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Carbon-based stock feed additives: a research methodology that explores ecologically delivered C biosequestration, alongside live-weights, feed-use efficiency, soil nutrient retention, and perennial fodder plantations

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Abstract

BACKGROUND: There is considerable interest in reliable and practical methods to sequester carbon (C) into agricultural soils to both reduce atmospheric greenhouse gas concentrations, and improve conventional productivity. This article outlines a research methodology to refine the efficacy and economics of using long-lived C species (biochars) as stock feed additives, produced from farm waste biomass, for ecologically delivered soil biosequestration, while generating renewable bioenergy. This article also draws attention to potential parallel outputs including annual feed use efficiency, fodder species expansion, soil nutrient retention, aquatic habitat protection, and forestry revegetation, using nitrogen fixing perennial fodder plant species.

RESULTS: A methodology to generate parallel results including: standing fodder tree C sequestration; optimised production of *Acacia sp*. biochar; animal growth on high-tannin fodder with biochar feed additives; soil nutrient and stable C fractions; and, economics of *Acacia sp*. bioenergy production.

CONCLUSION: This form of research is contextually dependent on the regional agricultural production system, legislation, and surrounding ecosystem. Therefore, this article suggests the use of a scenario approach to include regionally specific levels of biochar integration with respect to the local prices for C, fossil fuels, meat and livestock, fertilisers, fodder, feed additives, water, renewable energy, revegetation and capital.

Keywords

Acacia sp., biochar, carbon, fodder, renewable energy, soil

1. Introduction

Heating organic materials such as wood, manure or leaves in a closed container, at relatively low temperatures and limited oxygen, produces biochar. Biochar is a C-rich product produced for specific applications, usually concerned with soils. [1] There are several uses of biochar stated in the existing research literature, however, some have lacked a rigorous assessment for their appropriateness and cost-effectiveness to specific agricultural systems. One promising research opportunity that has received little coverage is the use of biochars as feed additives to improve stock growth on lower grade fodders and to sequester C in soils. The mechanism for this improvement is the "detannification" of vegetative species (such as *Acacia sp.*) to increase the available protein. [2,3] In the process of researching the addition of small amounts of biochar to the diet of grazing animals, the opportunity arises to simultaneously investigate the reported capacity and magnitude of the ecologically delivered biochar to: biosequester C; biologically immobilise inorganic nitrogen; retain soil nitrogen; reduce soil acidity; adsorp dissolved ammonium, nitrates, phosphate, as well as hydrophobic organic pollutants such as polycyclic aromatic hydrocarbons in soils. [4-10] The remaining levels of biochar in the animal excreta would also determine the C fractions that survive the digestive system to determine the maximum available long-lived C species fractions to be sequestered in soils via the ecological delivery method.

If the efficacy of biochar feed additives is promising, a reliable, cheap, and sustainable commercial supply will be required. The sustainable manufacture of biochars offer additional opportunities to determine the potential for deriving secondary energy-based products from the production of biochar, such as bio-oil, bio-gas, and heat suitable for displacing fossil-based transport and electricity input fuels. Another upstream research project from the biochar and fodder trial is the quantification of value and efficiency of using *Acacia sp.* plantations as a vegetative C sink and as a sustainable fodder source for periods of low animal feed availability. Due to the height of most *Acacia sp.*, many will require the upper foliage to be pruned to be available to grazing animals. Once the edible portion of the plant is eaten, the remaining inedible woody waste may provide a sustainable source of biomass C for biochar manufacture through pyrolysis. Integrated agricultural production systems research such as this, requires suitably high resolution data to determine the agricultural systems and regions that may be able to implement options cost-effectively and sustainably. Combining quantitative yield research with technical and socioeconomic production scenarios will be required to provide regionally customised tools for areas that have the capacity and opportunity to assimilate biochar feed additive research into natural resource management practices. [11]

Producing regionally specific analyses of the most productive and cost-effective use of energy and C from fodder species through the animal husbandry production cycle with soil return is a grand, but challenging objective. However, this work outlines a methodology that may reduce unnecessary research duplication to derive high-value data that enables regional industries and businesses to directly apply the research within bounds of uncertainty.

2. Research background and methodology

To achieve robust agricultural mitigation, policy developments will need to parallel field investigations of new soil and vegetative management practices and their effect on existing production systems. [12-15] This integrated research methodology is based on the research undertaken by Van et al. (2006), and attempts to reconcile the upstream and downstream uncertainties into a single collaborative project methodology. The twelve week experiment by Van et al. (2006) compared goat growth rates fed on tannin-rich *Acacia sp.* fodder. The experimental group was given less than 1g of bamboo biochar per day, per kilo of the animal's weight. The experimental group of goats showed significantly higher growth rates (20%) than the control group that received no biochar feed additive. The goats receiving the biochar feed additive weighed in 5.2% heavier than their control counterparts over the period. [2] While applying this research model to determine the efficacy of biochar detannifiers with other agriculturally significant animal species, the opportunity arises to expand the model to integrate biochar feed additive efficacy and ecological delivery method with: the soil organic carbon (SOC) fractions and totals sequestered in the soil; the stability of these C species in soils over time; changes to enteric fermentation emissions; changes in the soil nutrient profile; changes in soil nutrient retention; the potential benefits for water catchments; various suitable plant species biomass growth for vegetative biosequestration, and fodder production; suitable harvesting techniques, and; the cogeneration of biochar and renewable energy manufacture, amongst others. [10,16-20] (See Table 1 for a list of helpful information to refine the potential of *Acacia sp*. biochar as a feed additive).

The multiple project activities and outputs may seem like a dauntingly large project, and it is likely that it will be a large undertaking. However, smaller research projects, while easier to manage and obtain funding, are likely to produce results at higher overall cost and over a longer period. Smaller projects may also disregard significant regional advantages, symbioses, and omit important aspects such as seasonal labour and idle land or mechanical capital. For example, if the efficacy of biochar feed additives for animals fed on high-tannin fodder is demonstrated, this may provide enough of a direct financial reason to revegetate some land into *Acacia sp.* for a sustainable source of summer fodder, biofuels and feed additives for C biosequestration. Taken in isolation, the cost and benefits may not be a profitable option. Yet the inclusion of the positive externalities in an agricultural system may prove to be a more cost-effective option overall, in some production systems and regions. [21]

Assuming an experimental group of 100 sheep weighing 50 kg each are fed 1g of biochar per kg of live weight each day, for twelve weeks. This would total around 420 kg of biochar, representing roughly 1.3 tonnes of potentially biosequestered CO_2-e of over the experiment alone. This ecologically delivered C would be detectable from the experimental group paddock soil sampling, if the area is sufficiently small. With over three billion sheep, goats and cattle globally, if only five percent of the global flock/herd was consuming biochar feed additives at this rate for only twelve weeks of the year, around 1.3 million tonnes of biochar would be required. Using this five percent penetration scenario with the Van et al. (2006) growth figures, the potential value of the biochar additives to global animal husbandry could be significant. Additional benefits to the direct value of increasing the utility of high-tannin fodder may include: improvements in feed security over the lean period; additional utility of perennial cover; the permanently sequestered C in the standing fodder biomass; reduced fertiliser use; and, displacing fossil fuels with locally produced renewable bioenergy from waste. The sum of these regional synergies provides an excellent example of integrated research outputs that can be applied by local agriculturalists and renewable bioenergy industries. (See Table 2 for integrated biochar feed additive research activities).

Commercially available and scalable biomass conversion technologies can convert around 20 tonnes of waste wood into around 4000 L of bio-oil, 400 kg of solid biochar, and generate biogas to run a 350 kW electrical generator. The relative ratios of solid, gaseous and liquid fuel outputs are dependent on the technology used. [22-24] Generally, around two thirds of the energy in the biomass is converted to either renewable bio-oils, bio-gases, and heat, with the remaining one third locked up in the solid biochar feed additive. When maximising the biochar yield, biomass conversion technologies can enable biosequestration of around 30 kg of C for each GJ of energy produced. [10] Using the Van et al. (2006) results, the market value for the biochar used would be approximately USD500, based on the additional animal growth valued at USD1 kg^{-1}. This relatively nominal value may still be enough to push many biomass conversion technology investments into the mainstream. With the fluctuation in oil prices, and generally low electricity prices, the addition of a relatively stable demand for biochar feed additives is likely to be a welcome option for regional production. Combining sustainable plantation biomass pyrolysis with ecologically delivered biochar has a range of benefits, especially in terms of abating excessive nutrient loss from regional mass bioenergy production. [10,25-27] Determining whether this can be undertaken sustainably and cost effectively at the regional level requires feasibility analyses on the range of available renewable energy and C biosequestration technologies. However, their use will remain strongly bound to the practicality and effectiveness of C-based feed additives and soil ameliorants in the regional farm production system.

3. Fodder and feed additive externalities and system research

The available tree fodder in paddocks can be approximated by the use of allometry. Allometry can also be used to obtain approximations of both total biomass and C content of plantations under various management practices, without cutting them down. [28] When the fodder plant is harvested, the C and biomass in the harvest component can be used to verify or refine the allometric models by destructive sampling of the tree components including stems, crowns, roots and tops for various tree sizes, ages, spacing, and species. [28,29] Producing scenarios of various animal fodder, renewable energy generation and C biosequestration values can determine the highest value use of biomass resources, which is amenable to standardised investment indicators, such as net present values and internal rates of return. The establishment of perennial fodder species plantations offers a significant option for farmers to supplement stock diets in the feed gap period, which is a major constraint to livestock production. [30] Having the ability to defer the grazing of annual pastures and reduce hand-feeding has also generated much interest for suitable vegetative species. [31,32] The introduction of biochar to expand the pallet of useful fodder species during this period is an extremely valuable source of security. Deep-rooted perennials, such as *Acacia sp.*, can use water when annual pastures are dead, recover nutrients from deeper soils, reduce acidification, and minimise soil loss by both water and wind erosion. [33,34] *Acacia sp*. are nitrogen fixers, and their improved digestibility with bio-char feed additives may expand their utility within agricultural production systems. [19,31,35] If the efficacy of the *Acacia sp.* biochar feed additive yields significant results, this might provide a much needed direct financial reason to revegetate arid lands suitable to many native *Acacia sp.* for a sustainable supply of cleaner biofuels and feed additives for C biosequestration. [21,36] As *Acacia sp.* are native to regions with relatively low rainfall in Africa, Asia, the Americas, and Australia, this form of extensive agriculture has wide application.

If a statistically significant level of biochar remains in the soil over time after use as a feed additive, then the fodder forestry C biosequestration will be enhanced with additional soil biosequestration alongside any animal growth benefits or fossil fuel displacement. [10,27] At present, there is little scientific consensus on the stability of many of the biochar components under a range of oxidation and decomposition situations, such as degradation by ultraviolet light or decomposition by soil organisms. [10,36] In addition, it is currently unclear what impact biochar's adsorption behaviour would have on ground and surface waters from reducing runoff in agricultural waterways and catchments. [10,27] While increasing conventional SOC levels are known to improve soil biodiversity and productivity, the efficacy of increasing SOC using biochar additions to reduce fertiliser requirements, improve water use efficiency, and preventing plant and nutritional deficiencies, has failed to attract significant research capacity to date. [11,27,37-41]

The various potential biochar applications may significantly expand available climate change mitigation and adaptation options. However, much research is required to refine theory that currently exhibits too much uncertainty to attract significant private sector investment. [13,42] A coordinated research approach of production systems and regions that integrates conventional productivity with mitigation and adaptation goals, is a cost effective approach. [43]

4. Conclusion

Providing greater scientific rigor and certainty to farmers, investors, environmentalists, governments and the broader community requires undertaking biochar feed additive research alongside upstream and downstream options. These interrelated interests will all benefit from a cross-disciplinary scenario-based research project. The technical and economic feasibility studies in biomass conversion technology are suitable for both governments and decentralised renewable energy industries. The digestibility, animal growth, and soil nutrient impact data will be useful to small landholders and agricultural industries. The chemical properties of biochar and soil characteristic studies will be of interest to agricultural scientists and organic fertiliser manufacturers. Fodder biomass growth and biosequestration results will be useful for governments, farmers, forestry, and environmental sectors, as well as new climate change mitigation industries.

A feed additive and biosequestration research scenario approach can provide information on the upstream and downstream potential of its production and use, and to provide a form of indemnity to industries before potentially misapplying new systems and knowledge that may be only cost-effective in highly specific situations. The diversity of target groups and research output for this form of research parallels the interrelationships that must exist for agriculture to adapt and mitigate its way into the future successfully.

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Table 1. Required regional data to refine the *Acacia sp.* biochar feed additive potential.

- Harvested fodder tree standing plantation total C sequestration versus unharvested plantations
- Local harvested fodder tree plantation SOC sequestered versus unharvested plantations
- Acacia species biochar versus other chemical and physical properties
- Animal growth for high tannin fodder with and without biochar feed additives
- Economic & technical comparison between Acacia sp. biochar & bioenergy against other biomass
- Economic & technical comparison between Acacia sp. bioenergy outputs and their local value
- The optimal temperature and pressure to produce optimum C recovery & utility in Acacia sp. biochar
- The efficacy and cost-effectiveness of biochar feed additives as detannifiers versus alternatives
- The percentage of remaining biochar fraction in animal faeces after excretion
- Changes in manure nutrient characteristics with and without biochar feed additives
- The effect of biochar on animal emissions from digestive processes versus alternative feed additives
- Changes in total SOC and SOC component fractions before and after feed additive use in paddocks
- The net sequestration of the biochar feed additive in soils after ecological delivery over time
- Changes in soil nutrient profile, physical and chemical properties before and after biochar addition

Table 2. Biochar feed additive research activities.

- Determine above-ground total biomass, biomass growth over time, and the total standing C content over time
- Analyse fodder digestibility to determine available protein & other nutritional components
- Determine total energy available in dry biomass components
- Pyrolysis of Acacia sp. to produce biochar and other selected bioenergy products
- Collect input and output specifications, capital and running costs for biomass conversion technologies
- Measurement of total C, energy content, chemical and physical properties of the biochar
- Feeding of high tannin fodder (with and without biochar) and live weight monitoring
- Faeces analysis for biochar C content and digested fodder components
- Soil C and control plot sampling before and after trial for total SOC and SOC fractions
- Soil profile sampling to analyse for nutrient leaching and other soil physical or chemical properties
- Economic analysis of the biochar & feed additive use, including the importation of commercial biochars
- Technical analysis of on-farm emission abatement using available animal and energy emission factors