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The Potential of Biochar and Anaerobic Digestate use in a Temperate Conventional Wheat Production System

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ABSTRACT

Interest in the use of waste products as soil amendments, derived from renewable energy technologies, has grown of late as they offer the potential to reduce fertiliser costs and, in the case of biochar, promote carbon storage. This study examined the efficacy of two such waste products, digestate, produced by anaerobic digestion and biochar, produced from pyrolysis, in comparison and in combination with a commercial synthetic fertiliser. The arable field trial was located on a sandy soil in a commercial farm setting. Four treatments were tested; digestate alone, digestate with biochar, commercial fertiliser alone and commercial fertiliser with biochar. The biochar and digestate was applied on one date and the commercial fertiliser applied on four dates, but in either case the rate of Total Nitrogen (TN) applied was the same. Digestate produced the same level of above ground biomass (t/ha), grain yield (t/ha), grain protein and TN off-take (kg/ m2) as the commercial fertiliser with no statistically significant differences found (P>0.05). Leaf Soil-Plant Analyses Development (SPAD) readings were taken by a SPAD-502 chlorophyll meter (Minolta Camera Co., Japan) throughout the trial indicating chlorophyll levels. Both the commercial fertiliser only and commercial fertiliser and biochar produced leaf SPAD readings that were, on certain dates, significantly higher (P>0.05) than digestate alone, and in combination with biochar. However, just before harvest all readings on all treatments converged on the same SPAD level. Critically, treatments which included biochar resulted in lower aboveground biomass (t/ha), grain yield (t/ha), grain protein and TN off-take in all cases. It is clear that biochar may have negative effects on yield, even when combined with additional fertilisation and, as biochar use increases and its presence in soil would be of long duration, it is therefore vital that further studies are conducted in this area.

Keywords: *Anaerobic digestion; Biochar; Bio-based fertilizers; Sustainable agriculture; Nutrient recycling*

INTRODUCTION

The worldwide trend in increasing fertiliser prices has led farmers to consider alternative sources of soil amendment [1]. Using the by-products of renewable energy systems such as pyrolysis and anaerobic digestion would appear to offer a triple benefit of crop or food waste use, energy generation and the production of useful soil amendments [2]. However, there is some doubt as to how useful these soil amendments may be due to their perceived unreliable nutrient content [1] in commercial arable systems.

The two renewable energy derived by-products investigated here were biochar and anaerobic digestate. Biochar, or charcoal, results from pyrolysis, or the thermal decomposition of organic matter in the absence of air [3]. This organic matter can be waste food or agricultural discard and can therefore be a means to recycle waste but also, through pyrolysis, to generate energy. Anaerobic digestion (AD) uses bacteria to breakdown organic matter, producing useful gasses and a by-product referred to as digestate [4]. It can therefore mitigate global warming and climate change [5,6] as an alternative to the use of fossil fuels. Thus waste can now be recycled and returned to the land as soil amendments as opposed to taking up space in landfills [7]. These technologies also promote cycling of nutrient and carbon rich soil amendments which improve soil [8,9] and provide an effective, targeted and long term waste disposal to land solution [10]. The use of digestate and biochar also provide an alternative to the energy intensive production of mineral fertilisers [11].

However, as soil amendments, both digestate and biochar have limitations, if the goal is to improve crop yield, that result from the nature of their interaction with soil of their biological, chemical and physical characteristics. For instance, during AD the carbonaceous substances contained in the feedstock are degraded by microbial activity resulting in the generation of methane which is captured for use [12]. This leaves a carbon poor end product [13].

Carbon (C) is a critical component of soils where it exists as different compounds with different levels of degradability. A more labile fraction, such as fresh biomass (dead leaves, stalks and animals) provides a source of energy to critical soil microbes [14]. In its more recalcitrant form, for example, humus, it maintains structure [15], improves water holding capacity [6] and acts a long term sink for C, mitigating greenhouse gas emission and climate change [3]. Biochar exists mainly as a form of highly stabilised C which can exist in soil for millennia [16] therefore providing a long term C sink [14] in addition to improving a range of soil properties such as soil structure, water holding capacity and microbial biomass [8]. However, biochar, especially derived from wood feedstock, only contains limited amounts of other nutrients, such as N, potassium (K), and phosphorus (P) [17]. Digestate however, although low in C, does provide an array of other useful nutrients including high levels of available N [18].

However, N in digestate exists in volatile form as ammonium (NH4+) and presents practical handling challenges during application. For instance, ammonia losses from digestate reached in excess of 30% when applied during strong winds in a field trial when applied via trailing hose [19].

Critical to the uptake of AD and pyrolysis as energy generation and waste solutions are farmer's beliefs in the benefit of using AD and therefore, their willingness to spread the end product to land so that digestate and biochar does not stockpile as a waste and become a problem. For this, benefits must include improvement in soil quality and crop yield. This project therefore investigated whether the use of biochar and digestate, applied together, can mitigate each other's weaknesses and improve crop yield to the same level achieved by synthetic fertilisers.

MATERIALS AND METHODS

Location

A field trial was established in September 2015 at Budbrooke, Warwickshire, central England at 52°17'N 1°37'W, 84 m above sea level. Mean annual temperature is 6.4 °C and mean annual precipitation is 692 mm. The soil type was a sandy clay loam (more details are given in Table 1.) with particle size distribution having been determined using a laser diffraction particle sizer and classed according to the UK classification system [20]. Microbial activity was estimated from using a Solvita carbon dioxide (CO_2) burst standard soil protocol where the air dried and weighed sample of soil was moistened with deionised water, triggering a flush of CO_2. This burst was then measured with a digital colour reader (DCR) in ppm. This carbon dioxide burst is proportional to microbial biomass.

Table1. *Characteristics of the Field Trial Soil*

Soil Texture	**Particle Size Distribution % ***			**pH**	**OM****	**Microbial Activity** mg/kg	**P** mg/dm^3	**K** mg/dm^3	**Mg** mg/dm^3
	Sand	**Silt**	**Clay**						
Sandy clay loam	55	26	19	6.2	5.6%	162	77.8	473	458

**Size fractions: sand based on 200µm – 2mm; fine sand 63-200 µm; silt 2-63 µm, and clay < 2 µm*

*** Organic Matter - loss on ignition*

Experimental Design

The site was an existing agricultural field which had been used for commercial oil seed rape production in previous year. The stubble was shallow cultivated and subsoiled, then power harrowed and drilled using commercial machines. The plots were arranged in a randomised block design and included four different treatments with four replicates in plots of 3.2 m by 3.2 m. One meter strips were left between them to enable access to all plots without disturbing others and to minimize edge effects. The four treatments were as follows; digestate (250 kg/ha N) alone, commercial fertiliser (250 kg/ha N) alone, then each with biochar. The biochar plots were spread, by hand, at a rate of 20 t/ha (30th September 2015). All plots were harrowed again to ensure incorporation to a depth of 10cm.

A high tillering, bread making, winter wheat (*Triticum aestivum* L, cv KWS Lili) was drilled across the whole trial on1st October. Digestate was applied once to the soil surface, on 27th February 2016, at a rate of 53m3/ha to supply 250 kg/ha total nitrogen (TN). Fertiliser N was applied according to the normal farm practice as four split applications at a total rate of 243Kg N/ha on the following dates; 27th February 2016 – 50 Kg N/ha as ammonium sulphate/ ammonium nitrate (Grow how Double top), 26th March 2016 - 64 Kg N/ha as ammonium nitrate (Nitram), 24th April 2016 - 43 KgN/ha as ammonium nitrate (Nitram) and 5th May 2016 - 86 Kg N/ha as ammonium nitrate (Nitram). Pesticide applications were also made according to standard farm practice.

The type of biochar chosen was done so on the basis of availability in the UK. UK farmers are most likely to obtain biochar made from deciduous tree clippings (from woodland maintenance) (personal communication; David Hutchinson; 22nd March 2016). This biochar type was purchased from the Oxford Biochar in April 2015 with the physical and chemical characteristics as outlined in Table 2.

The digestate was obtained from a local supplier in Warwickshire with a feedstock of 100% maize grown for energy production. The chemical and physical characteristics of the digestate are also given in Table 2.

Plant Sampling and Analysis

Chlorophyll content measurements of leaf colour were first made on 1st April 2016 using a Minolta Chlorophyll Meter (SPAD-502) and every 2 weeks thereafter during the growing. For each plot, a minimum of 10 readings were taken, each from separate plants. The youngest fully expanded leaf was selected and the reading taken approximately 5 cm from the tip, avoiding the mid-rib.

Table2. *Biochar and Digestate Chemical Characteristics*

Determinand		Biochar	Digestate
DryMatter	%	84.8	6.42
PAH(EPA16)	mg/kg	18.6	-
pH		7.2	8.2
$CaCO_3$	% w/w	4.1	-
OM	% w/w	91.3	-
C:N		169:1	-
Total(%w/w)	N	0.41	0.47
	C	69.1	-
Total (mg/kg)	P	559	667
	K	1766	4406
	Mg	399	296
	Cu	7.65	6.38
	Z	35.5	25.1
	S	179	418

The crop was harvested on the 16th August 2016. Samples were taken, by hand cutting, from a 2.25m2 subplot. The total above ground biomass was weighed and the grain separated using a portable threshing machine. Sub samples were taken to determine the dry weight, grain N and the 1000 grain weight.

Total grain nitrogen was established by milling 75g of grain to pass through a 0.5mm screen followed by total combustion in an oxygen enriched atmosphere before passing through a T.C.D. detector through the Dumas method [21]. Protein levels were estimated from total nitrogen a factor of 5.49 according to [22].

Data Handling and Statistics

Treatment differences in soil and plant properties were compared by paired, two sample means T tests (P< 0.05) using GENSTAT.

Results and Discussion

Leaf Chlorophyll Levels

Leaf SPAD values measured throughout the growing season and results are shown in figure

1. There were no significant differences between treatments on all dates except May 7th and May 18th.On both dates, leaf SPAD values in both the commercial fertiliser treatments were significantly higher (P > 0.05) than the digestate treatments, with the addition of biochar making no significant difference. This may result from additional application of Nitram on four separate dates, whereas digestate (carrying an equivalent amount of TN) was only added once. The final leaf SPAD reading (of the flag leaf on the 14th June) revealed no significant difference between treatments. These results suggest that biochar did not affect plant N uptake as has been observed under different studies [14,23] where results were attributed to the high C/N ratio of the applied biochar causing N immobilisation.

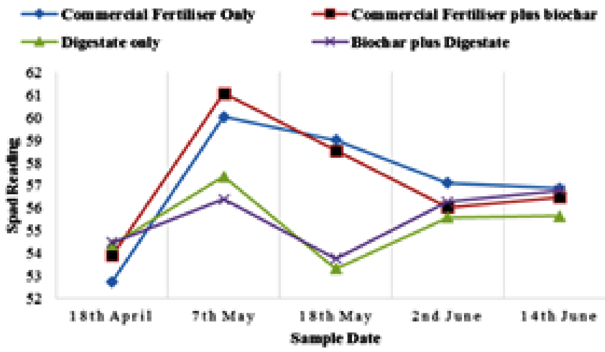

Figure1. *Leaf SPAD readings*

Above Ground Biomass And Grain Yield

In terms of above ground biomass and grain yield digestate ultimately produced very similar figures to the commercial fertiliser (Table 3) with there being no significant difference (P > 0.05) detected in a paired, two sample means T test. This surprising result was achieved even though the commercial fertiliser was added four times at optimal points throughout the growing season whereas digestate was only added once. The only significant difference detected was between commercial fertiliser alone and commercial fertiliser and biochar, with the latter producing significantly less grain yield (P > 0.05). There were no significant differences between other paired treatments, however, overall, biochar treatments produced the lowest above ground biomass (t/ha).

Table3. *The Effect of Biochar and Digestate on Crop Yield Parameters*

	Above Ground Biomass (t/ha)	**Grain Yield** (t/ha)*	**1000 Grain Weight** (g)	**Grain Protein** (%)	**Total N off-take** kg/ m^2
Commercial Fertiliser Only	19.6	11.6	47.5	11.06	21.5
Commercial Fertiliser plus Biochar	17.7	10.4	48.7	10.94	19.3
Digestate Only	19.2	11.3	47.1	11.52	21.9
Digestate plus Biochar	18.7	11.0	46.1	11.73	21.7

**Adjusted to 85% moisture.*

Although other studies have found biochar additions can increase above ground biomass [24,25] these were in pot trials and the effect diminished with subsequent croppings. In field trials the picture is much less clear. [26] report a significant increase in grass biomass production seen at both biochar application rates (25 and 50 t/ha) (P < 0.05), but no such response in maize. Many researchers report that, at higher application rates, biochar has been found to limit biomass production and yield [27, 28] and that appears to have been the case in this trial.

Thousand Grain Weight, Protein nd Nitrogen Off-Take

The 1000 grain weight is an important commercial parameter used to determine the value of the harvested grain. Depending on grain moisture content, the higher the weight, the greater the economic value. Only the difference between commercial fertiliser only and commercial fertiliser plus biochar treatment was statistically significant (P>0.05).

Again, virtually all pair-wise comparisons revealed no significant differences for grain protein content and nitrogen off-take except for commercial fertiliser plus biochar and digestate plus biochar (P>=0.05). This confirms [24] findings of no significant interactions between variables in their trials, which is further confirmed by the findings of [23] who, in a meta-analysis of 371 independents studies, including 34 involving treatments with biochar and other fertilisers, found little evidence of any synergistic effect when biochar was applied with fertilisers, chemical or otherwise (although most of these were in tropical and not temperate climates).

CONCLUSIONS

This paper is the first to compare the effect of combining biochar with digestate, and biochar and a commercial fertiliser, on the growth of wheat in a temperate, commercial scale, field study. The leaf SPAD values responded quickly to recent applications of N but, eventually, the SPAD values, above ground biomass and grain yield, recovered to match the commercial fertiliser plots with just a single digestate application. This surprising result has considerable implications for farming as one application of digestate could remove the need for the additional tractor passes required by commercial fertiliser, thus saving fuel costs and time, and also limiting compaction.

Except in the case of commercial fertiliser plus biochar and digestate plus biochar, all pair-wise comparisons revealed no significant difference between treatments for grain protein content and nitrogen off-take. This general lack of evidence for an interaction between biochar and chemical or organic fertilisers seems to suggest that biochar does not influence the effect of the fertiliser on plant growth. However, as [23] point out, there remains a considerable lack of research in this area and any mechanisms for interaction have not been fully investigated, especially in field trials. Equally, the effect of different soil types on the biochar-soil-digestate complex requires further analysis.

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Author's Biography

Donna Udall, studied Plant Science at Worcester University and has recently joined academia from a commercial farming background. She has written several publications concerning soil fertility and is completing her PhD entitled the *Effect of Soil Texture on the Biochar-Soil-Digestate Complex*.

Francis Rayns, Applied Biology at UCNW Bangor and received a PhD from De Montfort University in Leicester (Somatic Embryogenesis for Plant Propagation). For the last 25 years he has conducted research into organic methods of improving soil fertility for the Research Department of HDRA/Garden Organic, and later, CAWR. His wide range of research projects include practical organic horticulture, green manures, crop rotations, the use of composts and other amendments, vegetable transplant production, soil quality indicators and comparisons of soil managed organically and conventionally.

Susanne Charles worth, is a Professor in Urban Physical Geography. She is the author of more than 50 peer reviewed journal articles on urban pollution and sustainable urban drainage systems (SUDS), many book chapters, and has co-edited books on aquatic sedimentology and water resources. She collaborates with groups internationally and has given papers at international conferences worldwide. Recent work includes the role of biochar for pollution management in SUDS.

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