Suitability of biochar produced from copyrolysis of spent growing media and plastic grow bags in environmental applications

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Use of peat moss in horticultural GM

- Peat moss is the dark brown fibrous product of sphagnum moss and other organic materials that decompose in peat bogs over thousands of years
- Benefits of Peat Moss – clean and sterile, availability, moisture retention, have uniform composition
- Downsides of Peat Moss - virtually devoid of nutrients, acidic pH, nonrenewable resource

Physicochemical properties of different GM constituents

(AFP: Air filled porosity, WHC: Water holding capacity, BD: Bulk density)

GM constituents	pH	AFP	WHC	Dry BD g/cm^3
Sphagnum peat	3.5-4.5	12-20	70-80	0.09-0.17
Bark	5.7-6.4	16-26	30-34	0.16-0.23
Buffered coir	6.9-7.3	17-20	36-40	0.06-0.11
Green compost	7.5-8.2	5-15	36-46	0.23-0.52
Perlite	7.0-8.2	21-36	21-24	0.05-0.12

Peat extraction - sustainability?

- Peatlands
  - ~3% of the Earth's land surface
  - contain about 1/3rd of world's soil carbon
- Horticultural peat extraction facilitates GHG emissions
  - Current CO_2 emissions over 600 million tonnes per year


BBC NEWS

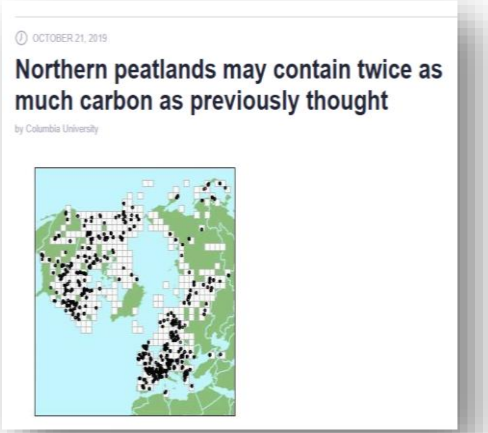
Science & Environment

Climate change: UK peat emissions could cancel forest benefits

By Roger Harrabin
BBC environment analyst

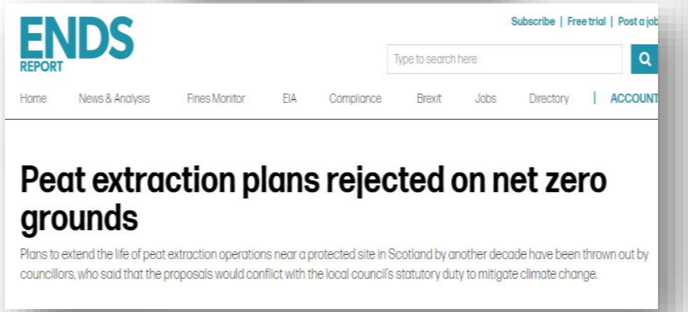
7 August 2020

Climate change


OCTOBER 21, 2019

Northern peatlands may contain twice as much carbon as previously thought

by Columbia University


ENDS REPORT

Peat extraction plans rejected on net zero grounds

Plans to extend the life of peat extraction operations near a protected site in Scotland by another decade have been thrown out by councillors, who said that the proposals would conflict with the local council's statutory duty to mitigate climate change.


HorticultureWeek

B&Q "not on track" to meet peat-free target

B&Q is at 43% of its target to sell 100% peat-free bagged growing media by 2020.

by Matthew Appleby

Biochar as a GM constituent

- Greater bulk density than peat, perlite and vermiculite
- Can be manufactured in different particle sizes
- High SSA, CEC, EC and pH (liming potential)
- Black in color
- Physicochemical properties depend on the feedstock composition and pyrolysis process conditions

Biochar feedstock	Production temperature (ºC)	pH (1:20)	EC (dS/m)
Digestate	700	10.18	1.85
Pine chips	400	7.38	0.09
Wheat straw	700	10.13	2.22
Wheat straw	550	10.23	1.32
Mixed soft wood	550	8.45	0.13
Greenhouse (tomato) waste	550	9.65	13.80
Poultry litter	550	9.51	2.29

Image source: https://www.researchgate.net/profile/WeiYin_Chen/publication/281066004/figure/download/fig3/AS:542529613295616@1506360547416/Illustration-of-normal-and-biochar-based-carbon-cycles-Lehmann-2007-Copyright-2007.png

Feedstock material

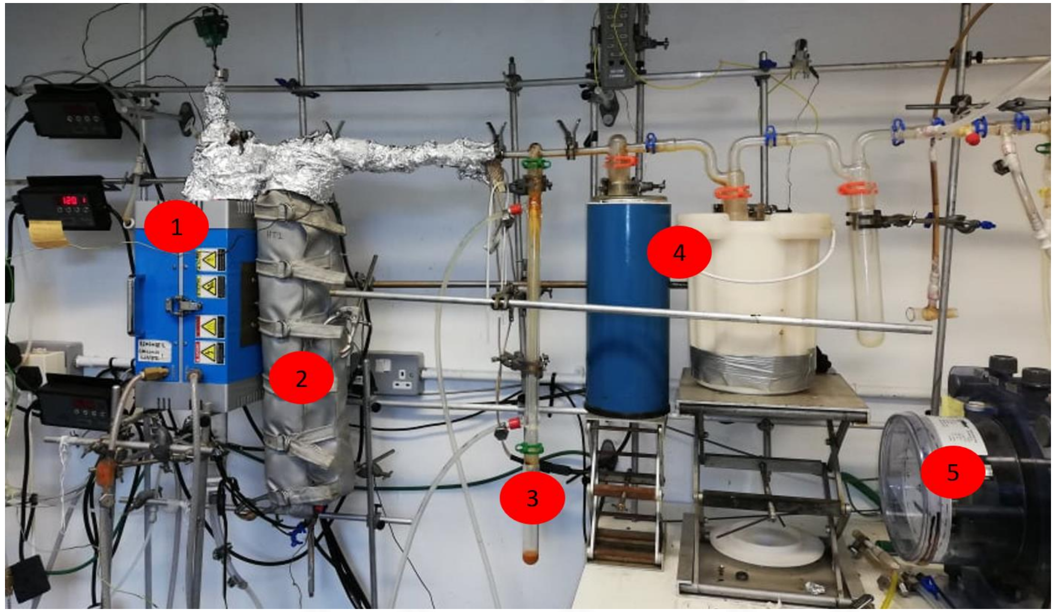
- Feedstock material: Spent strawberry growing mediums and plastic grow bags



Spent strawberry growing mediums used in this study

Biochar production

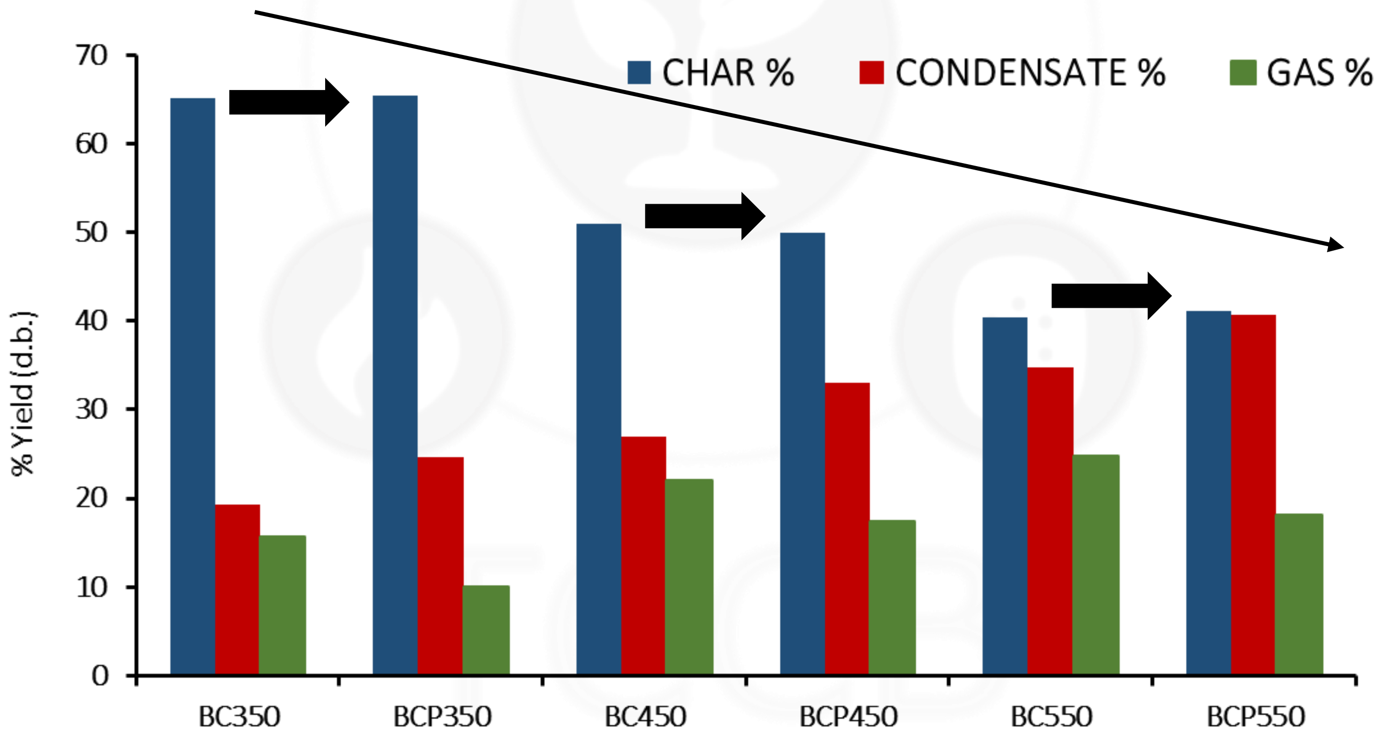
- Heating rate of 25 °C/min and residence time of 30 min
- At 350 °C, 450 °C, 550 °C
- 6 types of BC with (BCP) or without 2.5 % (d.b.) plastic addition



Stage 1 pyrolysis unit at UKBRC (1. gold Image furnace 2. tar collection 3. condensable liquids 4. cold traps, 5. flow meter)

Pyrolysis product yields

- The higher the temperature; less char, more oil and gas
- No significant effect of plastic in the feedstock on char yield; but effect on liquid and gas production: Condensate ↑ Gas ↓



Percentages of pyrolysis product yields (d.b.) under different pyrolysis conditions

PTEs and phytotoxicity of biochar samples

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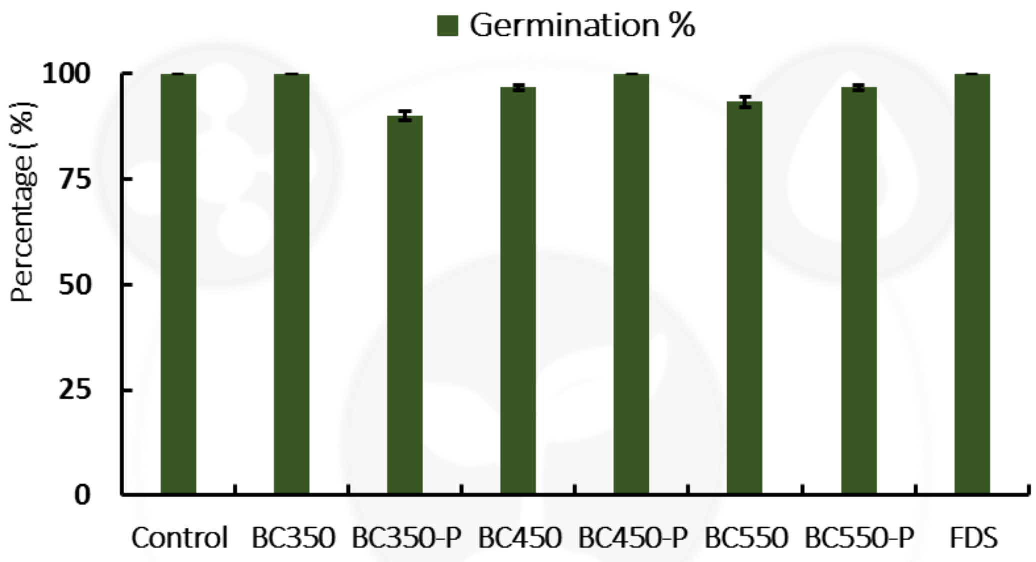
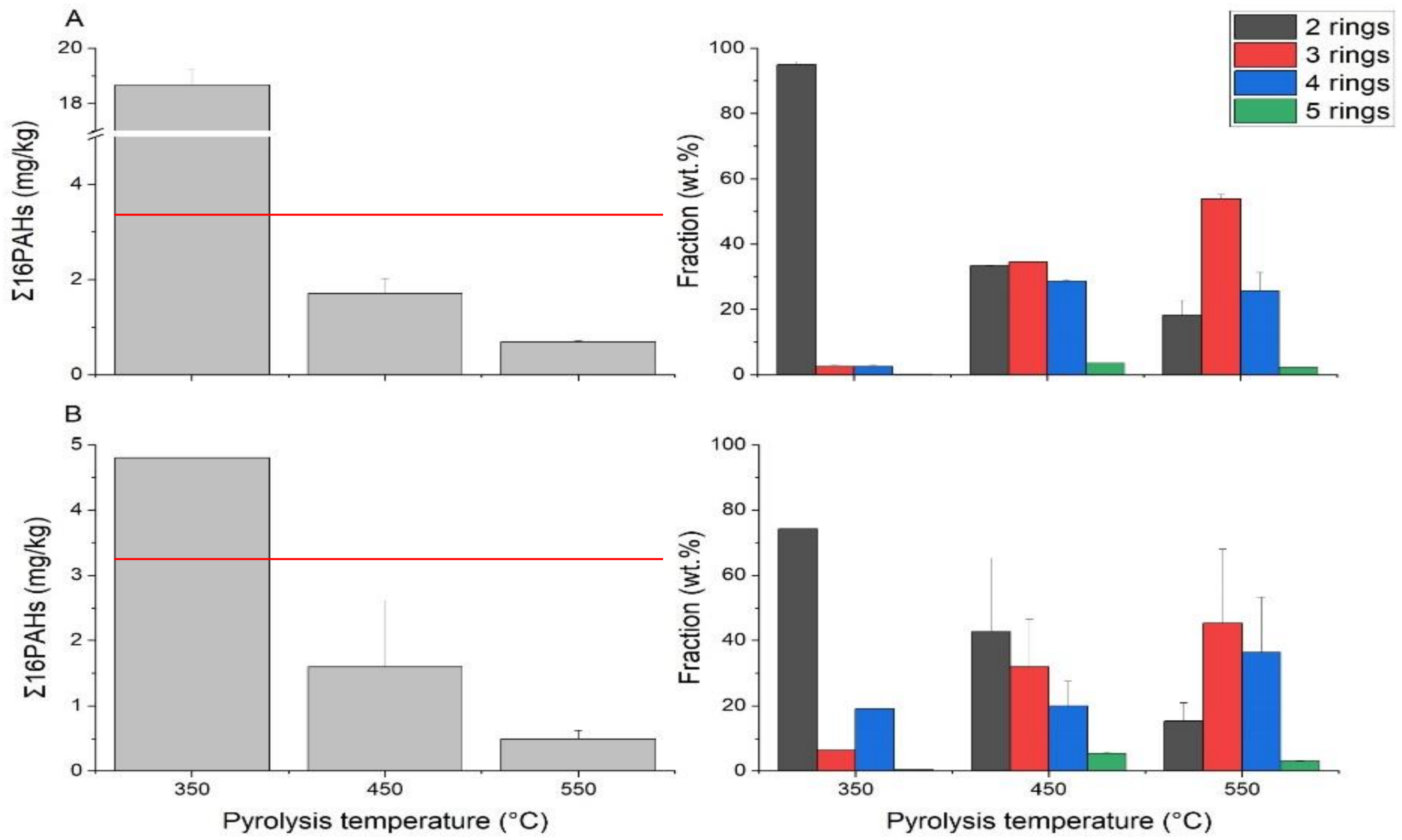


Germination % of Cress seeds among different treatments

PTEs in biochar samples

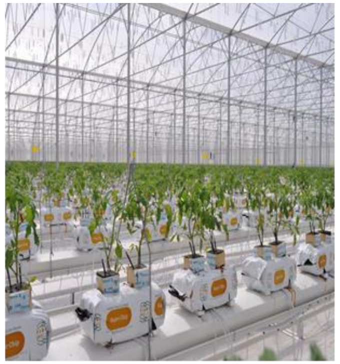
Sample type	Cr	Co	Ni	Cu	Zn	As	Mo	Cd	Pb
BC350	3.22 ± 0.64	0.65 ± 0.12	2.08 ± 0.20	27.92 ± 2.72	18.87 ± 4.57	1.28 ± 0.09	25.96 ± 5.29	0.06 ± 0.01	9.30 ± 1.07
BCP350	2.92 ± 0.06	0.84 ± 0.10	2.94 ± 0.77	22.28 ± 0.72	39.86 ± 3.33	0.96 ± 0.13	25.76 ± 0.91	0.07 ± 0.01	9.72 ± 0.37
BC450	4.20 ± 0.16	0.85 ± 0.01	2.93 ± 0.02	26.69 ± 0.21	15.92 ± 0.23	1.66 ± 0.08	32.14 ± 0.15	0.09 ± 0.01	11.30 ± 0.19
BCP450	3.29 ± 0.22	0.80 ± 0.02	2.45 ± 0.14	24.92 ± 0.43	41.29 ± 4.93	1.20 ± 0.13	32.84 ± 0.49	0.14 ± 0.09	13.61 ± 0.45
BC550	4.90 ± 0.68	1.00 ± 0.02	3.04 ± 0.03	32.27 ± 0.49	20.01 ± 0.94	1.37 ± 0.04	37.29 ± 0.35	0.15 ± 0.00	15.46 ± 3.15
BCP550	4.33 ± 0.33	1.01 ± 0.21	3.01 ± 0.58	28.20 ± 1.11	42.63 ± 6.01	1.02 ± 0.07	33.72 ± 0.97	0.15 ± 0.02	16.83 ± 0.20
IBI threshold	64-100	40-150	47-600	63-1500	200-2800	12-100	5-75	1.4-39	70-500

PAHs in biochar samples



Sum of 16 US EPA PAH concentrations of biochars and their fractions

Scale-up biochar production



Biochar for horticultural growing media

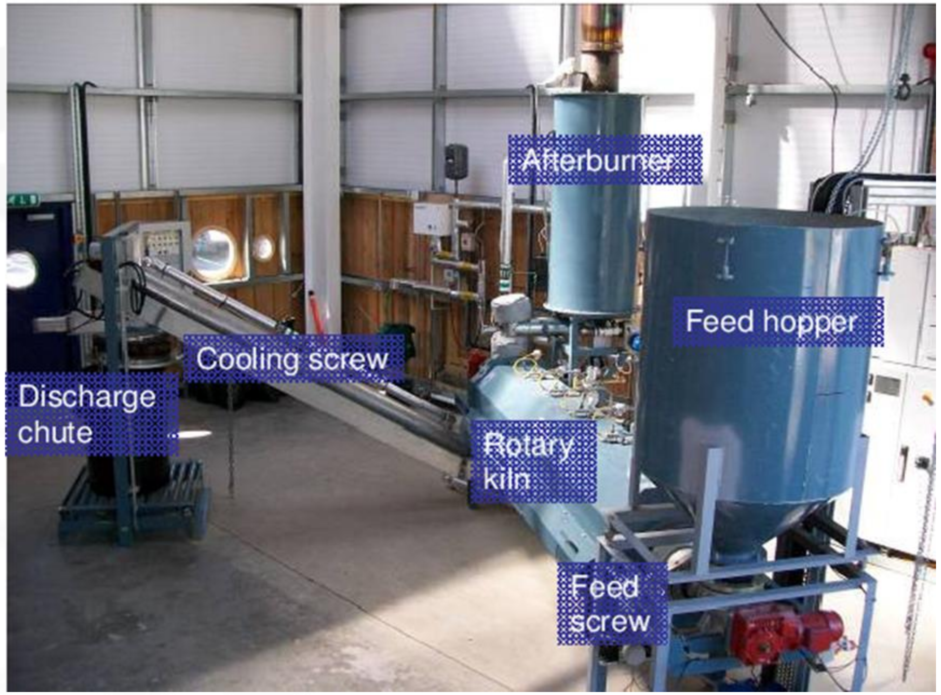
Two types of biochar (BC & BCP)

Syngas and pyrolysis oil

(heat and electricity production)

Greenhouse waste

Slow pyrolysis at 550 °C



Feedstocks:
1. Exhausted growing medium waste with plastic grow bag
2. Exhausted growing medium waste without plastic grow bag

Chemical characterization of biochar

Parameter	Unit	BC	BCP	IBI threshold
VM	% (d.b)	22.30±1.11	24.57±1.38	
Ash	% (d.b)	32.66±1.17	27.62±2.23	
FC	% (d.b)	45.04±1.32	47.81±1.14	
C	% (d.b)	55.74±0.19	59.16±1.11	
H	% (d.b)	1.82±0.12	2.22±0.18	
pH (1:10)	-	9.8 ± 0.1	8.5 ± 0.2	
EC	µS/cm	670.0 ± 6.0	589.7 ± 7.8	
N	% (d.b)	1.56±0.02	1.27±0.05	
P	g/kg	0.67±0.21	0.54±0.11	
K	g/kg	1.62±0.15	1.51±0.13	
Mg	g/kg	5.21±1.52	4.34±0.15	
Ca	g/kg	39.45±1.64	37.28±4.27	
Fe	g/kg	1.36±0.08	1.48±0.06	
Mn	mg/kg	42.16±5.98	45.83±9.84	
Cr	mg/kg	6.77±1.34	7.82±1.67	64-100
Cd	mg/kg	1.78±0.41	1.95±0.53	1.4-39
Pb	mg/kg	15.46 ± 3.15	16.83 ± 0.20	70-500
Ni	mg/kg	3.59±0.07	3.21±0.22	47-600
Cu	mg/kg	43.12±6.85	45.85±3.72	63-1500
Zn	mg/kg	37.76±4.87	38.61±5.73	200-2800
Σ16 US EPA PAHs	mg/kg	0.69±0.03	0.49±0.13	6-20
TTEC	mg/kg	0.02±0.00	0.02±0.00	<3

- BC – high ash, pH, EC and nutrients
- BCP- high C, H, low pH, EC and nutrients
- PTE – BCP>BC; lower than the IBI thresholds
- PAH – BC>BCP; lower than the IBI thresholds
- TTEC – Lower than the IBI thresholds

Substrate formulation and PSD

	% volume basis (v/v)			
	BC	BCP	Peat	Perlite
Control	0	-	70	30
BC23	23	-	47	30
BC35	35	-	35	30
BC47	47	-	23	30
BCP23		23	47	30
BCP35		35	35	30
BCP47		47	23	30

- <0.25 mm particles – increased with the BC content
- >2 mm particles – decreased with the BC content
- Particles in the range of 0.25 mm-2 mm – increased with the biochar content

Size fraction (mm)	Percentage fraction										
	BC	BCP	Peat	Perlite	Control	BC23	BC35	BC47	BCP23	BCP35	BCP47
<0.25	54.1	45.5	17.6	1.7	13.5	39.2	40	42.5	18.2	22	26.8
0.25-2	44.4	48.3	47.2	24.8	38.3	47.2	49.9	50.3	48.1	53.4	53.5
>2	1.5	6.2	35.3	73.5	48	13.7	10.2	7.1	33.9	24.6	19.6

Physicochemical properties of formulated substrates

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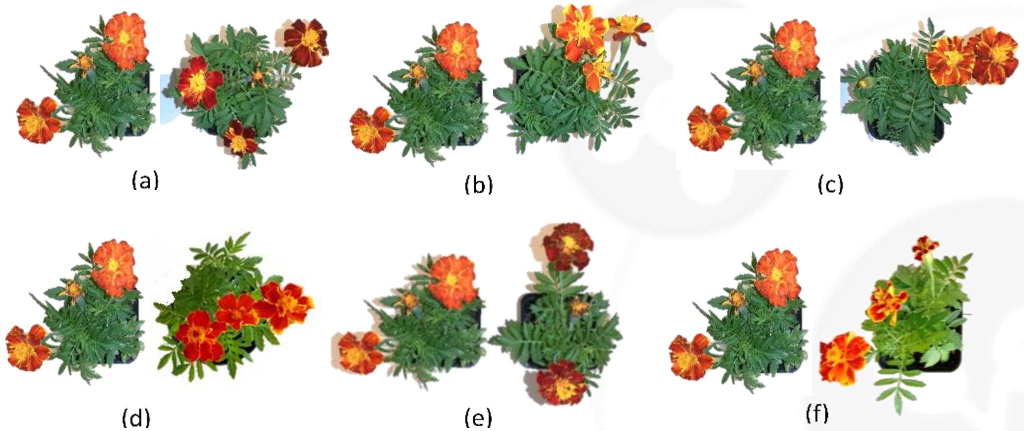
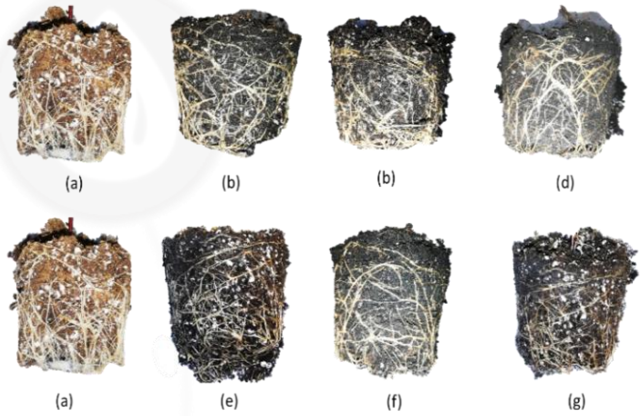
- pH, EC, and dry BD increased with the BC content
- AFP and WHC reduced with the BC content
- No phytotoxicity observed

	Growing medium formulations							
Parameters	Control	BC23	BC35	BC47	BCP23	BCP35	BCP47	Optimum level
Dry bulk density (g/cm^3)	0.10	0.14	0.15	0.17	0.13	0.16	0.18	0.4
Water holding capacity (%, db)	68.1	54.0	51.5	47.2	55.2	50.6	44.9	60 - 100
Air filled porosity (%, db)	12.5	10.9	9.7	7.2	11.7	8.5	7.6	10 - 30
Total porosity (%, db)	80.6	65.1	61.2	54.4	66.9	59.1	52.5	50 - 80
pH (1:5)	5.8	7.9	8.6	8.9	7.6	7.9	8.1	5.5 – 6.5
EC (1:5) µS/cm	283.2	407.3	490	569.7	390.7	462.7	569.3	<500
Germination rate (%)	100	100	100	100	100	100	100	100

Plant growth in different substrate formulations





Flower growth in different substrate formulations (a) Control vs BC23 (b) Control vs BC35 (c) Control vs BC47 (d) Control vs BCP23 (e) Control vs BCP35 (f) Control vs BCP47.

Root growth (root balls) in different substrate formulations (a) Control (b) BC23 (c) BC35 (d) BC47 (e) BCP23 (f) BCP35 (g) BCP47.

Biochar ratio	Number of flowers		Weight of flowers (g)		Shoot weight (g)		Root weight (g)	
	BC	BCP	BC	BCP	BC	BCP	BC	BCP
control	2.4 ± 0.9^{a}	2.4 ± 0.9^{a}	2.0 ± 0.8^{ab}	2.0 ± 0.8^{ab}	7.5 ± 0.3^{b}	7.5 ± 0.3^{b}	3.2 ± 0.4^{b}	3.2 ± 0.4^{c}
23	2.8 ± 0.8^{aA}	2.6 ± 0.5^{aA}	2.7 ± 0.1^{aA}	2.7 ± 0.1^{aA}	10.0 ± 0.7^{aA}	9.5 ± 0.2^{aA}	4.6 ± 0.5^{aA}	4.8 ± 0.3^{aA}
35	2.0 ± 0.0^{aA}	2.4 ± 0.5^{aA}	1.9 ± 0.6^{abB}	2.8 ± 0.2^{aA}	8.4 ± 0.5^{abA}	8.8 ± 0.5^{abA}	5.0 ± 0.5^{aA}	3.9 ± 0.3^{bcB}
47	2.2 ± 0.4^{aA}	2.4 ± 0.5^{aA}	1.7 ± 0.4^{bA}	1.5 ± 0.3^{bA}	7.8 ± 1.1^{bA}	7.6 ± 1.5^{bA}	4.2 ± 0.6^{aA}	4.4 ± 0.7^{abA}

Conclusions

- The investigated plastic level (2.5%) and plastic type (LDPE) in the feedstock and selected pyrolysis process conditions could produce biochar with less contaminants than the thresholds imposed by IBI.
- Both BC and BCP biochars can be used to replace peat up to 35% without compromising Marigold flower growth.
- Therefore, spent growing medium waste alone and together with waste grow bags (under the investigated plastic level in the feedstock in this study) can be used as a feedstock to produce biochar and that biochar can be effectively used for replacing peat in horticultural growing media without imposing any adverse impact on plant growth.

Acknowledgements

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- Academic and industrial partners:

Thank You!

Make carbon green again…

Sample type	Volatile matter (%. d.b.)	Fixed carbon (%. d.b.)	Ash content (%. d.b.)	pH (1:20)	EC (µS/cm) (1:20)
BC350	41.9 ± 1.8[a]	33.2 ± 1.2[c]	25.1 ± 1.5[c]	8.5 ± 0.0[d]	374.5 ± 6.4[c]
BCP350	41.3 ± 0.2[a]	34.1 ± 0.4[c]	24.7 ± 0.3[c]	8.3 ± 0.1[e]	329.5 ± 9.1[d]
BC450	30.6 ± 0.6[b]	39.8 ± 0.7[b]	29.6 ± 0.1[b]	10.3 ± 0.1[b]	444.0 ± 9.9[b]
BCP450	30.3 ± 1.5[b]	40.6 ± 1.7[b]	29.1 ± 1.2[b]	10.1 ± 0.0[c]	375.5 ± 8.9[c]
BC550	21.1 ± 1.2[c]	45.1 ± 1.8[a]	34.1 ± 0.6[a]	10.5 ± 0.1[a]	480.5 ± 10.6[a]
BCP550	21.2 ± 0.3[c]	45.6 ± 0.2[a]	33.4 ± 1.1[a]	10.3 ± 0.0[b]	454.5 ± 10.0[ab]
SGM	58.2 ± 2.4	22.1 ± 1.6	19.7 ± 3.1	6.5 ± 0.3	172.0 ± 9.5
GB	92.5 ± 0.3	0.4 ± 0.2	7.1 ± 0.1	nd	nd