Biochar, chemical characterization, nutrient effects, dynamics and preliminary plant growth tests

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Abstract
Four commercial grade biochar were evaluated as peat substitute. We characterised these biochars for plant nutrients and for biological stability. The results showed that there were negligible quantities of N and P and generally high levels of K and high biological stability. When these materials were mixed with peat at 10, 25 and 50 % and nutrients were added to bring them to the same level of nutrients as in fertilized peat, it was found that biochar mixes considerably reduced the levels of calcium chloride/DTPA (CAT) extractable N (including nitrate), P, and electrical conductivity– greater extent with higher rates of biochar addition except for K. Generally there was increase in pH and reduction of EC and extractable nitrate, ammonium and EC The drop in EC has important implications regarding the use of other materials used to dilute peat, for example, composted green waste as the rate of dilution is limited due to high EC and biochar addition gives the potential for higher peat dilution. Root development using Cress test and tomato plant height and biomass using containers, were in some cases better peat indicating it could be used to dilute peat e.g. for seedling where root development is very important. Application of biochar resulted in a big reduction of nitrogen (and phosphorus) in the plant, but not to the extent as predicted by CAT extractable N. However, there were very significant correlation between CAT extractable N and P and corresponding plant concentration, indicating the standard growing media test, CAT, would be suitable for assessing the nutrient status of peat biochar mixes.

Keywords: Biochar, peat, seed germination, tomato, CAT extractable nutrient, biological stability, nutrient dynamics

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Introduction

Biochar, a carbonaceous solid product of pyrolysis (thermal decomposition in absence of oxygen) of organic materials such as biomass has progressively been receiving increasing attention. This is due to several factors, such as it is one of the very few technologies that can actively remove carbon (C) from the atmosphere, and it is suitable for a range of environmental, agricultural and horticultural applications (Dumroese et al., 2011). Thus, biochar has attracted widespread interest as a growth medium amendment that enhances cation exchange capacity (CEC), nutrient and water retention, and that neutralizes acidity (Karami et al., 2011; Sun et al., 2012). It has been shown that biochar characteristics are influenced by production variable such as feedstock, temperature, and residence time. It is an option for climate change mitigation via C sequestration and promotion of resource efficiency. It is energy self-sufficient and/or energy positive for getting syngas and biofuel. Biochar has been successfully produced from among other things by municipal waste e.g. garden and park waste, agricultural wastes e.g. straw, food waste, digestate, and even sewage sludge.

Peatlands are valuable habitats and may provide environmental services such as biodiversity, regulation of the local water quality and local hydrology conditions including flood protection. They are also considered important C sinks, but as soon as a peatland is drained, aerated, limed and fertilized or when its peat is extracted, its organic matter decomposes quickly and turns into a source of greenhouse gases. Peat is the principal material for growing media in Europe and peat production in Europe is more than 40 million m^3. Almost all the peat is produced in northern Europe and is transported long distances e.g. Cyprus. Peat is a standard by which other growing media is compared. Biochar probably has the potential for reducing peat usage/replacement and affecting positive plant yield. Although a mean yield increase of 10% has been reported, averaging different crops, soils and climates (Jeffery et al., 2011) it is also well known that “all biochars are not created equal” (Amonette et al., 2009) and as a consequence the effects on crops are both biochar specific and site specific (Mukherjee and Lal, 2014). In order to better understand this complexity, more studies are required before introducing the biochars strategy among the common agricultural practices (Lorenz and Lal, 2014). All these papers relate to biochar application in soil *in situ.* There is very little published information on the use of biochar as peat replacement (Drumroese et al., 2011; Steiner and Harttung, 2014; Mendez et al., 2015) and some of the work that has been carried out has been done on an *ad hoc* basis. A desk study was conducted to look at a feasibility of biochar as growing media (Sohi et al., 2013). On top of that, there is lack of information on biochar characterization either on its own or when mixed with peat using tests developed specifically for growing media e.g. peat, compost. Recently European Committee for Standardization (*CEN*) has developed methods specifically for growing media. Information on the performance and changes in nutrient in peat biochar mixes using *CEN* tests is almost non-existent.

The objective of the current study was a) to characterize the materials, b) to evaluate the effect of biochar addition in peat on extractable nutrient content and on nutrient dynamics over a short period, c) to evaluate four biochars produced commercially in Europe as a peat diluent (growing media) as evidenced by plant growth e.g. germination and root development and short term plant growth, d) to evaluate the effects of biochar addition in peat on plant nutrient content and finally e) evaluate if the *CEN* tests for growing media (peat, compost etc.) are suitable for peat/biochar mixtures. No attempt was made here to look at the physical effect of biochar on peat.

Material and Methods

Biochars material

The current study took place at Bord na Mona, Ireland. Four commercial grade biochar, one from Switzerland (A) and three from Germany (B, C, and D) were used in these trials. The four biochars had the following feedstocks: A = woodchips, B = wood screenings from tree branches, C=Forest wood, beech, spruce, ash etc. and D= husks and paper fibre. Exact info of their production details are not known due to commercial sensitivity. A good quality commercial grade H_4-H_5 on von Post scale peat was used as a control and as primary material to which the biochar was added. The four biochar materials were characterized for pH, Electrical Conductivity (EC), and calcium chloride/DTPA (CAT) extractable NH_4-N, NO_3-N, total extractable N (NH_4-N+NO_3-N), P, K and Oxygen Uptake Rate (OUR) (Table 1).

Experimental setup

In the first experiment the biochars were added at the rates of 10%, 25% and 50% to the peat. Then mixtures were brought to N, P and K levels to 170 mg/L as ammonium nitrate, 70 mg/L as triple superphosphate and 100 mg/L as potassium sulphate respectively of peat biochar mixtures and of limed peat by dolomitic lime (4 g/L). Account was taken of the CAT extractable N, P and K that came from the biochars and fertilizer levels were adjusted accordingly. In most cases there were almost negligible amount of N, some P and excess of K. Where K was in excess, no K was added into the mixture. In the first experiment the moistened samples at around 60% moisture was left for a week and a subsample was taken to analyse for pH pr *EN*13037, Electrical conductivity pr *EN* 13038, NH_4-N, NO_3-N, P and K using the CAT extraction pr *EN* 13651 and autoanalyzer Lachat. Subsamples were taken again at 6 and 14 weeks in order to study the dynamics of pH, EC and extractable NH_4-N, NO_3-N, P and K. Samples were also analysed for phytotoxicity using the pr *EN*16089 method. Germination rate and root length was measured. Growing trials was carried out in a heated glasshouse in plastic trays and pots. In the first trial 10 tomato seeds were sown in 10 modules (1.5cm x 1.5 cm) (one seed per module*)* on 28th August. The two tomato trials were grown for 4 ½ weeks and 5 ½ weeks respectively, and plant height was measured.

In the second experiment the same materials were used and treatment were similar as in the first experiment, but substrate was analysed only at week one for pH, EC, NH_4-N, NO_3-N, P and K using the CAT extraction. Growing trials were carried out in a heated glasshouse and seedlings were grown in pots (10 cm) with 3 replicates. Fresh and dry weights were measured after about 5 weeks of growth. Plant mineral analysis was carried out on the whole tomato plants after acid digestion using standard methods.

Statistical analysis

Statistical analysis was carried out in fresh weight and dry weight and on the nutrient content. Extractable N, P and K were regressed against dry weight and N, P and K in the whole plant in order to assess the suitability of these tests for biochar. Data were tested for normality, and then subjected to analysis of variance (ANOVA). Significant differences between mean values were determined using Duncan's Multiple Range test following one-way ANOVA. Statistical analyses were performed using SPSS (SPSS Inc., Chicago, Ill.).

Results and Discussion

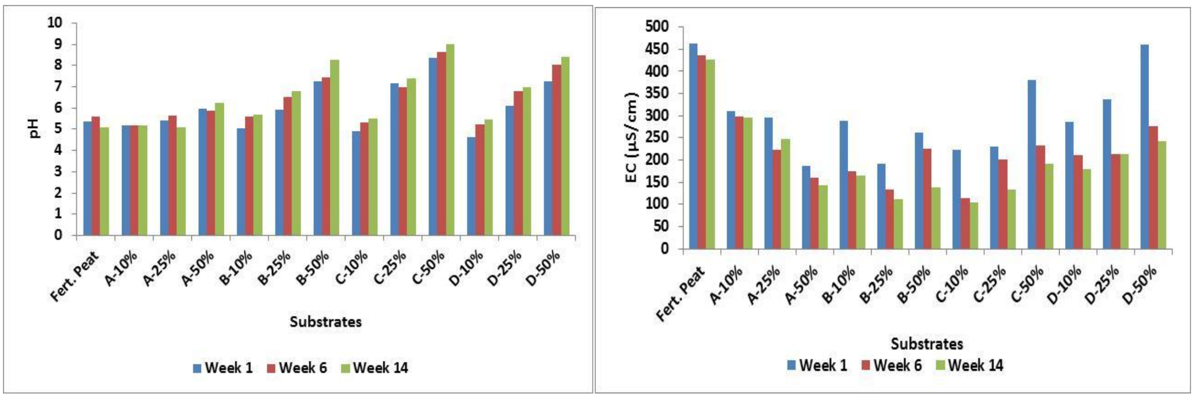
The Biochar samples had in general very high pH (averaged 8.78) and high levels of EC (averaged in 439 µS/cm) except of the Biochar A, which revealed pH of 6.58 and EC of 55 µS/cm (Table 1). EC is an important property for the use of materials as growing media, as form one point EC can be nutrient supporting value while from the other point salinity represents the main limiting factor for seed emergence and germination as well as plant growth (Bustamante et al., 2008). Similarly K levels were very high (ranged from 671-990 mg/L) except for Biochar A. Commercial Biochars (A-D) contained P which was ranged from 3-11 mg/L whereas peat had almost zero P content. There was negligible extractable N in peat and biochars. These results indicate that at least same amounts of N and P that is added to peat need to be added to all 4 biochars and on 3 cases (Biochar

B, C and D) there would be no need to add K. The Oxygen Uptake Rate (OUR), an indicator of biological stability of compost and peats, was very low in relation to compost and peat respectively. Compost is considered stable when the OUR value is 13-15 mmol O_2 kg $^{-1}$ OM hour (Prasad et al., 2010). Thus biochar can be used as a structure builder of growing media when mixed with unstable constituents e.g. woodfiber.

The effects of different ratio (10-25-50%) of biochar into peat-based substrates are presented in Fig. 1. The addition of biochar to fertilized peat increased the pH particularly at the higher rate and there was a very slight tendency of the biochar treatments to increase the pH over time except for limed peat and peat + biochar indicating the need for no lime or smaller quantity of lime on peat biochar mixes. The addition of biochar greatly reduced the EC of the peat/biochar mixtures and this was particularly noticeable at the later sampling for Biochar B and C. At highest rate for Biochar C and D there was little or no change in relation to peat at first sampling. To the authors knowledge this reduction of EC as a result of biochar addition has not been reported before in literature. This result has important implications as materials normally used for peat dilution have often high EC e.g. composted green waste. Such materials could be used at higher rate if biochar was also added as high EC is very often the limiting factor regarding the addition. These results when put in practice would reduce peat usage. Similarly NH_4-N was reduced at the first sampling and there was a general reduction of NH_4-N at later sampling (data not presented). This effect was most pronounced with peat at the last sampling and this was probably due to nitrification as NO_3-N increases in the last sampling. At higher rates of biochar application there was a marked reduction in NO_3-N in the first and second sampling. Higher rates reduced it further except for Biochar C. It seems that it is not only the biological immobilization of N as the OUR results indicate a very biologically stable material. This trend is also reflected in reduction of total extractable N (NH_4-N, NO_3-N) with greater effects were marked at higher biochar ratio (i.e. 50% v/v). There was a marked tendency of extractable P to be reduced with biochar addition especially at higher rates and at first and second sampling. This P tendency was not found for Biochar B, C and D at 50%. This is the first time it has been reported that the addition of biochar in growing media leads to a reduction of nitrate, and P and further study is required to explain the mechanism which undergoing. Kammann et al. (2015) reported decrease in nitrate when biochar is added during composting of organic municipal waste while Prendagast-Miller et al. (2014) also reported nitrate capture in soil. In contrast to reduction of P as a result of biochar application in peat soil available P increased in biochars amended plots, which is associated to the positively charged sites in biochars that increase soil capacity to retain and exchange phosphate ions (De Luca et al., 2009; Major et al., 2009). The mechanism suggested was that biochar can reduce the activity of cations that interact with phosphate (e.g., Al^{3+}, Fe^{3+} and Ca^{2+}), by adsorbing them on its surface and, therefore, delaying phosphate adsorption and/or precipitation in the soil (De Luca et al., 2009; Xu et al., 2013).The explanation for this apparent anomaly is that Al, Fe occur at very low levels. As expected K levels increased with increasing rate of biochar addition with the exception of Biochar A which had low levels of extractable K. Sampling date had less effect except at high rate.

Table 1. Nutritional status of different mixtures consisted of commercial peat-P and different biochar (A-D).

	pH	**EC (µS/cm)**	**NH_4-N (mg/L)**	**NO_3-N (mg/L)**	**N (mg/L)**	**K (mg/L)**	**P (mg/L)**	**OUR mmol O_2 kg $^{-1}$ OM hour**
A	6.58	55	0	1	0	25	3	1.1
B	9.55	410	1	1	2	671	8	2.6
C	9.51	638	1	1	2	990	3	2.3
D	9.51	652	1	1	1	891	11	4.4
Unfertilized Peat-FP	3.13	34	17	3	22	8	0	5.5



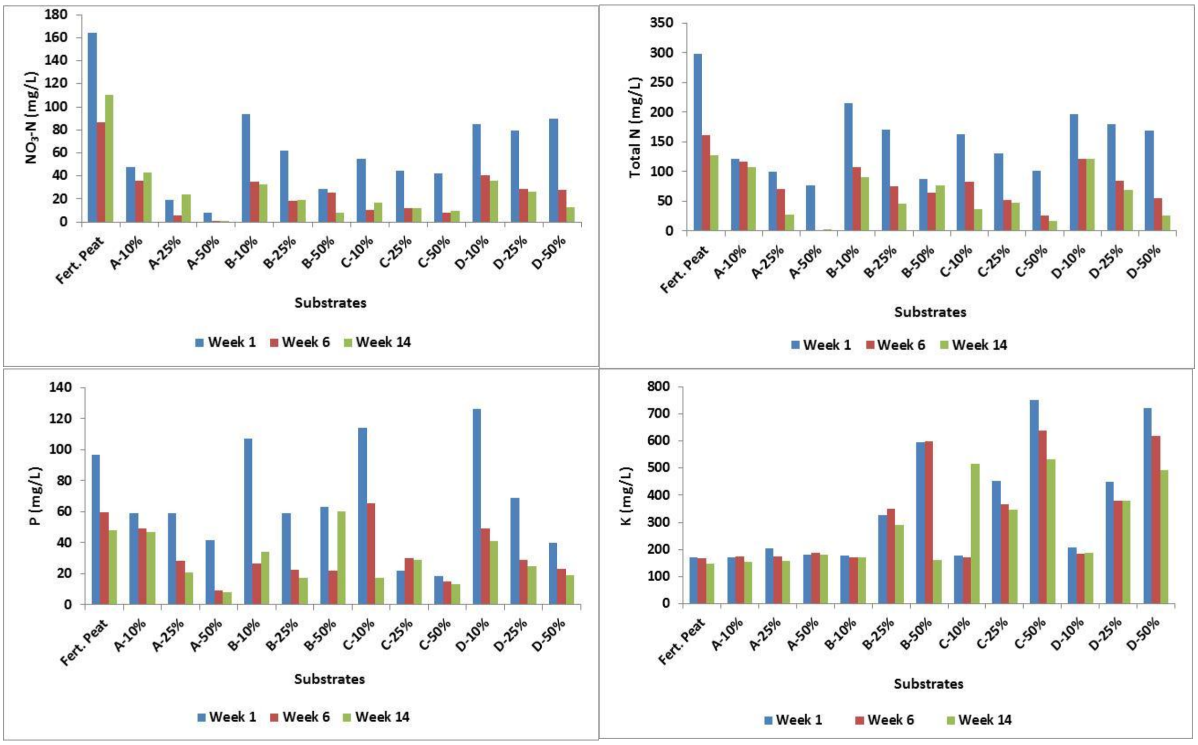


Figure 1. Effect of different mixtures consisted of commercial peat-P and different biochar (A-D) on substrate pH, EC and nutrient content.

The different mixtures consisted of commercial peat-P and different biochar (A-D) on phytotoxicity was also examined using the *CEN* test. The phytotoxicity cress test showed 100% germination in all treatments (results not presented), indicating that the examined biochars could be considered as phytonutrients or phytostimulants (Nieto et al., 2016). The increasing levels of biochar negatively affected the root length which was impeded. However, in many cases the addition of biochar at 10 and 25% improved the root length and this was most noticeable at Biochar A and C at 25% and B at 10%. Thus the addition of small amounts of biochar in growing media could be useful for specialized seedling growing, acting as stimulant to root length. This may have increased interest as growth promoter during seedling propagation under nursery condition, but further study is needed before final conclusions and commercialization. Robertson et al. (2012) also reported better forest seedling growth where biochar was mixed into forest soils.

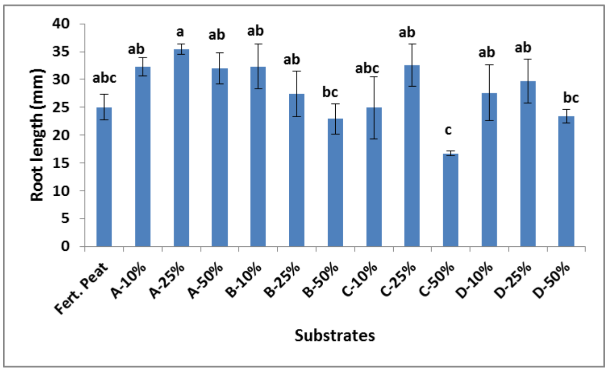


Figure 2. Effect of different mixtures consisted of commercial peat-P and different biochar (A-D) on cress root length. Values represent mean (±SE) of measurements made on ten seedlings per treatment. Values columns followed by the same small letter are not significantly different, $P \leq 0.05$.

Under heated glasshouse condition, in the first trial, tomato seedlings were examined regarding the plant growth and mineral content. Thus, plant height was measured at two dates showed a slight depression of height at the Biochar 50%-based substrates at each measurements and this generally more pronounced at later dates. However, at a later date there was a better plant growth based on seedling height at Biochar A, C and D 10% and at 25% with Biochar C at 25%.

In the second trial, employing exactly the same treatments and biochar materials were used as in the first trial. Peat and peat biochar samples were taken for analysis after one week. The results showed highly significant correlation with the previous CAT result of early sampling in the first experiment. For instance the trends were similar as regards EC and NO_3-N and total N (NH_4-N + NO_3-N) and P reduction and increase of pH and K. The correlation coefficient R^2 between the first sampling from the first experiment and the sampling from the second experiment were 0.91; 0.75; 0.76; 0.96 and 0.93 respectively.

There was no significant difference in the fresh weight between the peat control and the biochar treatments in Trial 2. There was a trend, however towards a reduction of fresh weight with increasing rate of biochar application except for Biochar D where there was an increase in fresh weight from 10% to 25% mixtures. Treatment B at 10% gave the best growth. Similarly, the dry weight showed no significant differences except for D at 10% where it outperformed peat. The same trend of reduced dry weight with increasing rate of biochar was also evident. Longer term growing trial is now required using peat/biochar mixes to confirm some of these positive results. .Mendez et al,. 2015 also found that lettuce grew better in peat biochar mixture than 100% peat but it appears that the peat they used was of inferior quality as evidenced by high ash content and very low air space.

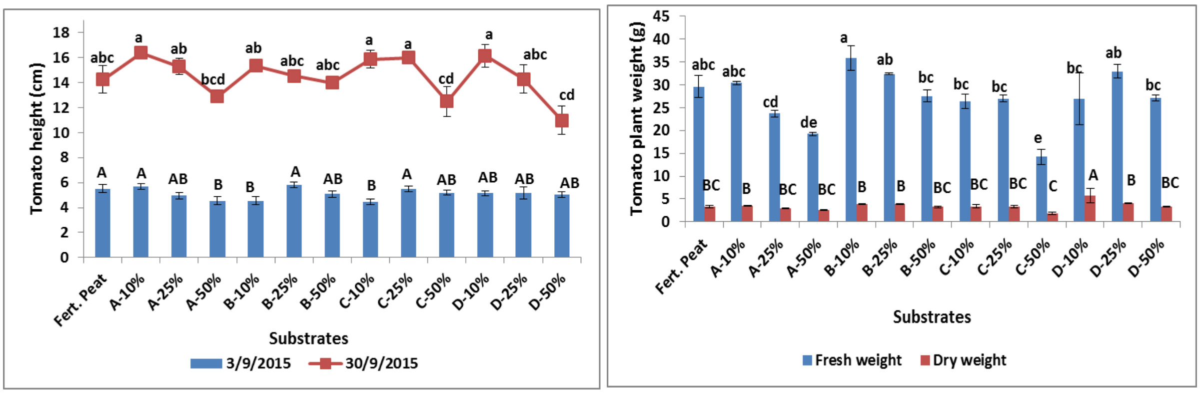


Figure 3. Effect of different mixtures consisted of commercial peat-P and different biochar (A-D) on tomato plant height (cm) (Trial 1) and fresh and dry weight (g) (Trial 2). Values represent mean (±SE) of measurements made on ten plants per treatment. Values columns followed by the same small or capital letter are not significantly different, $P \leq 0.05$.

Considering the analysis of l whole tomato plant growing in different media, there was a general decrease in the N content with increasing rates of biochar with the exception being Biochar B and Biochar C at 25% (Table 2). Increasing rates of biochar also reduced P availability as evidenced by a reduction in the P content of the whole plant. In contrast the K levels in the whole plant increased with increasing levels of Biochar application and this was even with Biochar A which had relatively low available K. Increased K levels due to biochars application is of great importance as it affects positive fruit quality parameters, such as soluble solids in watermelon (Villocino and Quevedo, 2015). Magnesium reduced as a result of Biochar application but this may have been simply being due to the dilution of dolomitic limestone in the peat as a result of Biochar application. Oppose to N content, results showed that S plant content increased as Biochar rates increased with exception Biochar B at 25%. Regarding micronutrients, Mn content into plants followed the same trends as Mg did. The content of Cu, Zn and B was fluctuated among different treatments. No major differences were found on Fe content among plants grown in difference Biochar types and mixtures.

Table 2. Macronutrient and micronutrient leaf tissue analysis (mg/kg) of tomato plants grown in different substrates.

	N	K	Ca	P	Mg	S	Fe	Mn	Zn	Cu	B
Fert. Peat	26100 a[Y]	27702 c	9291 d	9522 bc	8257 a	7423 cd	59.4 ab	123.0 bc	32.0 f	4.9 bc	23.6 d
A-10%	24200 ab	30698 bc	9254 d	9691 abc	6925 b	8376 bc	65.3 a	109.5 c	47.7 e	6.1 abc	33.2 bc
A-25%	22150 bcd	36179 abc	11296 bcd	8741 cd	5912 c	10235 ab	59.7 ab	124.0 bc	65.6 b	7.3 ab	36.8 a
A-50%	18450 de	36296 abc	16637 a	6544 fgi	3530 f	11277 a	52.8 ab	135.0 b	62.5 bcd	8.9 a	33.6 abc
B-10%	22500 abc	26294 c	10125 cd	8564 cde	5384 cd	5711 de	53.5 ab	83.1 d	51.5 cde	6.9 abc	34.6 ab
B-25%	21350 bcde	43111 a	14519 ab	7743 def	3620 f	4494 e	59.3 ab	73.4 de	63.9 bc	8.4 ab	34.1 abc
B-50%	21600 bcde	42323 ab	16781 a	5892 i	3331 f	6272 cde	47.6 ab	46.1 fg	35.5 f	3.4 cd	31.1 c

C-10%	21850 bcd	28805 c	9106 d	10946 a	4548 de	3809 e	48.7 ab	227.5 a	53.8 bcde	6.7 abc	37.0 a
C-25%	22150 bcd	35277 abc	11209 bcd	9230 c	4181 ef	4096 e	50.2 ab	219.0 a	49.9 de	5.6 abc	34.3 abc
C-50%	17900 e	38270 abc	10296 cd	6206 gi	3868 ef	7729 cd	44.1 ab	124.0 bc	18.1 g	1.6 d	16.6 e
D-10%	21600 bcde	29848 c	13507 abc	10673 ab	5059 cd	4887 e	50.3 ab	81.4 d	112.5 a	7.2 ab	33.8 abc
D-25%	20050 cde	43054 a	16912 a	9029 cd	3993 ef	5392 de	50.9 ab	53.3 ef	102.3 a	5.3 abc	21.6 d
D-50%	17900 e	36619 abc	16010 a	7421 efg	3817 ef	6275 cde	38.2 b	25.2 g	55.0 bcde	6.7 abc	14.6 e

[Y]values in columns followed by the same letter are not significantly different, $P \leq 0.05$.

There were significant correlation between substrate CAT extractable total N (NH_4-N + NO_3-N) and total plant N(p=.001) Despite decreases in CAT extractable nitrogen levels as a result of the addition of biochar, this is only reflected partly in a decrease of total N content of the plant. Significant correlations were also found between substrate extractable P and total plant P (p=.001) (see Fig. 4). There was also a significant correlation between extractable K and plant K but the relationship was not so good (R^2=0.48, p=.001). These results indicate that CAT extractable N and P found to be suitable for peat and compost can also be used on peat biochar mixes. However more work needs to be done to explain why the CAT extractable N overestimates plant N availability.

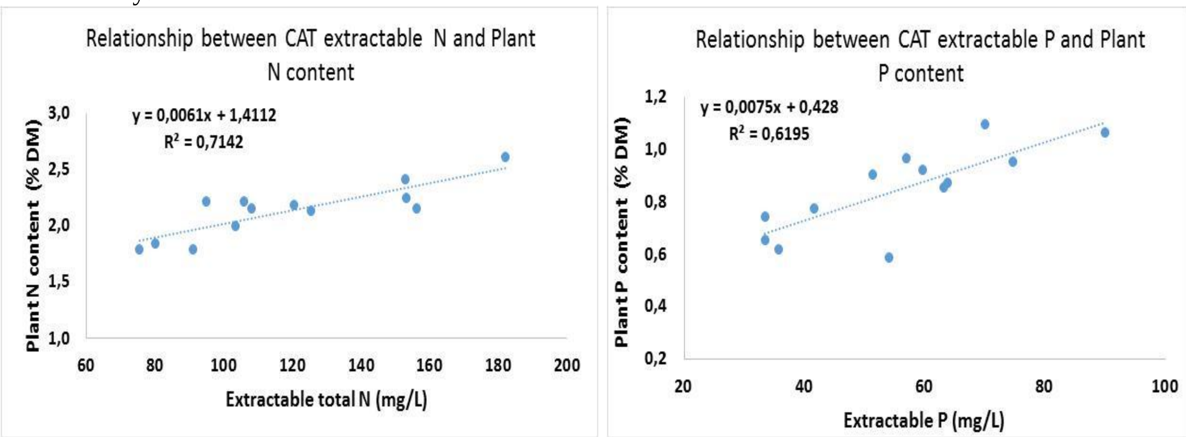


Figure 4. Regression analysis of CAT extractable N and P of different mixtures consisted of commercial peat-P and different biochar (A-D) with the relevant plant N and P content.

Conclusion

Under the examined biochars, negligible amounts of N and P are present in Biochar and large amounts of K was present in 3 biochars. Biochars are very biologically stable as evidenced by oxygen uptake in relation to peat and compost. There is a big decrease in EC and extractable total N including NO_3-N, and P as result of biochar application but an increase in pH and K. Better rooting in cress and in some cases tomato plant growth was found at low rates of biochar application to peat. CAT extractable N and P was found to be suitable in predicting N and P content in plant while there was a consistent reduction of N and P in the plant as a result of biochar application. Despite the 4 biochars coming from different sources and feedstock, they behaved broadly in a similar fashion.

It is possible to prepare adequate growing media materials by mixing some biochar samples with peat (H_4-H_5). These results have implications regarding the strategy of nutrient application in peat biochar mixes. In summary, the results have a high environmental relevance as it may involve the replacement of a non-renewable resource (peat) by biochar made from organic waste.

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