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# Reducing Impacts of Poultry Litter on Water Quality by Developing Markets for Energy and Mine Land Reclamation

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Dr. Gregory T. Papanikos
President
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## Abstract

Manure from livestock operations is increasingly viewed as an environmental liability due to water and air pollution concerns. In particular, the poultry industry in the Chesapeake Bay watershed (eastern North America) is under increased regulatory scrutiny due to nitrogen and phosphorus inputs into the Bay. Although poultry litter is valued as fertilizer, the cost of shipping the bulky material out of the watershed is prohibitive and much is still used on over-fertilized farmlands in the watershed. One solution for excess litter is to burn it; thereby producing energy and converting the litter into biochar. Biochar has value for soil fertility improvement and heavy metal remediation. Our overall program goal is to develop a comprehensive strategy to convert poultry litter from an environmental liability into an economic and ecological asset. Our specific objectives are to evaluate the potential of biochar for reclamation of surface coal mine soils and to develop a comprehensive conceptual model for improving poultry litter waste management through market-driven alternatives. Our conceptual model evaluates poultry litter energy production (compost, methane, fuel oil, pyrolysis), water remediation (acid mine drainage, shale gas hydraulic fracturing water), and biochar production (mine soil amendment and poultry feed supplement) environmentally and economically. Biochar manipulated with various leaching and saturation pretreatments influenced: germination rates, number of days to germination, and aerial biomass of lettuce (*Lactuca sativa*) in topsoil and mineland soil experiments. Increased application rates and pretreatment saturation times improved germination and growth properties (compared to fertilizer, topsoil and mine soil only) particularly under drought conditions. Pretreatment leaching and saturation conditions reduced Na and K concentrations. Worm avoidance tests indicated that biochar had fewer worms than soil alone. Our biochar results indicate potential for mineland remediation and our conceptual model holds promise for reducing ecological liability, and enhancing economic and energy concerns.

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## Introduction

The poultry industry is an important component of the agricultural industry in the Chesapeake Bay Region of the United States (U.S.). Production of poultry is becoming more streamlined and the worldwide demand is strong (Windhorst 2006). However, poultry litter (i.e., a combination of poultry manure, bedding material, and dead birds) disposal is a financial and logistical concern for the poultry industry. A standard poultry operation can produce 125 to 600 metric tons (mt) of poultry litter annually (Lehmann and Joseph 2009). Recently limitations by the U.S. Environmental Protection Agency (EPA) on nutrient runoff are driving concerns among agricultural producers that their livelihoods are threatened. Agriculture has been implicated in up to 50% of the phosphorus entering the Chesapeake Bay (NRCS 2010). The forthcoming EPA regulations are not alternatives to the status-quo, but mandates for reductions and compliance. Thus it is critically important to find alternative strategies for nutrient export from the Chesapeake Bay if these farms are to remain viable.

Numerous alternatives to fossil fuels are being explored. Conversion of biomass to energy has tremendous potential for reducing fossil fuel demand if the appropriate types of biomass are used (Tilman et al. 2009). Waste material from agricultural operations may be one potential biofuel; the value of converting animal waste to energy can be increased when nutrients are integrated into the management of soil fertility. In addition to the heat or energy created by charring poultry litter in a fixed-bed gasifier unit, biochar can, under appropriate conditions, be produced at a ratio of about 1 metric ton (mt) biochar per 5 mt of poultry litter processed (Lehmann and Joseph 2009).

Biochar is a carbon-rich product formed by thermally-decomposing biomass in a closed vessel with little to no available air at temperatures <700°C (Lehmann and Joseph 2009). When applied to soil, biochar (in the proper form) has the means to sequester carbon (C) while concurrently improving soil functions (Verheijen et al. 2009). Poultry litter biochar has resulted in higher levels of microbial carbon, especially at higher rates of application (Liesch et al. 2010). Biochar has potential value for remediation of heavy metals on minelands and other areas. The sequestered carbon in biochar attracts and immobilizes heavy metals that can impair natural successional processes (Lima and Marshall 2005). Moreover, when biochar is incorporated into soils, the ecosystem changes actually produce less $NO_x$ (a greenhouse gas) than unamended soils (Singh et al. 2010). However, much remains unknown about how to prepare biochar for commercialization.

Our overall program goal is to develop a comprehensive strategy to convert poultry litter from an environmental liability into an economic and ecological asset. Specifically, our long-term objectives are to evaluate the potential of biochar for reclamation of surface coal mine soils and to implement a comprehensive strategy for improving poultry litter waste management through market-driven alternatives. The primary objectives of this study are to 1) evaluate germination and growth of lettuce (*Lactuca sativa*) in poultry biochar, 2) evaluate worm response to biochar, 3) evaluate leachate properties of biochar, and 4) develop a conceptual model for biochar research and use in the Chesapeake Bay Region.

## Methods

We acquired biochar from Frye's Poultry Farm located in Wardensville, West Virginia, USA. The Frye Poultry Farm has been using poultry manure to produce energy and biochar since 2007 when funding from the U.S. Department of Agriculture was obtained to purchase and install the demonstration system. The Frye facility is equipped with a pyrolysis-gasification unit that can process 10.9 mt of chicken manure in a 24 hour period, creating energy, and resulting in approximately 3.6 mt of biochar product, depending on variations in pyrolysis temperatures and the properties of the litter.

*Germination Experiments*

We conducted germination and growth trials in the summer and fall of 2011 in the West Virginia University (Morgantown, WV) greenhouse using natural light conditions and automated misters. Biochar was applied to soil at rates of 0.91 mt $ha^{-1}$ (3.18 g biochar $kg^{-1}$ soil)(low) and 4.5 mt $ha^{-1}$ (9.09 g biochar $kg^{-1}$ soil)(high) by applying the recommended dose onto 4 cm thick topsoil and mixing it together thoroughly. Some of the biochar was treated with deionized water (0.37 L water $kg^{-1}$ biochar) in an attempt to leach salts. The water immersion treatments were 24 hr water immersion and 48 hr water immersion. The 48 hr water immersion consisted of two 24 hr water immersion treatments separated by a 48 hr dry period. The water was changed between immersions. During water immersion the biochar was separated from the water by a metal sifting box lined with cotton cloth.

We performed a total of three germination experiments from June to October 2011. During the first two experiments six lettuce seeds were planted in 8 x 8 cm pots and allowed to grow until no new plants emerged for three days. Treatments were organized in a Latin square arrangement. After germination ceased, plants were randomly culled to two plants per pot and were allowed to grow an additional 8 days in both the topsoil experiment (Experiment 1) and mine soil experiment (Experiment 2). Experiment 3 followed the same protocols as experiments 1 and 2 but the two remaining plants were not harvested until they began to outgrow the pots. At the termination of each experiment the plants were harvested and their aerial tissue mass was determined.

Experiment 1 was conducted from 10 June to 1 July 2011 (22 days). The plants were planted in Scott's® topsoil. The eight treatments were 1) unamended topsoil, 2) topsoil amended with a high dose of 12:12:12 N:P:K commercial inorganic fertilizer, 3) topsoil amended with high and 4) low doses of untreated biochar, 5) topsoil amended with high and 6) low doses of 24 hr treated biochar, and 7) topsoil amended with high and 8) low doses of 48 hr treated biochar. Experiment 2 was conducted from 6 to 22 July 2011 (17 days); seeds were planted in mine soil acquired from a strip mine near Morgantown, WV. The treatments were unamended mine soil, and topsoil amended with low dose of untreated, 24 hr treated, and 48 hr treated biochar. Experiment 3 was conducted from 19 August to 31 October 2011 (74 days) using two separate Latin squares. This experiment used the same eight treatments as Experiment 1 except that mine soil rather than topsoil was used in the mixtures.

*Worm Experiments*

The worm avoidance experiment was conducted using five replicates from 10 to 12 June 2011. We placed 10 adult common red worms (*Eisenia foetida*) into a 10-cm diameter opening in the center of a 40 by 50 cm plastic chamber which was surrounded by 4 different treatments of soil (plain topsoil, untreated biochar, 24-hr biochar and 48-hr biochar) of equal volume. All biochar treatments were 0.91 mt $ha^{-1}$. After 48 hrs each worm was located and their position recorded.

*Biochar Properties*

We placed 0.5 g of air-dry biochar on Whatman 42 filter paper in a polycarbonate vacuum filtration apparatus, in triplicate. Distilled, deionized water was added in eight 100 mL increments. After each increment, the leachate was collected for determination of pH, electrical conductivity (EC), dissolved organic (DOC) and inorganic carbon (DIC) (Sievers 5100C, GE Analytical Instruments, Boulder, CO), and the elements Na, K, Ca, Mg and P by ICP-OES (Perkin-Elmer Optima DV2100, Perkin-Elmer Corp., Norwalk, CT). Sodium and the plant available nutrients (K, Ca, Mg and P) were determined from Mehlich 1 (0.05M HCl + 0.05M $H_2SO_4$) extracts by ICP-OES as described above on the biochar as received and a sample that had been leached with 600 mL $g^{-1}$ distilled, deionized water to remove excess salts.

Total carbon, nitrogen and hydrogen were determined by dry combustion (LECO TruSpec, St. Joseph, MI) before and after acid treatment to remove carbonates in triplicate, with duplicate subsamples. A known mass of biochar was allowed to soak overnight in 0.5M HCl, rinsed with distilled water to remove excess acid and oven dried overnight at $104^0$C.

*Data Analysis*

A multivariate analysis of variance (MANOVA) was used to quantify treatment effects and the effect of individual pots in the Latin squares for all response variables in lettuce germination and growth experiments. A significant MANOVA was followed with an analysis of variance (ANOVA) on each response variable to determine which variables were significantly different among treatments. A Tukey honest significant difference (HSD) post hoc test was used to make pairwise comparisons between treatment levels in significant ANOVAs. ANOVA was also used to test the effects of biochar treatments in the worm avoidance and biochar property experiments where a significant ANOVA was again followed with a Tukey HSD post hoc test as needed. *A priori* significance for all statistical tests was set at $P < 0.05$.

## Results and Discussion

*Germination Experiments*

In Experiment 1, days to germination, percent germination, and aerial mass were significantly different among treatments (Wilks' lambda = 0.51; $P < 0.001$). Percent germination averaged 87.2% (SE = 1.77) after 14 days across all treatments. Percent germination was lower for the high dose of untreated biochar than all other treatments which were similar (Fig.1a; $F_{7,49} = 3.1$, $P < 0.01$). The average number of days until seed germination was 5.85 (SE = 0.23). Seeds germinated the quickest in the soil only treatment, but the length of time was not different from the 48 hr low dosage biochar or fertilizer treatments (Fig.1b; $F_{7,49} = 14.1$, $P < 0.001$). Aerial biomass was greater for the low doses of untreated, 24 hr, and 48 hr immersion biochar than fertilizer or soil alone (Fig.1c; $F_{7,49} = 7.7$, $P < 0.001$).

The global MANOVA indicated significant differences among treatments in Experiment 2 (Wilks' lambda = 0.07; $P < 0.001$). Percent germination averaged 96.7% (SE = 1.4) and was similar among treatments ($F_{4,16} = 0.67$, $P = 0.62$). The average number of days until seed germination was 3.67 (SE = 0.11) and also was similar among treatments ($F_{4,16}$ = 0.09, $P$ = 0.99). Fertilizer produced significantly higher aerial mass than low dose, 24 and 48 hr treated biochar and untreated, low dose biochar ($F_{4,16}$ = 10.33; $P < 0.001$; Fig. 2).

In Experiment 3, a MANOVA for Latin square one indicated significant differences among treatments (Wilks' lambda = 0.30; $P$ = 0.047). Percent germination averaged 35% (SE = 5.1) and was lowest for soil, but similar for all other treatments ($F_{7,49}$ = 2.30, $P < 0.05$; Fig. 3a). Number of days until seeds germinated averaged 38.0 (SE = 4.27) and was higher in soil than in fertilizer or high dose 48 hr treated biochar ($F_{7,49}$ = 2.87, $P$ = 0.012; Fig. 3b). Fertilizer and high dose 48 hr biochar produced significantly higher aerial biomass than soil alone ($F_{7,49}$ = 2.5, $P < 0.05$; Fig. 3c). A global MANOVA for Latin square two indicated significant differences among treatments (Wilks' lambda = 0.21; $P < 0.001$). Average percent germination was 34% (SE = 4.2) and was lowest for soil, fertilizer and low dose untreated biochar compared to other treatments ($F_{7,49}$ = 3.40, $P < 0.01$; Fig. 3a). Number of days until seeds germinated averaged 43.9 (SE = 3.97) and was higher for fertilizer than high dose 48 hr treated biochar ($F_{7,49}$ = 3.67, $P$ = 0.002; Fig.3b). Aerial biomass was significantly higher for high dose, 48 hr biochar compared to all other treatments ($F_{7,49}$ = 5.30, $P <$ 0.001; Fig. 3c).

Results from the 3 germination and growth experiments varied, but it is clear that: 1) poultry biochar needs to be treated to maximize benefits; 2) biochar can be as effective as commercial fertilizer; and 3) the need for a pre-application treatment is increased as application rates increases. We found that higher concentrations of biochar yielded larger plants in at least one trial and similar masses were obtained in the other trials.

Our results indicate only the high application of untreated biochar negatively affected plant germination in some trials. Biochar generally increased wheat seed germination at the lower rates of biochar application and decreased or had no effect at higher rates of application (Solaiman et al. 2012). To improve germination and yield we recommend application of the high rate 48-hr treated biochar rather than the 24-hr or low application rates that we tested. We do recognize that there are other variations of treatment types and length and application rates that we have not tested which may prove useful and further investigations are warranted.

During Experiment 3, the two Latin squares were placed on the same mist table in the greenhouse and were set to receive the same amount of water and at the same times every day. However, the misters malfunctioned (particularly in Latin square 2) and therefore pots received less water than expected, which likely accounted for some of the difference seen in the results of the two Latin squares. Under dry soil conditions, which are experienced on some reclaimed minelands that have lost topsoil, biochar increased germination rates compared to fertilizer. The ability to enhance germination may be related to its ability to hold soil moisture (Verheijen et al. 2009). This finding is promising as we move forward with mineland biochar reclamation demonstration plots.

*Worm Experiments*

Worm selection of substrates was relatively consistent across the five replicates. A mean of 77% (SE = 11.4) of worms occurred in topsoil, with fewer worms in the 48-hr treated (17.3%; SE = 8.6), 24-hr treated (1.8%; SE = 0.89), and none in untreated biochar ($F_{3,12}$ = 15.69, $P < 0.001$). Liesch et al. (2010) found that earthworm avoidance rate increased and survival rate decreased in poultry litter biochar compared to pine chip biochar. This supports our results that worms avoided all poultry litter biochar treatments and preferred the plain soil. Additional experimentation is needed to improve biochar properties for worm inhabitation.

*Biochar Properties*

Leachate EC (Fig. 4a), K, Na and Ca concentrations (Fig. 4b) decreased continuously during the incremental leachate experiment. Leachate Mg and P concentrations also decreased but the relative changes were much smaller than for K, Na and Ca. Leachate EC had the strongest correlation ($R^2$ = 0.9989) and linear relation with leachate K concentration. Leachate DOC and DIC also decreased during the incremental leaching experiment, with the largest change occurring in DOC (Fig. 4c). Leachate pH was relatively constant with a mean of 6.9 (SE = 0.7). The mean pH of the distilled, deionized water was 5.6.

Leaching with 600 mL $g^{-1}$ distilled deionized water significantly decreased the Mehlich 1 extractable Na (untreated: mean = 36,650, SE = 150; treated: mean = 2,530, SE = 149)($F_{1,4}$ = 33,869; $P < 0.001$), K (untreated: mean = 146,700, SE = 980; treated: mean = 3,270, SE = 84)($F_{1,4}$ = 21,469; $P < 0.001$), Ca (untreated: mean = 8,480, SE = 63.4; treated: mean = 2,670, SE = 78.4)($F_{1,4}$ = 3,327; $P < 0.001$), and Mg (untreated: mean = 2,070, SE = 16.7; treated: mean = 1,900, SE = 8.41)($F_{1,4}$ = 78.83; $P < 0.001$), but not P (untreated: mean = 4,250, SE = 52.8; treated =4,050, SE = 99.3) ($F_{1,4}$ = 3.42; $P = 0.138$) .

The percent total C (untreated: mean = 53.6, SE = 0.14; treated: mean = 40.2, SE = 1.14)($F_{1,4}$ = 135.58; $P < 0.001$), N (untreated: mean = 4.9, SE = 0.044; treated: mean = 3.8, SE = 0.07)($F_{1,4}$ = 176.58; $P < 0.001$) and H (untreated: mean = 3.7, SE = 0.15; treated: mean = 3.0, SE = 0.08)($F_{1,4}$ = 15.71; $P = 0.017$) concentrations of the acid treated biochar were significantly smaller than the untreated biochar. The differences may be due to the distilled, deionized water rinsing that occurred after acid treatment (Figure 4c), but also reflects the loss of carbonate carbon.

The largest decreases were observed for K, Na, and Ca. Sodium and K concentrations in untreated biochar were high indicating that a leaching treatment would be beneficial when using as a soil amendment. Even after leaching, biochar is a good source of plant available Ca, Mg and P.

*Conceptual Model*

We have developed a conceptual model to guide future research and applied uses exploring the potential value of poultry-based biochar and other uses of poultry litter, as well as ways of decreasing the ecological footprint of poultry production (Fig. 5). Our concept focuses on poultry-house efficiency retrofits, energy production, water remediation, and biochar production. Each of these areas has research outcomes as well as economic development and workforce advancement opportunities. Our conceptual model contributes to our overall program goal of developing a comprehensive strategy to convert poultry litter from an environmental liability into an economic and ecological asset.

Although our conceptual model was developed in the Chesapeake Bay, our approach is universal because the ecological and economic benefits occur together, and not at the expense of one another, which represents a model that can be applied in the Chesapeake Bay Watershed and beyond.

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Figure 1. Experiment 1. A) Percent of lettuce seeds germinated, B) Number of days to germination, and C) Average aerial mass of lettuce plants in greenhouse trials based on eight treatments, summer 2011. Same letters represent no significant difference between treatments (unt = untreated, bio = biochar; lo = 0.91 mt $ha^{-1}$ (low); hi= 4.5 mt $ha^{-1}$ (high)).

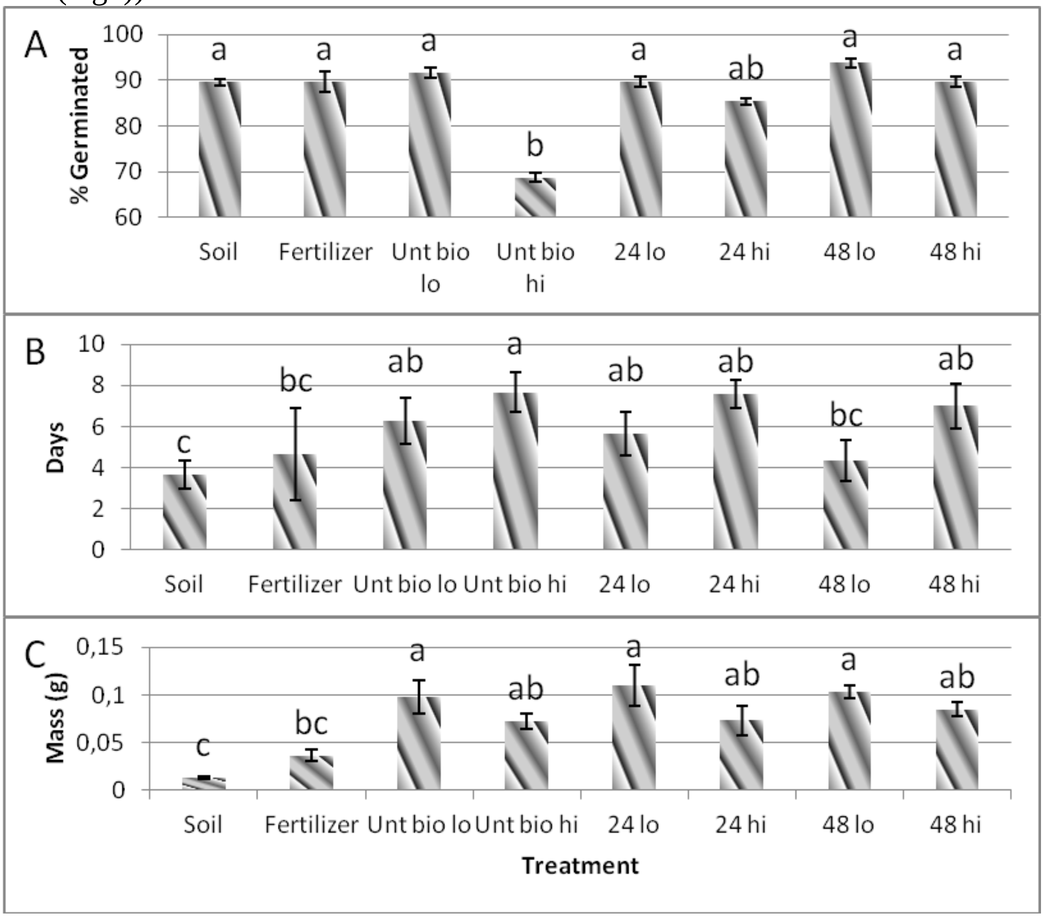



Figure 2. Experiment 2. Average aerial mass of lettuce plants in greenhouse trials based on five treatments, summer 2011. Same letters represent no significant difference between treatments (unt = untreated, bio = biochar; lo = 0.91 mt $ha^{-1}$ (low); hi= 4.5 mt $ha^{-1}$ (high)).

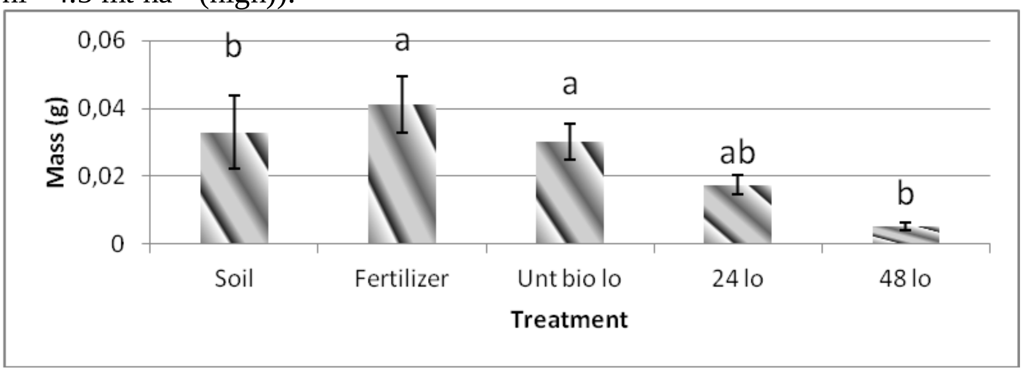


Figure 3. Experiment 3. A) Percent of lettuce seeds germinated, B) Number of days to germination, and C) Average aerial mass of lettuce plants in greenhouse trials based on eight treatments, summer 2011. Same uppercase letters (Latin Square 1) or same lowercase letters (Latin Square 2) represent no significant difference in treatments (unt = untreated, bio = biochar; lo = 0.91 mt $ha^{-1}$ (low); hi= 4.5 mt $ha^{-1}$ (high)).

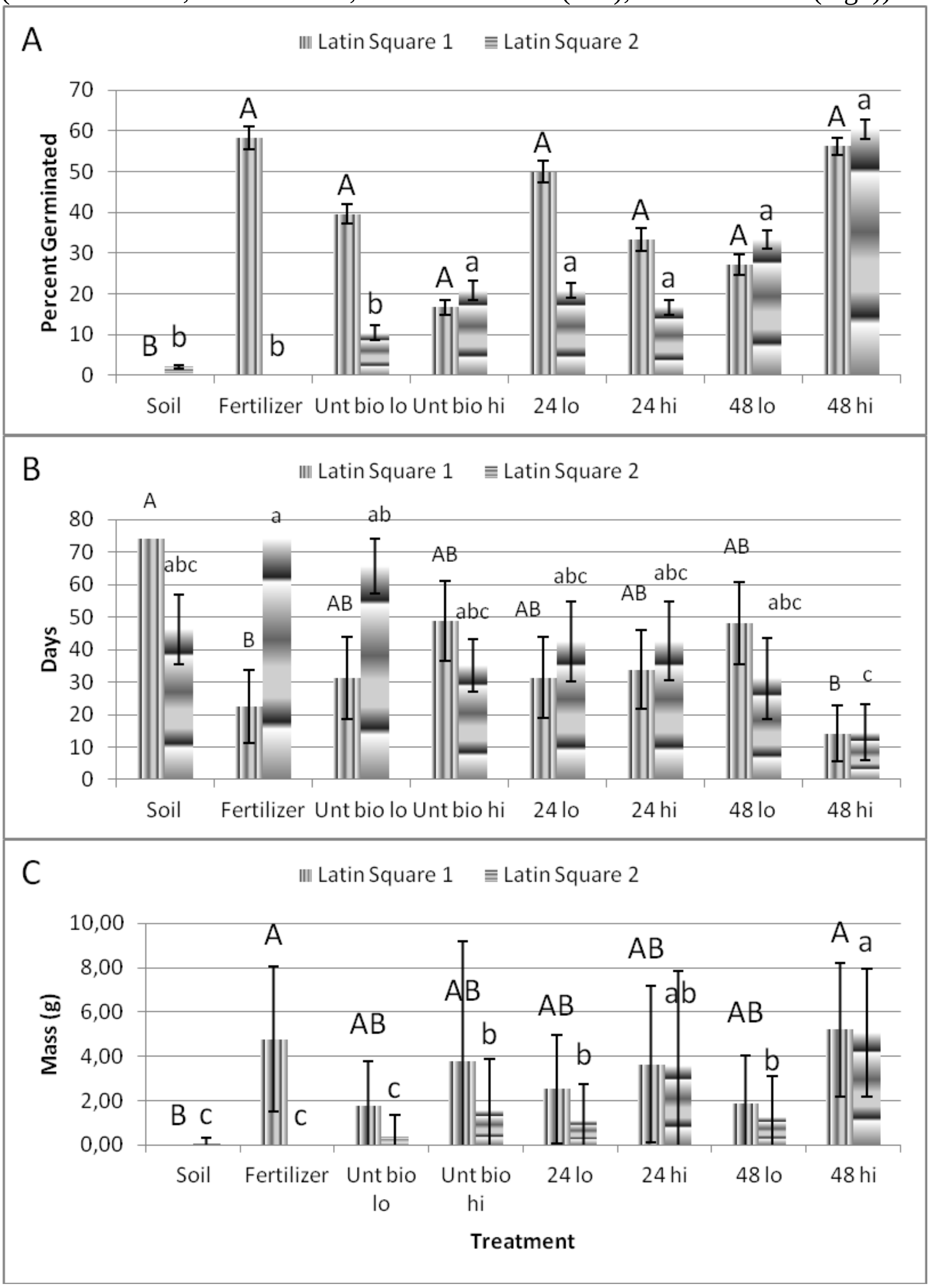
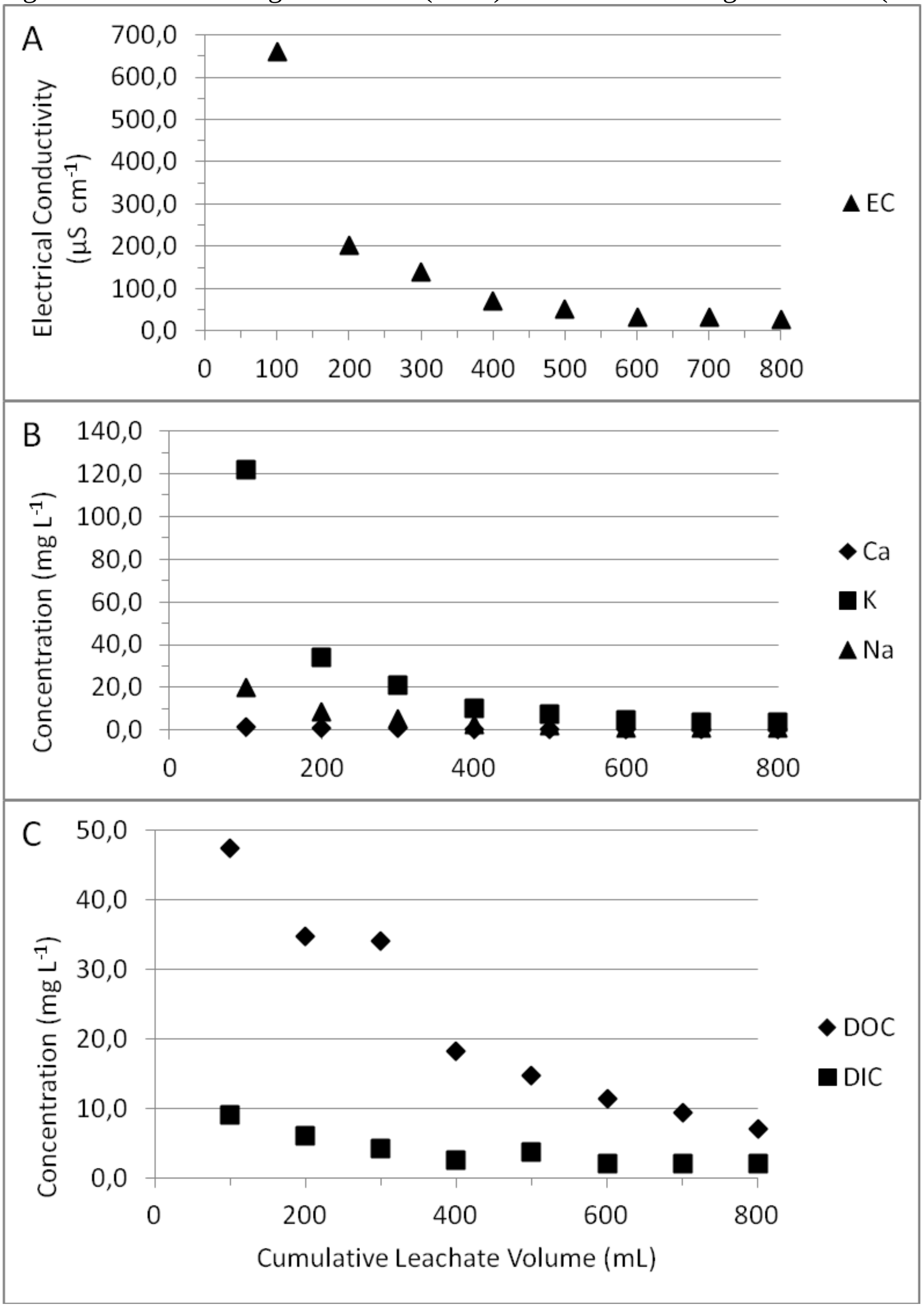


Figure 4. A) Cumulative leachate volume in mL per electrical conductivity (EC) in µS $cm^{-1}$, B) Cumulative leachate volume in mL per concentration in mg $L^{-1}$ for calcium, potassium, and sodium, C) Cumulative leachate volume in mL per concentration in mg $L^{-1}$ for dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC).



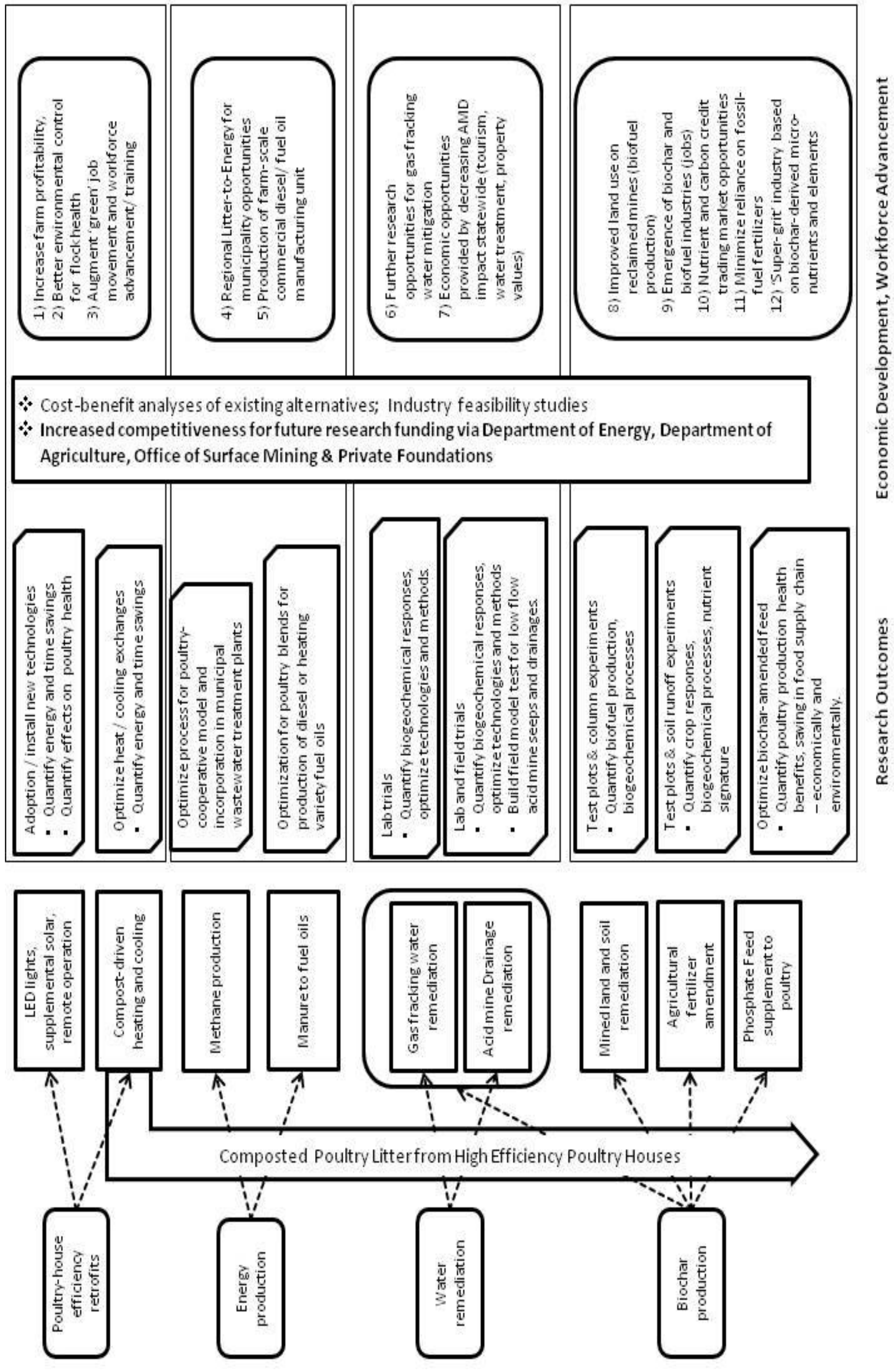



Figure 5. Conceptual model depicting future research avenues and other potential uses for poultry biochar and other poultry products.