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A COMPARISON OF VARIABLE ECONOMIC COSTS ASSOCIATED WITH TWO PROPOSED BIOCHAR APPLICATION METHODS

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ABSTRACT

The addition of biochar to agricultural soils has been shown to improve crop productivity and sequester carbon in soils over a millennial timeline. However, little formal research has assessed the logistics or economics of transitioning to a biochar economy. This paper examines the problem of biochar application to soil. Specifically, we look at two methods of application-broadcast-and-disk and trench-and-fill and provide cost estimates for each under varying rates of saturation. Our findings show that the broadcast process is generally cheaper; however, we consider a trench-and-fill method to be more suitable for storing large quantities of biochar in soil. For broadcast application, we found that at saturation rates of 2.5, 5, 10, 25, and 50 tons per acre, a respective cost per acre is $29, $44, $72, $158, and $300. Our examination of the trench-and-fill process revealed that cost depended on several variables, including saturation rate, trench depth, and operator efficiency. We found that at saturation rates of 5, 10, 25, 50, and 75 tons per acre, with trenches 2 feet deep, and at trenching and application rates of 15 feet per minute, a respective cost per acre of applied biochar is $34, $85, $171, $341, and $512. In both methods, we found results that suggest biochar application could constitute a considerable cost, many times greater than typical agricultural processes. Although our findings offer only a basic guide to calculating the cost of application, the intent of this paper is to serve as a launching pad for the much-needed additional research into the costs and other potential constraints of biochar application to agricultural soils.

Keywords: biochar, application methods, economics, conservation tillage, carbon sequestration

1. INTRODUCTION

Biochar is the carbon-rich product obtained when biomass is heated in a closed container with little or no available air through a process called pyrolysis [1]. Biochar can be used to improve agriculture in several ways and its stability in soil and nutrient-retention properties make it an ideal soil amendment to increase crop yields [2]. Biochar has been shown to serve as a habitat for microorganisms and to increase soil microbial diversity [3], reduce emissions of non-CO_2 greenhouse gases from soil [4], reduce soil nutrient leaching [5], and increase soil water retention [6]. In addition to the known agronomic benefits, biochar application to soil, in combination with sustainable biomass production, can be carbon-negative and therefore used to actively remove carbon dioxide from the atmosphere on a millennial timeframe [7]. Biochar production can also be combined with bioenergy production through the use of the gases and liquids that are given off in the pyrolysis process [8].

The ability of biochar to store carbon and improve soil fertility will not only depend on its physical and chemical properties, which can be varied in the pyrolysis process or through the choice of feedstock [9], but also on the technical and economic limitations of handling biochar at quantity in an agronomic setting. Despite growing interest among scientists and policy-makers over the potential benefits of biochar, little is known about the physical act of applying biochar to soil [10]. We believe this is a critical area for investigation since a more complete understanding of various constraints of application will help enable an adequate assessment of the overall feasibility of biochar. For example, little research has explored the agronomic impacts and costs of incorporating biochar in soil at various quantities [11]. Additionally, most biochar scenarios considered have emphasized use on conventionally managed arable land, where biochar could be added to soil as part of an existing tillage regime. However, the negative long-term consequences associated with high-impact soil management practices are well known [12], and it is conceivable that biochar could be incorporated into

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conservation-tilled and grazed grassland systems. Unfortunately, few such scenarios have been considered formally to date [13]. These unknowns constitute significant gaps that when filled could substantially shape the future of biochar research and development.

Biochar application will likely be subject to a wide array of constraints-environmental, technical, economic, and even social [14]. So little presently is known about application that it is impossible to determine which, if any, methods would be suitable for achieving the environmental, agronomic, and economic benefits that are anticipated from biochar. As a result, investigating the constraints of different application methods is essential in order to prepare for a comprehensive assessment of biochar.

In this paper we summarize our findings on the costs of two techniques: trench-and-fill and broadcast application. We draw on data from experimental work at Flux Farm and elsewhere [15], regional custom rates [16], implement specifica-tions, and, where necessary, our own calculated cost estimates. Our calculations cover variable costs only - those costs that depend on the rates of application - and therefore ignore capital costs associated with the machinery needed for application. We also disregard the cost of biochar itself since projecting a market value at present is still speculative due to a lack of an established market [17]. Our hope is that the findings provided herein will offer some baseline data for application costs that can help inform future discussions regarding the financial and technical practicality of proposed biochar uses.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1 Implement

The results conveyed in this paper have been derived from theoretical data provided by custom rates, manufacturer specifications and in-field experimental measurements. To guide our investigation we considered the use of specific equipment models for each application method. For the broadcast-and-disk, we considered data for a 160 HP John Deer tractor and a tractor-propelled lime spreader made by Atelier Desprès Inc in Val-Alain, Québec. No specific disking equipment was considered because we incorporated standard custom rates for this process and capital costs were not a factor in our calculations. For the trench-and-fill application, we considered the use of a John Deere 8875 Skid Steer along with a CAT T-9B trencher attachment to create the trenches and a Mill Creek Row Mulcher with a plow attachment for the application process.

2.1.2 Biochar Material

Biochar is the charcoal-like product resulting from the heating of biomass in a oxygen-deprived environment. The process of making biochar known as pyrolysis is an ancient concept, but modern pyrolyis equipment enables biochar production at quantity with precise controls. Biochar used in this trial was made and supplied by DynaMotive Energy Systems Corporation (West Lorne, Ontario, Canada) using fast pyrolysis technology to convert hardwood waste biomass into biofuel and biochar, which is commercially available under the name CQuest™. The bulk density of this material is 351.5 g/L. For comparison, the bulk density of agricultural lime ranges from 600 – 1,300 g/L.

2.2. Methods

2.2.1 Broadcast-and-disk application process

Broadcast application of biochar to topsoil is a relatively simple concept that may bring agronomic benefits such as enhanced soil chemistry [18]. The broadcast application process entails using conventional agricultural application equipment to apply biochar to the soil surface along with a disking pass to enable shallow incorporation of the biochar into the soil. We find that biochar's low bulk density makes a simple broadcast application inefficient, messy, and potentially hazardous to health due to dust, although the dust concern could be mitigated with appropriate equipment and safety training [10]. Yet, invasive incorporation techniques such as moldboard plowing may be undesirable due to soil erosion or sustainability concerns [19]. As a result, we have considered the costs of broadcasting along with the modestly invasive practice of disking. Disking minimizes soil exposure and risk of erosion by employing a disc set at a shallow angle [13]. A detailed description of this method of biochar application may be found in Husk and Major [15].

Broadcast application begins with the dispersal of biochar by way of a tractor-propelled lime spreader or similar equipment. Depending on the discharge rate achieved by the equipment, many passes per acre may be required to accomplish desired saturation rates. The broadcast pass is followed by a disking pass that helps incorporate the biochar into the topsoil, thereby preventing blowing of biochar.

2.2.2 Broadcast-and-disk cost estimation method

The cost (C_b) of broadcast-and-disk application is derived from the sum of the cost of disking (D) and the cost of biochar application (A_b) as follows:

$$C_b = D + A_b \tag{1}$$

Since disking is a common agricultural practice, custom rates for disking are annually published from region to region. For our purposes we used those supplied by the Colorado State University Agricultural Extension, which estimates $15 per acre [16]. The variable A_b was estimated using a function that considered labor cost (l_b), fuel cost (f_b), and maintenance cost (m_b), all of which vary with time (t_b) as follows:

$$A_b = t_b * (l_b + f_b + m_b) \tag{2}$$

The variable t_b is the ratio of saturation rate (s) to discharge rate (r), Equation (3).

$$t_b = \frac{s}{r} \tag{3}$$

We calculated costs for *s* at 2.5, 5, 10, 25, and 50 tons/ac. Discharge rate was computed at $8.9ft^3$/minute to match the trial experience documented in Husk and Major [15]. The remaining variables were determined as follows, l_b = $12/hour, f_b = $17.42/hour, and m_b = $3.97/hour as summarized in Table 1.

2.2.3 Trench-and-fill application process

Forming trenches in order to incorporate biochar into soil is a slow, labor- and capital-intensive process relative to other standard farm operations [20]. The process of trench-and-fill involves using implements such as a skid steer with a trenching attachment to cut trenches and then using a lime spreader or similar device to fill trenches with biochar. Despite the considerable investment in effort and capital, it is conceivable that trenching might provide significant agronomic benefits, a stable method to store biochar (i.e. prevent wind erosion), and a technically effective way for land to contain biochar at high saturations to maximize carbon sequestration. While the agronomic benefits have yet to be validated for the trench-and-fill method (a five year trial is currently underway at Flux Farm, Carbondale CO), this cost analysis provides an important first step in understanding the basic economic hurdles of establishing biochar application by way of trench-and-fill as a customary agricultural practice.

Table 1 Definitions for broadcast-and-disk application cost factors

Variable	Definition	Units	Notes:
t_b	Total time	hours	s/r
s	Saturation rate	Tons/acre	Ideal rate unknown
r	Discharge rate	ft^3/minute	$8.9ft^3$/minute[a]
l_b	Labor	$/hour	$12/hour[b]
f_b	Fuel	$/hour	17.42[c]
m_b	Maintenance	$/hour	$3.97/hour[c]
A_b	Application Cost for Broadcast	$	$A_b = t_b * (l_b+f_b+m_b)$
D	Cost of Disking	$	$15[d]
C_b	Total cost – broadcast app.	$	$C_b = A_b + D$

[a] ref [15]; [b] CSU Agricultural Extension, "Custom Rates for Colorado Farms and Ranches in 2008," see "Tractor Drivers-High Level Positions – Western, NW, Mtn, SW," pg 9; [c] Based on estimates for mid-sized (160 HP tractor). William F. Lazarus. "Machinery Cost Estimates." University of Minnesota Department of Applied Economics, June 2009. http://www.apec.umn.edu/faculty/ wlazarus/tools.html; [d] CSU Agricultural Extension, "Custom Rates for Colorado Farms and Ranches in 2008," see Disking.

Although a variety of techniques and equipment could be employed to accomplish biochar application through trenching, we have envisioned the following process. Step 1: Determine layout and number of trenches based on desired saturation level and trench dimensions. Step 2: Dig trenches using skid steer with trenching attachment or a ditch witch. Step 3: Apply biochar to trenches using tractor-propelled lime spreader fitted with a targeted applicator column, row mulcher or similar device. While we believe trench-and-fill could be accomplished along these lines, one unsolved problem is managing the soil excavated from the trenching process. Large-scale, on-the-ground trials are needed to determine a solution to this question, and as a result this potentially cumbersome and costly component of this application process has been left out of our analysis.

2.2.4 Trench-and-fill cost estimation method

The cost of biochar application with trenching (C_t) equals the sum of the cost of trenching (T) and the cost of application (A_t) as follows:

$$C_t = T + A_t \tag{4}$$

Variables T and A_t depend on time variables, t_{tr} and t_a, respectively. Variables affecting time are: saturation rate (s_t) as measured in tons per acre, trench dimensions (d_t) as determined by width and depth, trenching rate (r_t) as measured in feet per minute, and application rate (a_t) as also measured in feet per minute.

As in broadcast application, all expenditures vary with time taken for each of the two procedures (t_{tr}, t_a) as follows:

$$T = t_{tr}(l_{tr} + f_{tr} + m_{tr}) \tag{5}$$

$$A_t = t_a(l_a + f_a + m_a) \tag{6}$$

Trenching rates will likely vary based on region, equipment, and operator experience. Based on ongoing onsite experimentation with trench-and-fill application, we accomplished trenching rates at 15 feet per minute. However, in order to account for varying efficiencies, we have included additional cost estimates with r = 12, 15, and 20 feet per minute. Currently, we have no baseline data for application to trench rates, but since we expect targeted application to take about as much time as trenching, we used the same array of rates as trenching (a = 12, 15, 20 feet per minute).

Table 2 Definitions for trench-and-fill application variables

Variable	Definition	Unit	Notes
s	Saturation Rate	Tons/acre	Ideal rate unknown
d	Trench depth	ft	1-2’
n	Number rows/ acre	n/a	Depends on s, d.
r_t	Trenching/application rate	ft/minute	Between 12-20’/minute
t_{tr}	Time - trenching	hours	
$l_{t,a}$	Labor cost of trenching, application	\$/hour	Both based on custom rate for high level tractor operator in Western Colorado[a]
f_{tr}	Fuel cost for skid steer	\$/hour	7.2 ga/hour * \$2.50/ga = \$18.00[b]
m_{tr}	Maintenance for skid steer	\$/hour	\$4/hour; estimated from average maintenance cost over 1,000 hours[c]
T	Subtotal cost for trenching	\$	
f_a	Fuel cost of tractor/applicator	\$/hour	\$17.42/hr[d]
m_a	Maintenance for tractor	\$/hour	\$3.97/hour[e]
A_t	Subtotal cost for Application	\$	
C_t	Total cost Trenching Process	\$	

[a] CSU Agricultural Extension, “Custom Rates for Colorado Farms and Ranches in 2008,” see “Tractor Drivers – High Level Positions – Western, NW, Mtn, SW,” pg 9; [b] Assuming diesel fuel @ \$2.50 per gallon and an expected consumption rate of 7.2 gallons per hour. Based on field experience at Flux Farm Foundation; [c] Based on data maintenance data supplied by Wagner Equipment in Carbondale, CO, September 15, 2009; [d] Lazarus, 2009; [e] Based on estimates for mid-sized (160 HP tractor).

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Table 3 Broadcast-and-disk application results

Biochar saturation rate		Time	Application Costs			Subtotal	Disking	Total
Tons/acre *S*	ft^3/acre *28.3L/ft³*	Total (hr) t_b	Labor L_b	Fuel f_b	Maint. m_b	Application A_b	Disking D	Cost C_b
2.5	228	0.4	$5	$7	$2	$14	$15	$29
5	456	0.9	$10	$15	$3	$29	$15	$44
10	912	1.7	$20	$30	$7	$57	$15	$72
25	2280	4.3	$51	$74	$17	$143	$15	$158
50	4559	8.5	$102	$149	$34	$285	$15	$300

3. RESULTS AND DISCUSSION

In this paper, we have provided some preliminary estimates of the cost of biochar application. We summarize these findings in Tables 3 and 4. These findings suggest that the total cost of biochar application to soil using a broadcast method could range from $29-300/acre for application rates of 2.5 to 50 tons/acre. When using the trench-and-fill application method, application costs range from $26-1,280/acre for rates between 5-75 tons/acre. As might be expected, the more time-intensive activity of the trenching method drove up costs to nearly double those of the broadcast method. Considering these cost estimates, we find that the method and cost of biochar application to soil is a critical component of an overall biochar regime.

Much is still unknown about the relative agronomic benefits of various application methods, and there is also much room for improvement in our understanding of the costs of application. What the results of this study tell us is that the cost of biochar application itself is substantial enough to become a key factor in considering the overall viability of a biochar market. Even at low saturation rates, the cost of application exceeds that of any other common agricultural process [16]. While it is possible that a well-established carbon credit trading market could push the economic benefits of biochar application above the application costs, the large uncertainty over both the agronomics and economics of biochar will likely deter landowners and investors from using biochar in the near future.

4. CONCLUSIONS

We find it crucial that future research efforts focus more on application and associated life-cycle costs of various biochar application processes. Advancing our understanding of best practices for application and their costs in various agricultural settings will enable a more comprehensive assessment for the feasibility of a large-scale biochar regime. The estimates provided in this analysis offer only a preliminary idea of expected costs of application for only two of many possible proposed and emerging methods. Confirmation of these results will only come through further on-the-ground testing. Future biochar research should focus on both basic research and the development of innovative and scalable application methods that are cost effective and ecologically sustainable. In addition, more testing of the effects of various application rates on the soil needs to occur. There is still uncertainty regarding the benefits of various saturation rates, and it is also unknown what potential negative impacts various application methods can have on different types of soils for different types of crops and the regional impacts on application costs. As part of this testing, special attention needs to be paid to the enduring effects of biochar in soil. Understanding how long the economic or agronomic benefits from biochar can continue to accrue may help justify the potentially high cost of application we observe in this paper.

It is inconceivable that a significant decrease in the variable cost of the current application practices considered here would be experienced due to the inherent physical limitations of earth moving and materials handling. However, we do anticipate that innovative application methods, not yet developed or tested, could conceivably decrease costs through the implementation of intentionally designed and optimized biochar handling equipment.

5. ACKNOWLEDGEMENTS

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Table 4 Trench-and-fill application results

SATURATION				TRENCHING						APPLICATION						
Saturation Rate		Trench Size		Time		Costs			Subtotal	Time		Costs			Subtotal	TOTAL
Tons/ac s_t	ft^3/acre $28.3L/ft^3$	Depth (ft) d	Rows/ ac n	Rate (ft/m) r_t	Total (hr) t_{tr}	Labor l *\$12*	Fuel f *\$18*	Maint. m *\$4*	Cost c_t	Rate (ft/m) r_a	Total (hr) t_a	labor l *\$12*	Fuel f *\$17.42*	Maint. m *\$3.97*	Cost A_t	Cost C_t
5	456	1	4	12	1.3	\$15	\$23	\$5	\$43	12	1.3	\$15	\$22	\$5	\$42	\$85
				15	1.0	\$12	\$18	\$4	\$34	15	1.0	\$12	\$18	\$4	\$34	\$68
				20	0.8	\$9	\$14	\$3	\$26	20	0.8	\$9	\$13	\$3	\$25	\$51
5	456	2	2	12	0.6	\$8	\$11	\$3	\$22	12	0.6	\$8	\$11	\$3	\$21	\$43
				15	0.5	\$6	\$9	\$2	\$17	15	0.5	\$6	\$9	\$2	\$17	\$34
				20	0.4	\$5	\$7	\$2	\$13	20	0.4	\$5	\$7	\$2	\$13	\$26
12.5	1140	1	11	12	3.2	\$38	\$57	\$13	\$108	12	3.2	\$38	\$55	\$13	\$106	\$213
				15	2.5	\$30	\$46	\$10	\$86	15	2.5	\$30	\$44	\$10	\$85	\$171
				20	1.9	\$23	\$34	\$8	\$65	20	1.9	\$23	\$33	\$8	\$63	\$128
12.5	1140	2	5	12	1.6	\$19	\$28	\$6	\$54	12	1.6	\$19	\$28	\$6	\$53	\$107
				15	1.3	\$15	\$23	\$5	\$43	15	1.3	\$15	\$22	\$5	\$42	\$85
				20	0.9	\$11	\$17	\$4	\$32	20	0.9	\$11	\$17	\$4	\$32	\$64
25	2280	1	22	12	6.3	\$76	\$114	\$25	\$215	12	6.3	\$76	\$110	\$25	\$211	\$343
				15	5.1	\$61	\$91	\$20	\$172	15	5.1	\$61	\$88	\$20	\$169	\$274
				20	3.8	\$46	\$68	\$15	\$129	20	3.8	\$46	\$66	\$15	\$127	\$206
25	2280	2	11	12	3.2	\$38	\$57	\$13	\$108	12	3.2	\$38	\$55	\$13	\$106	\$213
				15	2.5	\$30	\$46	\$10	\$86	15	2.5	\$30	\$44	\$10	\$85	\$171
				20	1.9	\$23	\$34	\$8	\$65	20	1.9	\$23	\$33	\$8	\$63	\$128
50	4559	1	43	12	12.7	\$152	\$228	\$51	\$431	12	12.7	\$152	\$221	\$50	\$423	\$853
				15	10.1	\$122	\$182	\$41	\$344	15	10.1	\$122	\$176	\$40	\$338	\$683
				20	7.6	\$91	\$137	\$30	\$258	20	7.6	\$91	\$132	\$30	\$254	\$512
50	4559	2	22	12	6.3	\$76	\$114	\$25	\$215	12	6.3	\$76	\$110	\$25	\$211	\$427
				15	5.1	\$61	\$91	\$20	\$172	15	5.1	\$61	\$88	\$20	\$169	\$341
				20	3.8	\$46	\$68	\$15	\$129	20	3.8	\$46	\$66	\$15	\$127	\$256
75	6839	1	65	12	19.0	\$228	\$342	\$76	\$646	12	19.0	\$228	\$331	\$75	\$634	\$1280
				15	15.2	\$182	\$274	\$61	\$517	15	15.2	\$182	\$265	\$60	\$507	\$1024
				20	11.4	\$137	\$205	\$46	\$388	20	11.4	\$137	\$199	\$45	\$381	\$768
75	6839	2	33	12	9.5	\$114	\$171	\$38	\$323	12	9.5	\$114	\$165	\$38	\$317	\$640
				15	7.6	\$91	\$137	\$30	\$258	15	7.6	\$91	\$132	\$30	\$254	\$512
				20	5.7	\$68	\$103	\$23	\$194	20	5.7	\$68	\$99	\$23	\$190	\$384

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Appendix A Table of variables

Var.	Definition	Units	Notes:
Broadcast			
s	Saturation Rate	Tons/acre	*Ideal rate unknown*
t_b	Total time	hours	Discharge rate = 8.9ft^3/minute
l_b	Labor	$/hour	$12/hour[a]
f_b	Fuel	$/hour	17.42[b]
m_b	Maintenance	$/hour	$3.97/hour[b]
A_b	Subtotal Cost for Broadcast	$	$A_b = t_b * (l_b+f_b+m_b)$
D	Cost of Disking	$	$15[c]
C_b	Total cost – broadcast app.	$	$C_b= A_b + D$
Trenching			
s	Saturation Rate	Tons/acre	Ideal rate unknown
d	Trench depth	ft	1-2'
n	Number rows/ acre	n/a	Depends on *s*, *d*.
r_t	Trenching/application rate	ft/minute	Between 12-20'/minute
t_{tr}	Time - trenching	hours	
l_t	Labor cost of trenching, application	$/hour	Both based on custom rate for high level tractor operator in Western Colorado[d]
f_{tr}	Fuel cost for skid steer	$/hour	1.9 ga/hour * $2.50/ga = 4.75[e]
m_{tr}	Maintenance for skid steer	$/hour	$4/hour; estimated from average maintenance cost over 1,000 hours[f]
T	Subtotal cost for trenching	$	
f_a	Fuel cost of tractor/applicator	$/hour	$17.42/hr[g]
m_a	Maintenance for tractor	$/hour	$3.97/hour[h]
A_t	Subtotal cost for Application	$	
C_t	Total cost Trenching Process	$	

[a] CSU Agricultural Extension, "Custom Rates for Colorado Farms and Ranches in 2008," see "Tractor Drivers – High Level Positions – Western, NW, Mtn, SW," pg 9; [b] Based on estimates for mid-sized (160 HP tractor). William F. Lazarus. "Machinery Cost Estimates." University of Minnesota Department of Applied Economics, June 2009. http://www.apec.umn.edu/faculty/ wlazarus/tools.html; [c] CSU Agricultural Extension, "Custom Rates for Colorado Farms and Ranches in 2008," see Disking; [d] CSU Agricultural Extension, "Custom Rates for Colorado Farms and Ranches in 2008," see "Tractor Drivers – High Level Positions – Western, NW, Mtn, SW," pg 9; [e] Assuming diesel fuel @ $2.50 per gallon and an expected consumption rate of 1.9 gallons per hour. Based on 8-hour expected run time for Caterpillar 242B, which carries a 15.3 gallon fuel tank. Wagner Equipment, GJ, CO, September 13, 2009; [f] Based on data maintenance data supplied by Wagner Equipment in Carbondale, CO, September 15, 2009; [g] Lazarus, 2009; [h] Based on estimates for mid-sized (160 HP tractor). Ibid.

Appendix B Unit analysis

Unit analysis for conversion used from tons/acre to ft^3/a:

$$\frac{1\text{ton}}{1\text{ac}} * \frac{2000\text{lbs}}{1\text{ton}} * \frac{1\text{kg}}{2.205\text{lbs}} \frac{1000\text{g}}{1\text{kg}} * \frac{100\text{ml}}{35.15\text{g}} * \frac{1\text{L}}{1000\text{ml}} * \frac{1\text{ft}^3}{28.3\text{L}} = 91.2\text{ft}^3/\text{ac}$$

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