground case, the DBCP without the addition of SDRBC was fully degraded on Day 25, and that with the addition was fully degraded on Day 35. The addition of SDRBC can slow down the degradation of DBCP, and the developed DBCP can be used in different cultivation period for plug seedlings as the DBPC can possibly assist fertilizer retention after transplanting or during field planting, and then be totally degraded in the soil.

Key words: Sorghum Distillery Residue (SDR), Old Corrugated Cardboard (OCC), Degradable Biochar Plug (DBCP), Sorghum Distillery Residue Biochar (SDRBC), Fertility Index

INTRODUCTION

Taiwan's Environmental Protection Administration advocates 4R (Reduce, Recycle, Reuse and Recovery) as an environmental and resource conservation implementation policy for the reduction and recycling of wastes to solve environmental pollution problems. The percent recovery of paper and paperboard is higher by about 65% and the percent utilization is about 74%. Old Corrugated Cardboard (OCC) is one of the discard packaging materials and often used as a decomposable and reproducible environmentally friendly green material (EPA, 2016). OCC plays an important role in the composite material structures of the research and development of strength properties, and is self–degradable for the main ingredient of plugs because it is made of wood fibers (Nechita *et al.*, 2010). Plug seedling cultivation is characterized by normalization, regularity, shorter days to seedling growth, and convenient transportation; therefore, the petrochemical plastic plug is mostly used at present. In the transplantation of plug seedlings, the seedlings are manually removed and transplanted into the fields, and then numerous petrochemical plastic plugs are discarded after transplantation. The petrochemical plastic plug cannot be decomposed, and accumulate in landfills for long periods of time, leading to severe pollution (Wu *et al.*, 2013; Liew and Khor, 2015). To solve this problem, some of plant industries actively seek substitutes for petrochemical plastic plugs.

In recent years, the research on replacing petrochemical plastics with degradable materials to reduce pollution is paid significant attention. The "biomass plug" is the general designation of spontaneously degradable plugs, which can be directly transplanted to the soil together with seedlings without affecting the roots, and then degraded due to soil environment factors, such as: temperature, relative humidity and microorganisms etc., in order to allow the root system to penetrate through the plug to the soil. For convenient growth of seedlings, the biomass plug have to be with appropriate mechanical strength, be able to be transplanted to the field together with seedlings, and be degraded in the soil after transplanting or during field planting (Nechita *et al.*, 2010; Wu *et al.*, 2013). In the present biomass plug, "bioplastic" is extensively used, meaning the material for biomass plugs is a sort of plastic that can be degraded by microorganisms during field planting period. While bioplastic is degradable, additional synthesis is required, and it degrades very slowly in the soil. Bioplastic is also combined amount of fatty group, and CO_2 is released during the degradation process, which indirectly influences the greenhouse warming effect. Therefore, how to

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obtain a more direct, low cost and environmentally friendly material is an important factor in the research and development of plugs.

The daily output of Sorghum Distillery Residue (SDR) from the brewing process of Kinmen Kaoliang Liquor INC. in Taiwan is about 300 MT (Lee, *et al*., 2011), and contains abundant nutrient substances, which are mainly used as farming and poultry feed (Yang *et al*., 2003; Ma *et al*., 2006). However, the daily output quantity is still large as it is not used properly, meaning it is a nutrient waste, which may breed microorganisms and produce toxins. Kuo *et al*. (2018) prepare SDR into biochar at the carbonization temperature of 450°C, which has been used in the plug seedlings cultivation substrate to increase seedling growth quality. The addition of Sorghum Distillery Residue Biochar (SDRBC) can enhance the electrical conductivity and cation exchange capacity of peat. In addition, SDRBC prepared from SDR has the "carbon fixation" effect, which not only reduces CO_2 emissions, it also increases the utility value of soil environments; therefore, the hard disposal of excessive wastes–SDR can be solved. In stock farming, animal droppings are the main source of waste, as one dairy cattle creates about 30 kg of manure per day, which contains fibers and potassic fertilizer, as well as nitrogen, phosphorus, calcium, and sodium contents, which are mostly composted to make organic fertilizer (COA, 2008). Nambuthiri *et al*. (2015) indicate that cattle manure, resin, glue, wax, and emulsion can be as adhesives, meaning they can be bonded as a consolidation material for biomass plug composition materials.

In order to solve the pollution resulted from the long–term accumulation of petrochemical plastic plugs, waste reduction and recycling are the current non–negligible trends. This study mixed OCC, biochar prepared by SDR and cattle manure, which were made into a biochar paper mat using the method of making handmade paper for physical testing, which then were shaped by the self–designed mold and dehydrated to develop the Degradable Biochar Plug (DBCP), and the plant root system expansion limitation degree in the time–dependent degradation was evaluated according to the dry and wet strengths and degradability. The basic properties, such as pH value, electrical conductivity, cation exchange capacity, and the fertility index, including total nitrogen content, effective phosphorus content, and exchangeable potassium ion content, were investigated. The differences in the dry strength and fertility indices before and after degradation in different seasons were analyzed, in order to investigate the effect of the addition of SDRBC on the DBCP and the feasibility of degradable seedling plug. The developed DBCP is expected to have adequate strength, degradability, and fertility index for increasing seedling growth quality, and can be a substitute for the extensively used petrochemical plastic plugs.

MATERIALS AND METHOD

Experimental materials

1. Old Corrugated Cardboard (OCC) recycled from Wood Working Factory, National Chiayi University (NCYU), Taiwan. The OCC specimen with dimensions of 10×10 mm was prepared and then defibrillated by a grinder for future use.
2. Sorghum distillery residue (SDR) was as the feedstock from K Liquor Inc., and pulverized to 5–10 mesh.
3. The cattle manure (CM) specimen obtained from Animal Research Farm, NCYU, Taiwan.

Experimental methods

Basic properties of experimental materials

Moisture content: the prepared feedstock–SDR, mixed materials–CM, and OCC specimens were taken at random, placed in an oven at 105°C, dried to constant weight, and the moisture content was calculated. The chemical composition analysis of SDR and CM were included the contents of holocellulose and lignin and ethanol–toluene extractives. The holocellulose was measured according to the CNS 6948 (2004) Method of test for holocellulose content of pulpwood and other fibrous materials (Chlorite method). The formula for holocellulose (%) = (absolute dried weight of holocellulose / absolute dried weight of experimental material) ×100.

The lignin content was tested by the CNS 2721 (2010) Method of test for determination of acid–insoluble lignin in pulp and the CNS 12108 (1987) Method of Test for Acid–Soluble Lignin (Klason lignin) in Wood and Pulp. The formula for acid–insoluble lignin (%) = (absolute dried weight of lignin / absolute dried weight of experimental material) × 100. The formula for acid–insoluble lignin (%) is (B×V×100) / (1000×W), where B is the concentration of acid–soluble lignin (g/L); V is the total volume of solution (mL) and W is the absolute dried weight of the experimental material. Furthermore, B = (A×D) / 110, where A is the absorbance and D is the diluted fold. Lignin content (%) = acid–insoluble lignin + acid–soluble lignin. The ethanol–toluene extractives were measured according to the CNS 4713 (2005) Method of testing for ethanol–toluene extractives in wood. The formula for ethanol–toluene extractives (%) = (absolute dried weight of extractives / absolute dried weight of experimental material) × 100.

Preparation and basic properties of biochar

The feedstocks were absolutely dried. About 20 g SDR specimen was put in the crucible, and placed in a vertical high temperature activation furnace (Chi–How Heating Co., Ltd.). After vacuum pumping, the inside furnace was free of oxygen, carbonization was set the temperature at 450°C and the heating rate was 10°C/min. The nitrogen was put into the carbonization process, the gas flow was 200 mL/min, and the temperature was maintained for 60 min. Finally, the nitrogen was flowed into the furnace for cooling to room temperature, and then the SDRBC specimen was taken out and weighed. The yield was calculated. Yield (%) = (absolute dried weight of SDRBC / absolute dried weight of SDR) × 100.

The basic properties of SDRBC included pH value, EC value (Electrical Conductivity) and CEC (Cation Exchange Capacity). The pH value was measured by pH meter (SUNTEX TS–1) after the solution of SDRBC with distilled water mixed in ratio of 1:5 (v/v%) was kept still for 2 h by the CNS 698 (1965) Method of test for activated carbon (power, for industrial use). The EC value was same as the acid–alkali mixed solution ratio, measured by pen type EC meter (CD 4301). The CEC was investigated. The detail experimental steps of CEC refer to (Hendershot and Duquette, 1986).

Development and basic properties of DBCP

DBCP included OCC, CM and SDRBC, where the OCC fiber was the main ingredient of biomass plugs, which was mixed with CM as the binding material for consolidation, and then SDRBC was mixed uniformly into a cylinder paper machine by the CNS 12495 (1992) Laboratory Beating of Pulp (Beater Method) combined with the CNS 11212 (1992) Method of Preparation of Handsheets for Physical Testing, made into DBCP mat and, then DBCP was developed by the self–designed aluminum mold. The appropriate conditions were the addition percent weight for the molding of DBCP, where the basic weight of DBCP was 360 g/m^2 (Lin *et al.*, 2015; Lin *et al.*, 2017; Lin *et al.*, 2018), which was mixed with 20% (w/w%) CM, and put in SDRBC according to percent weight 0, 20, and 35% (w/w%). The specimen code is DBCP–SDRBC (%), meaning Degradable Biochar Plug with different addition percent weight (0, 20, 35%): DBCP–0, DBCP–20 and DBCP–35.

Evaluation of the application properties of DBCP

Referring to CNS 487 (2013) Method of test for density, relative density (specific gravity), and absorption of fine aggregate, the DBCP was put in a beaker, filled with deionized water until it was immersed, and then taken out and weighed after 10, 20, 30 min, and 1, 6, 12, 24, 48, 72 h. The water absorption rate of DBCP in each time interval was calculated according to the following equation. Water absorption rate (%) = [(S–A) / A] × 100, where S: weight (g) of DBCP after water absorption; A: initial weight (g) of DBCP.

The detail experimental steps of water loss rate of DBCP were followed. The DBCP was put in a beaker as well, filled with water till it was immersed, taken out, and weighed after 72 h and then being filtered by suction, as well as finally reweighed after 10, 20, 30 min, and 1, 6, 12, 24, 48, 72 h. The formula of water loss rate (%) = [(A–B) / B] × 100, where A: weight (g) of DBCP after 72 h and then being filtered by suction; B: weight (g) of DBCP after putting in each time interval.

Dry and wet strength tests of DBCP are designed by referring to the biomass plug strength test method of Nechita *et al*. (2010). The DBCP was divided into dry and wet conditions: the dry condition was the air–dried condition under atmospheric pressure; the wet condition was the moist state after it was removed from the water 15 min later. Afterwards, the self–designed test mold for DBCP strength was used; the DBCP was fixed into the cup model, and put the rod model that provided the plug penetrating pressure. The strength was tested by a universal testing machine (Shimadze AG–250KNI, Japan) and the loading rate was 0.05 mm/s. The dry strength of DBCP was tested before degradability and after overground in the time–dependent degradation, and the wet strength was only investigated before degradability.

Fertility index of DBCP

The fertility index, including the total nitrogen, effective phosphorus and exchangeable potassium ion contents, in DBCP was evaluated before degradability and after the time–dependent degradation. The detail experimental steps of the total nitrogen, effective phosphorus, and exchangeable potassium ion contents refer to (Kuo *et al.*, 2019).

For total nitrogen assay, the following equation was used. Nitrogen concentration (mg/kg) = $[(V_1–V_2)\times0.01\times14\times25]$ / (recovery rate$\times Wt\times V_s$), Where, V_1: titration volume (mL) of nitrogenous standard; V_2: blank titration volume (mL) of the specimen solution; Wt: specimen weight (g) for decomposition; V_s: volume (mL) of the specimen solution for distillation. Recovery rate (%) = $[(V_1–V_2)\times0.01\times14\times1000]$ / 500 ppm×1 mL

The phosphorus content assay first obtained the absorbance value, and a standard curve f (x) was made with the given phosphorus concentration, and the concentration corresponding to the measured value was calculated by f (x). The f (x) equation was followed. f (x) = 0.40177x+0.0103, Where x: value measured by spectrophotometer. Effective phosphorus content (mg/kg) = [f (x)×50 × 45] / [2×filtrate dosage (mL)]

For the exchangeable potassium ion content assay, the potassium ion content in the solution was measured by an atomic absorption spectrophotometer (Analyst 700, Perkin Elmer). The spectral wavelength for assay was 766.5 nm.

Simulation test for degradation of DBCP in plug seedlings

When the seedlings have grown to some extent in the plug, they need to be transplanted to the field because the root system requires larger space for growth. The biomass plug demands an appropriate degradation degree in the greenhouse (overground) for plug seedlings and the field (underground) growth. The developed DBCPs therefore were used for the simulated plug seedlings in this study, and the records provided by the central weather bureau in Taiwan and were used as the climatic factors influencing the degradation degree in the test, such as temperature, relative humidity (RH), precipitation, etc. The DBCP degradation degree was judged according to the percent weight, and the disintegration degree according to appearance.

The DBCP degradation during the plug seedlings was simulated in two seasons. The test environment was divided into overground and underground degradations.

As the vegetable seedling stage is 2–5 weeks, the winter test duration is set as 28 days, and the spring test duration is set as 45 days. For the degradation test in the two seasons, the seedlings were watered in the morning and evening daily. In the spring test, in order to simulate fertilization during the plug seedlings, Peters Professional No. 8 (Peters professional, Scotts Company, N–P–K: 20–10–20) was applied once every three days, where the diluted concentration was 2000 times (Nechita *et al*., 2010; Liew and Khor, 2015; Kuo *et al*., 2018), and the seedlings were still watered in the morning and evening daily. The total nitrogen, effective phosphorus and exchangeable potassium ion contents in the tested DBCP, including before and after degradation, were determined. The percent weight (%) of DBCP = $[(W_1–W_0) / W_1] \times 100$, Where W_1: absolute dried weight (g) of the original plug; W_0: absolute dried weight (g) of plug after simulation test.

Statistical analysis

The test results are represented by a mean (standard deviation), and the control group and test group are compared by Duncan's multiple range tests. If the ρ value is smaller than 0.05, meaning a significant difference between the test group and the control group, it is represented by different superscript upper case letters.

RESULTS AND DISCUSSION

Chemical composition of SDR and CM

The holocellulose, lignin content, and ethanol–toluene extractives of SDR were 47.94, 21.98, and 9.50%. Lin *et al*. (2006) report the analysis of thermal–resistance components from bark of *Acacic confusa*, and indicate that the thermal–resistance components are from ethanol–toluene extractives. The ethanol–toluene extractives of SDR were higher than those of bark of *Acacic confusa* (2.51–3.33%). The char preparation yield of different feedstocks is related to the ethanol–toluene extract and lignin content (Kuo, *et al*, 2018). The holocellulose and lignin content in the CM were 51.62 and 31.44%, and the ethanol–toluene extractives were 13.33%. The CM including some of fiber materials can create both the structural and consolidation materials in the preparation of biomass plugs (Nechita *et al*., 2010), and the CM contains lignin, and can be the adhesives for biomass plug materials (Nambuthiri *et al*., 2015). There are biomass cattle manure pots (CowPot®) for increasing seedling growth currently available on the market.

Basic properties of experimental materials of DBCP

Kuo *et al*. (2018) use different agricultural and forestry wastes as the feedstocks to prepare biochar at 200 to 450°C, which were used as cultural medium substance. The SDRBC prepared from SDR at the carbonization temperature of 450°C was mixed with peat in the volume ratio of 15/85 (v/v%) as the cultural media, and the pH value, EC value, and CEC were better than the others. Therefore, the SDRBC was prepared under this appropriate condition in this study. The yield of SDRBC was 29.32%. The pH values of SDR and SDRBC were 3.58 and 8.49, respectively. The change in the pH value of biochar is related to the feedstock and carbonization temperature, which increases with carbonization temperature, and the alkaline property of biochar can improve or/and adjust the soil pH value (Yuan *et al*, 2011). The CEC of SDRBC was 6.29 cmol/kg, and that of SDR was 14.06 cmol/kg.

Development and basic properties of DBCP

According to preliminary testing, the formatting failure of DBCP when the basis weight of OCC used was 360 g/m^2 with the CM addition percent weight less than 20%, and when the percent weight of CM was more than 40% added the mat formation of DBCP was unfixed. The DBCP is therefore developed by mixing OCC with the basis weight of 360 g/m^2 with 20% CM and mixed with 0 (as the control), 20 and 35% SDRBC, in order to evaluate the effect of the different percent weight of SDRBC for degrading the DBCP.

The pH value of three type of DBCPs was slightly alkaline (Table 1) and no significant difference between the test group (DBCP–20 and –35) and the 0% SDRBC (DBCP–0). While the EC value of the DBCP with the addition of SDRBC decreased, but the addition percent weight of SDRBC was insignificantly effect. The CEC is the capability of retaining nutrient cations, which is related to the nutrient preserving capability and buffer capacity, meaning the culture medium or soil organics is negatively charged, and adsorbs cations, such as ammonium nitrogen, potassium, calcium, magnesium, and iron cations; therefore, a high CEC represents high nutrient preserving capability (Lemaire, 1995). While the CEC of the DBCP with the addition of SDRBC increased, there was no significant difference in the addition percent weight. Lua *et al*. (2004) indicate that, when the biochar carbonization temperature increases from 250 to 500°C, the volatile matter released from the structure promoted the pores, the specific surface area (SSA) was

Table 1. Basic properties of degradable biochar plug

DBCP	pH value	EC value (mS/cm)	CEC (cmol/kg)	Dry Strength (N)	Wet Strength (N)
DBCP–0 [1)]	7.59 (0.16) ^{a} [2)]	0.14 (0.00) ^{a}	22.19 (2.71) ^{b}	120.30 (4.64) ^{b}	14.20 (0.70) ^{b}
DBCP–20	7.56 (0.02) ^{a}	0.12 (0.00) ^{b}	31.56 (1.95) ^{a}	141.30 (4.64) ^{a}	16.70 (1.30) ^{a}
DBCP–35	7.65 (0.09) ^{a}	0.12 (0.00) ^{b}	29.78 (1.82) ^{a}	136.50 (5.26) ^{a}	18.00 (0.51) ^{a}

[1)] DBCP–SDRBC (%): Degradable Biochar Plug with different addition percent weight (0, 20, 35%)
[2)] Mean (standard deviation) by Duncan's multiple range tests at 5% significant level

enlarged, and the high alkalinity and high specific surface area of biochar can increase the pH value and CEC of acid soil, in order to retain soil nutrients (Chen *et al*., 2010; Laird *et al*., 2010; Yuan *et al*., 2011;Kuo, *et al*, 2018; Kuo, *et al*, 2019).

Application properties of DBCP

Nambuthiti *et al*. (2015) report that the biomass plug is with the semiporous characteristics, prepared by hot pressing of the fiber materials, such as agricultural and forestry wastes and cattle manure, which can improve the water and air exchange capacity between the root system and environment during the seedling growth, but the physical properties of plug are varied with the experimental materials or process.

Dry and wet strengths

For biomass plugs, the dry strength is correlated with the packaging, transportation, and storage before use. The wet strength can evaluate the strength state of hand holding, substrate carrying, and transplanting actions under moist conditions when the biomass plug is used for growing seedlings (Beeks and Evans, 2013). Referring to the method of Nechita *et al*. (2010), the plug and its application to plug seedlings are simulated, in order to evaluate the bearable strength in practical application, and the bearable maximum penetrating strength of DBCP is judged according to the maximum failure strength. In terms of dry strength, there was significant difference between the case without the addition of SDRBC and that with the addition; however, there was no significant difference between the addition percent weight 20 and 35% (Table 1). The wet strength had the same trend, but there was insignificant difference in the addition specimen. This is therefore suggested that the addition of SDRBC can maintain a higher dry and wet strengths of DBCP in wet conditions.

The case with the addition of SDRBC had higher dry and wet strengths than that without the addition. DBCP was developed by uniformly mixing OCC, CM, and SDRBC with a dispersing pulp, which flowed downward with the drain in the circular handmade paper machine to aggregate on the filter screen. The fibers were interwoven, and the SDRBC fills the fiber gaps (semiporous); thus, the structure with SDRBC was relatively compact. As undecomposed lignin in the SDRBC prepared at 450°C could be consolidated with fibers, the strength might be higher than DBCP–0 composed of fibers only. The strength of DBCP in the wet condition was lower than that in the air–dried condition, where the dry strengths of three DBCPs were 8.47, 8.46, and 7.58 times that of the wet strength, respectively, as the structural material of DBCP was mostly fibers. Evans *et al*. (2010) indicate that the water in the fibers of biomass plugs expand and soften the plug, meaning the plug wall becomes vulnerable, easy to tear, and is more likely to fail, as well as the strength thus decreases. Besides, the biomass plugs prepared using rice hulls, coconut shells, and recycled paper fiber materials as the raw materials have good vertical and transverse dry and wet strengths, and therefore, are similar to the strength of petrochemical plastic plugs.

Water absorption and loss rates

DBCP absorbed the maximum amount of water in 1 h and then the water absorption slowly increased at 6, 12, and 24 h, but the water absorption rate of DBCPs reached its maximum after 48 h, which was 355.88, 286.83, and 274.71%, respectively. While the case without the addition of SDRBC was higher than that with the addition by about 1.3 times, there was no significant difference between DBCP–20 and DBCP–35 (results not shown in Table). DBCPs became water saturated in 72 h, at 353.86, 286.79 and 274.80%, respectively according to the addition percent weight. The case without SDRBC (DBCP–0) was only composed of OCC and CM, which was the fiber material and easily absorbed water and expands.

DBCPs had relatively high water loss rate in 0–24 h; the water loss rate was almost 0 at 48–72 h, and there was no significant difference among different addition percent weight (results not shown in Table). Kuo *et al*. (2018) indicate that the water loss rate of SDRBC approximates the air–dried condition within 6 h. DBCP reached equilibrium until 48 h in this study, meaning the water loss rate of DBCP was significantly influenced. According to this water absorption and the wet strength results (Table 1), the case with the addition of SDRBC had lower water absorption than that without the addition and the fiber swelling degree was larger; therefore, the wet strength of DBCP with addition SDRBC in the wet condition was higher.

Fertility index of DBCP

The probability of the total nitrogen, effective phosphorus, and exchangeable potassium ion contents in the DBCP for the plug seedlings, as well as the effect of the addition of SDRBC, is analyzed. This is because the demands for nitrogen, phosphorus, and potassium are the largest in the plant growing process. The nitrogen is the main constituent for crops to synthesize protein, amino acid, and chlorophyll. Phosphorus is the nucleic acid component composing the plant nucleus, which is closely related to cell division, carbohydrates, protein synthesis, and respiratory action. Potassium can promote the synthesis, transformation, and transportation of carbohydrates, which can promote photosynthesis (Watson, 2015). The total nitrogen in cases without the addition of SDRBC and with 20 and 35% were 3.35, 5.37, and 8.71 g/kg, respectively, while the effective phosphorus content was 146.70, 373.83, and 448.71 mg/kg, respectively; and the exchangeable potassium ion content was 3.01, 5.17, and 5.96 cmol/kg, respectively (results not shown in Table). In addition, the nutrients of the case with the addition might be from the SDRBC and CM (ethanol–toluene extractives), the total nitrogen, effective phosphorus, and exchangeable potassium ion contents in the DBCP were able to be increased, and there was significant difference from the increase in the addition percent weight. It is indicated that the CM and the addition of SDRBC may result in a better fertility index while the addition of SDRBC helps retain the contents of nitrogen, phosphorus, and potassium, which may outflow with the water and then into soil for seedlings.

Degradability of DBCP

When different crop seedlings are mature, they need to be transplanted to a larger space for spreading the root system (Nambuthiri *et al*., 2015). Different crop seedlings have different maturation times. The biomass plug must have enough time to support the growth of seedlings before transplantation, and then be expected to degrade smoothly without influencing the development of the seedling root system after the seedlings are transplanted to the field.

Overground and underground degradation tests in winter

Figure 1 (A) temperature change; (B) RH change; (C) variance in percent weight of DBCP during overground tests; (D) variance in underground tests; (E) appearance in the time–dependent overground degradation of DBCP; (F) underground DBCP. According to the data from the weather bureau, the total sunshine duration was 110 h during the winter degradation test, the average ultraviolet light (UV) level was Level 4, the cumulative rainfall was 44.7 mm, the temperature was 20–25°C (average: 23°C), the RH was 70–90% (average: 79%).

Figure 1 (C) showed that the percent weight of DBCP decreased with time, the percent weight of DBCP–0, DBCP–20 and DBCP–35 were 16.69, 9.59 and

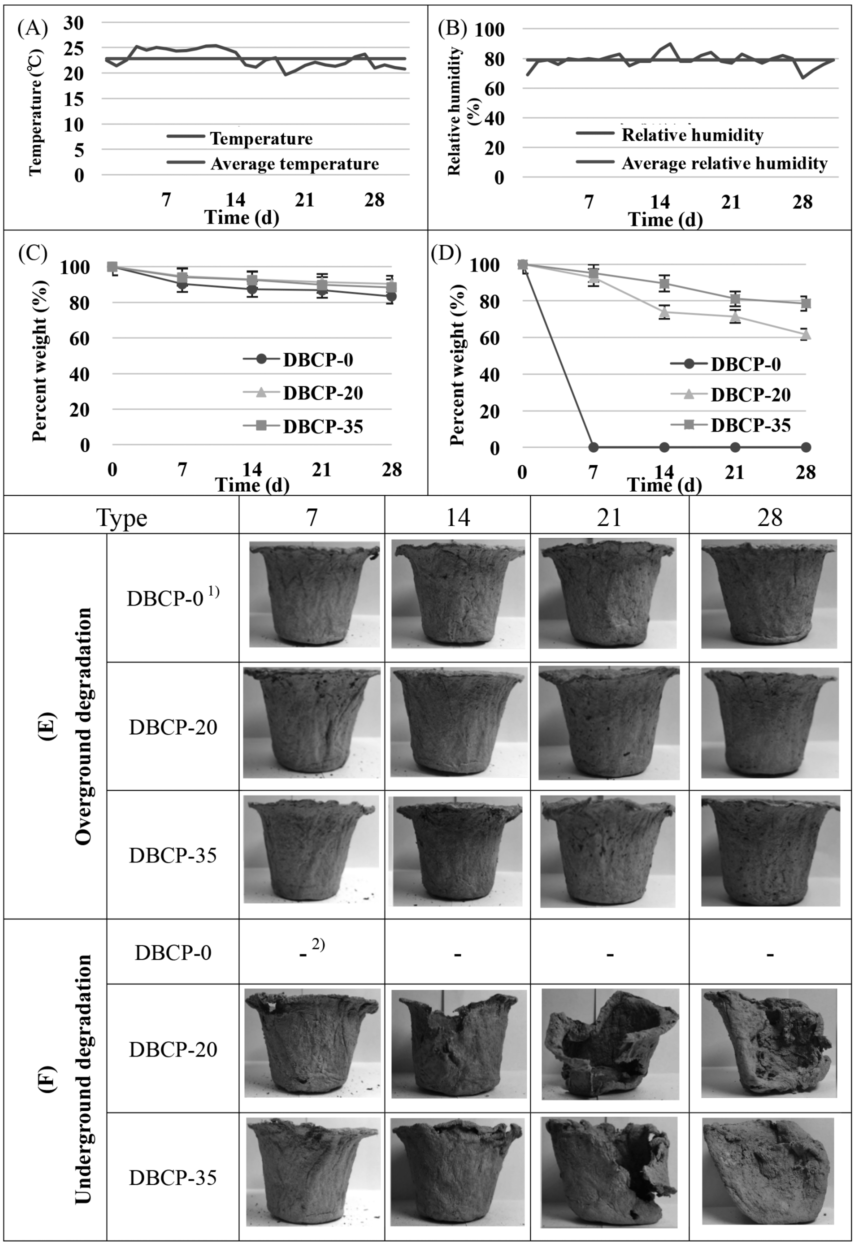

Fig. 1. Weather conditions, percent weight and appearance of degradable biochar plug in winter degradability test.
Note: 1) See Table 1, 2) Total degradation

11.58%, respectively; on Day 28 of degradation, and there was significant difference between the cases without the addition of SDRBC and with the addition, but there was insignificant difference between two cases with the addition. Figure 1 (D) shows that the underground and overground degradation of DBCP had the same trend, meaning they decreased with time. The DBCP–0 was degraded completely within 7 days, and the DBCP–20 and DBCP–35 only lost 7.34 and 4.93%, respectively. The addition of SDRBC therefore might slow down degradation. As shown in Figure 1 (E) and (F), the underground degradation was more intense than overground. This may be due to the organisms in the soil (Nechita *et al.*, 2010).

Therefore, the DBCP–0 degraded faster, whereas the DBCP–20 and DBCP–35 with SDRBC degraded slowly. Compared with the dry and wet strengths (Table 1), the case without the addition of SDRBC has a vulnerable structure, whereas the case with the addition has higher strength, meaning it degrades slowly.

Overground and underground degradation tests in spring

Figure 2 (A), (B) were the temperature and RH changes; (C), (D) were the variances in the percent weight of DBCP during overground and underground tests; (E) and (F) appearance in the time–dependent overground and underground degradation. The total sunshine duration was 152.1 h in spring, the average UV level was Level 6, the cumulative rainfall was 234.7 mm,

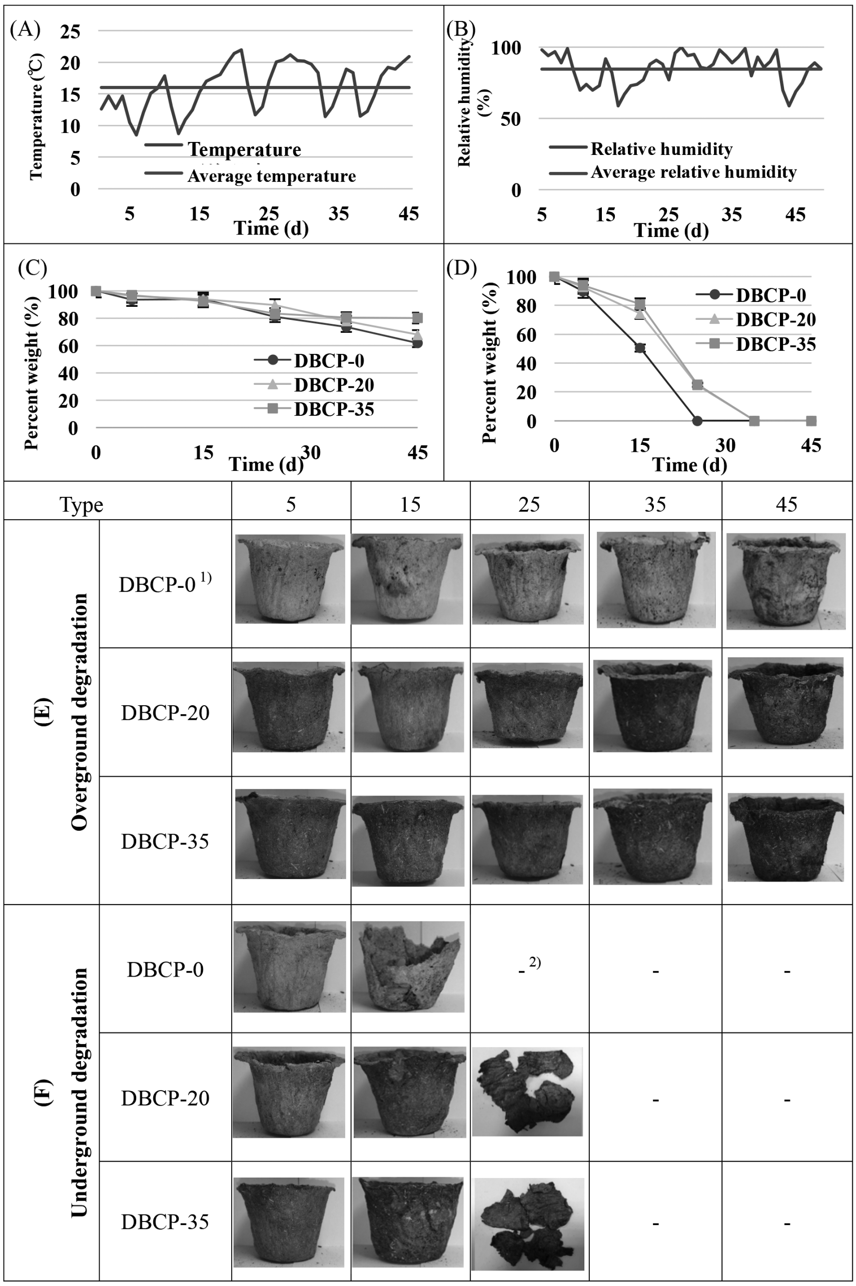

Fig. 2. Weather conditions, percent weight and appearance of degradable biochar plug in spring degradability test.
Note: 1) and 2) See Table 1 and Fig. 1.

the mean temperature was 16˚C, and the mean RH was about 85%.

As shown in Figure 2 (C), (D), the overground and underground degradation of DBCP decreased with time in spring. Before Day 15 of overground degradation, the three DBCPs had low percent weight, and degradation was slow, which might be due to the low air temperature. The temperature was high after 15 days, the percent weight decreased, and the degradation degree decreased intensely. The percent weight was 38.20, 32.10, and 19.91%, respectively, on Day 45. According to the underground test, the DBBP–0 degraded faster, and has been degraded completely on Day 25; while the case with SDRBC degraded slowly, the percent weight was 75.34 and 74.90%, respectively, and they were completely degraded after 35 days. According to the appearance of overground and underground degradation (E, F), the underground degradation degree was higher than overground degradation.

According to the comparison between winter and spring degradations, the DBCP–0 had the higher percent weight, while the case with SDRBC degraded slowly. The spring degradation was higher than winter degradation, which was due to the mean temperature, RH, rainfall and UV level. It is indicated that the overground degradation in winter and spring can maintain the shape, and degradation is slow, as the case in the soil gradually degrades. In addition, the CEC values (Table 1) of DBCP–0, DBCP–20, and DBCP–35 were 22.19, 21.56, and 29.78 cmol/kg, respectively. The overground DBCP degraded slowly, as its fertilizer retention property was performed during the plug seedlings to help the growth of seedling; moreover, the total nitrogen, effective phosphorus, and exchangeable potassium ion contents in DBCP might help the growth of seedling during the plug seedlings. Liew and Khor (2015) mix the biomass plastics and crushed newspaper in different proportions to prepare four kinds of biomass plugs, and planted leucaena (*Leucaena leucocephala*) seedlings in the plugs for 60 days' overground and underground degradation. The results show that the maximum percent weight is all over 30% on Day 28 of degradation, the percent weights are about 40 and 65%, respectively, on Day 45, and the percent weight of underground degradation is less than 100% on Day 60, which may also related to the effects of ants, termites, diplopods and snails in the soil.

Analysis of the strength and fertility index of DBCP after overground degradation

After overground degradation in winter, the dry strength of DBCP–0 decreased from 120.30 N before degradation to 18.57 N, while the dry strength after spring overground degradation decreased to 50.53 N, which were 0.15 times and 0.42 times that of the original strength (before degradation), respectively. The dry strength of DBCP–35 decreased from 136.50 to 12.23 N after winter overground degradation and to 56.76 N after spring overground degradation, which were 0.08 times and 0.42 times that of the original strength, respectively (Table 2). In comparison to the dry strength of spring overground degradation, the overground degradation of DBCP–0 and DBCP–35 in winter had a larger degree.

The fertility index after degradation was analyzed to evaluate the influence on the seedling and soil environment during the plug seedlings or after the seedling was transplanted into the soil. The fertility index analysis results after overground degradation in winter and spring are shown in Table 3. The fertility index of winter

Table 2. Dry strength of degradable biochar plug after overground in degradability test

DBCP – SDRBC (%)[1)]	Dry strength before degradability	Dry strength after overground in winter degradation (N)	Dry strength after overground in spring degradation (N)
DBP–0	120.30 (4.64) [a 2)]	18.57 (2.84) [b]	50.53 (9.30) [c]
DBP–35	136.50 (5.26) [a]	12.23 (2.62) [b]	56.76 (13.65) [c]

[1)] See Table 1
[2)] Results and the statistical analysis were from Table 1

Table 3. Fertility index of degradable biochar plug after overground degradability test in winter and spring

DBCP– SDRBC (%)[1)]		Total nitrogen (g/kg)		Available phosphorus (mg/kg)		Exchangeable potassium ion (cmol/kg)	
		before degradation	after degradation	before degradation	after degradation	before degradation	after degradation
Winter	DBP–0	3.35 (0.16) [aB 2)]	4.36 (0.30) [aA]	146.70 (3.77) [aA]	89.44 (21.47) [a3)B]	3.01 (0.09) [aA]	0.78 (0.09) [aB4)]
	DBP–20	5.37 (0.53) [bB]	7.56 (0.09) [bA]	373.83 (6.34) [bA]	174.51 (22.49) [bB]	5.17 (0.17) [bA]	1.38 (0.04) [bB]
	DBP–35	8.71 (0.88) [cB]	8.99 (0.15) [cA]	448.71 (6.60) [cA]	225.71 (20.54) [cB]	5.96 (0.12) [cA]	1.42 (0.18) [bB]
Spring	DBP–0	3.35 (0.16) [aB]	10.52 (0.33) [aA]	146.70 (3.77) [aB]	362.29 (42.48) [aA]	3.01 (0.09) [aB]	3.50 (0.22) [aA 4)]
	DBP–20	5.37 (0.53) [bB]	15.57 (1.36) [bA]	373.83 (6.34) [bB]	629.48 (41.08) [bA]	5.17 (0.17) [bA]	4.52 (0.45) [bB]
	DBP–35	8.71 (0.88) [cB]	21.50 (0.90) [cA]	448.71 (6.60) [cB]	755.28 (66.17) [cA]	5.96 (0.12) [cA]	5.35 (0.49) [cB]

[1)] See Table 1
[2)] Mean (standard deviation), with the different small alphabets abc for the specimen in the same season, with the different large alphabets ABC for the specimen with the same additive percent weight SDRBC, is significantly different (ρ <0.05) by Duncan's multiple range tests by Duncan's multiple range tests at 5% significant level

degradation was analyzed, the total nitrogen content was determined on Day 28 of overground degradation test, and the effective phosphorus and exchangeable potassium ion contents were determined on Day 21. In terms of spring degradation, the total nitrogen and exchangeable potassium ion contents were determined on Day 45 of overground degradation, and the effective phosphorus content was determined on Day 35. The DBCP–35 was higher after winter overground degradation, the fertility index increased with the addition percent weight of SDRBC, and there was significant difference. The winter overground degradation was compared with the case without degradation, there were significant differences among total nitrogen, effective phosphorus, and exchangeable potassium ion contents in the DBCP after degradation, the total nitrogen content after degradation was 1.30, 1.40, and 1.03 times that without degradation, and the effective phosphorus and exchangeable potassium ion contents decreased accordingly.

The fertility index of DBCP after overground degradation in spring increased with the addition of SDRBC. In comparison to the case without degradation, there was significant difference between the fertility indexes before and after the degradation of DBCP, the total nitrogen and effective phosphorus contents were increased by 3.14 and 2.46 times, respectively, and the DBCP–20 was increased by 2.89 times and 1.68 times, respectively; while the DBCP–35 was increased by 2.46 times and 1.68 times. According to the water absorption of DBCP, the water absorption rates of DBCP–0, DBCP–20, and DBCP–35 in the saturated state (after 48 h of immersion) were 355.88, 286.83, and 274.71%, respectively, while water absorption was 2–3 times that before water absorption. The exchangeable potassium ion content in the DBCP was compared with the case without degradation, and the content in DBCP–0 increased from 3.01 to 3.50 coml/kg; while the DBCP–20 and DBCP–35 decreased, they were higher than winter overground degradation.

In addition, spring degradation was different from winter degradation. The seedlings were irrigated with Peters Professional No. 8 instead of water every three days, with the exception of rainy days during the test, and the results showed that the total nitrogen and effective phosphorus contents in the DBCP after spring overground degradation were higher than the case without degradation and winter overground degradation. The exchangeable potassium ion content after spring overground degradation was slightly different from the case without degradation, but was higher than winter; thus, the DBCP with the addition of SDRBC might absorb the nutrients in the fertilizer solution.

CONCLUSION

This study prepared SDRBC at the carbonization temperature of 450°C and then mixed OCC and CM for developing DBCP, with basic properties, such as pH value, EC value, and CEC; application properties, such as dry and wet strengths, water absorption and water loss rate; and fertility indix, such as total nitrogen, effective phosphorus, and exchangeable potassium ion contents; overground and underground degradation properties in spring and winter; and the dry strength and fertility index after winter and spring overground degradations were analyzed, in order to evaluate the influence of the addition of SDRBC on DBCP, as well as the feasibility of biomass plugs for plug seedlings. The case with the addition of SDRBC had slight difference in pH value, and the results showed that the CEC, dry and wet strength, fertility index, degradability, and fertility index after degradation were better than the DBCP without the addition of SDRBC. The total nitrogen, effective phosphorus, and exchangeable potassium ion contents assisted the growth of seedling, as well as the preservation of fertilizer nutrients resulted in the DBCP with the addition of SDRBC. According to the degradation tests, overground degradation was slow, underground degradation was time–dependent, which had slight influence on the spread of the seedling root system. The SDRBC of DBCP can fix carbon, and then the carbon can be stored, as well as the soil fertility enhanced after it is degraded in the soil, which means that after the biomass plug containing biochar is degraded underground, the biochar can be stored in the soil for "carbon fixation". Therefore, the developed DBCP with the addition of SDRBC as the biomass plugs for plug seedlings has development potential.

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AUTHOR CONTRIBUTION

Han Chien LIN designed this research, performed the experiments and wrote the paper. Ruei–Yi JHAO assisted the experiments, analyzed the data and the statistical analysis. Noboru FUJIMOTO participated in the design of the study and supervised the works. The authors assisted in editing of the manuscript and approved the final version.

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