Willingness to Pay for Potting Mix Containing Eastern Redcedar Biochar under Alternative Information Sets

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Abstract. **Biochar is considered an environmentally friendly potting mix ingredient because it sequesters carbon, and its biomass can be obtained from renewable resources. If the biomass is obtained from the undesirable eastern redcedar (*Juniperus virginiana*), then it has the additional benefit of helping to curtail its spread and protect natural habitats. If consumers recognize this benefit, then they may be willing to pay a premium for potting mix made from eastern redcedar biochar. This study used an internet survey of potting mix customers to measure the size of this potential premium. The results showed that consumers were willing to pay $2.42/ft³ more for potting mix containing 20% eastern redcedar biochar (by weight). This premium was even larger for respondents who were aware of the weedy nature of eastern redcedar.**

Millennia ago, humans in the Amazon rainforest began improving the soil by mixing it with charcoal and organic matter. At some point, they stopped, and the practice was forgotten until researchers stumbled on an unusually fertile soil in a rainforest where soils are usually deficient in nutrients and carbon. In these curious areas, the soil was black and contained carbon levels 70-times greater than that of surrounding soils. Investigations concluded it was anthropologic in origin, and further studies revealed that instead of using "slash and burn" agriculture, they used "slash and char." Vegetation would be felled, set on fire, and then buried, creating what scientists call biochar. The soils were named Terra Preta for "dark earth," and sometimes they were called Terra Preta de Índio for "Amazonian dark earths"; both names are Portuguese (Bezerra et al. 2019; Glaser and Birk 2012; Rees et al. 2001).

At the same time when the Amazonians were inventing biochar, eastern redcedar (ERC) was growing in North America. The shrubs or small trees mostly thrived on limestone outcrops and areas protected from wildfires. The plants spread prolifically by seed and can grow quickly in the presence of little water, but natural wildfires historically kept their populations contained (Ramli et al. 2017). As the prevalence of fires decreased with settlement by European colonists, its population has increased so much that although it is native to North America and, thus, not technically an invasive species, "invasive" is a common adjective applied to the tree. For example, the Oklahoma State University Extension Service has remarked that ERC is "claimed as an invasive species" (Hiziroglu 2018), and a recent Tulsa World newspaper article described ERC under the caption "invasive species warning" (Bostian 2023).

Although ERC can be controlled, the expense of doing so is considerable (Coffey 2011). This expense can be lowered by two means: finding less expensive means of killing the tree or developing a valuable by-product whose revenues can help pay for its eradication. A number of by-products have been explored, including podophyllotoxin for health treatments (Stenmark 2021) and furniture (Hiziroglu 2018).

Perhaps the lessons from the Terra Preta can be imported to the United States to help control ERC? Biochar is already being used as a potting mix ingredient. If biochar can be made economically from ERC, then this Neolithic practice might be a key to curtailing its spread. The ability of ERC biochar to be a profitable product as a potting mix ingredient is partially dependent on its ability to command a price premium because of its environmental benefits. The purpose of this study was to estimate the magnitude of such premiums.

Biochar effectiveness in potting mix depends on the type of biochar used and the specific recipe of potting mix (Dunlop et al. 2015; Guo et al. 2018; Vaughn et al. 2015). For example, biochar made from hardwood and corn (*Zea mays*) stalks has no effect on germination rates, and biochar from olive (*Olea europaea*) mill byproducts causes phytotoxicity (Fornes and Belda 2018). The literature regarding the impact of biochar on plant performance is too large to describe here, but some examples have been provided to demonstrate the variety of questions that this literature has addressed. Biochar can be substituted for vermiculite to grow unrooted vegetative cuttings of poplar (*Populus* hybrid) trees (Headlee et al. 2014). A media containing as high as 70% hardwood biochar (30% peatmoss) achieves the same plant biomass for tomato (*Solanum lycopersicum*) and basil (*Ocimum basilicum*) seedlings as commercial mixes (Yu et al. 2019). Margenot et al. (2018) concluded that biochar from softwood trees can be a substitute for peatmoss in marigold (*Tagetes erecta*) production, and Nemati et al. (2015) concluded it can substitute for peat or vermiculite.

Research is currently being conducted to determine the performance of biochar made from ERC (Vaughn et al. 2021). This source of biomass might have the benefit of eliciting a higher premium in the potting mix market if it is marketed as a product that reduces the ERC population. Potting mix

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.0283	ft^3	m^3	35.3147
0.9464	qt	L	1.0567

containing any source of biochar can tout some environmental benefits. For example, carbon in biochar is stable for ~1000 years (Sohi et al. 2010), making it a carbon sink, and its use reduces the need to extract peatmoss.

Measuring the premiums that a business can charge for an environmentally friendly product can be performed using valuation methods and is also known as willingness to pay (WTP). Valuation or WTP studies differ according to whether the subjects are evaluating products hypothetically (stated preference) or whether real money is exchanged (revealed preference). They also differ according to how subjects are asked to express their desire for a product: they can rate their willingness to buy using a scale, choose one product from a set of choices, or bid money in an auction.

Several previous studies have applied these WTP methods to horticultural topics. Khachatryan et al. (2014) used an online survey to ask consumers to use a scale to rate their willingness to purchase various plants based on attributes that differed by the species, production practice used (e.g., conventional vs. sustainable), type of container, origin of production, and price. Then, a mixed-ordered probit model was used to infer consumers' WTP for changes in various attributes, resulting in the finding that plants with environmentally friendly attributes could be sold at a premium. Khachatryan et al. (2014) studied hypothetical purchases and no money changed hands. However, Fuller et al. (2022) held auctions using real money to measure the WTP for more ethical coffee (*Coffea* sp.) beans. Likewise, Yue et al. (2015) combined the previous two studies and used both a hypothetical rating mechanism and conducted a nonhypothetical auction. Instead of asking survey respondents to rate their willingness to buy various products, Chen et al. (2020) used choice experiments, whereby subjects were presented with different plastic mulches at various prices and asked which one they would hypothetically purchase. Then, a mixed logit was used to estimate their WTP higher prices for biodegradable mulches. Sometimes more direct WTP approaches are used. For example, Waliczek et al. (2020) simply asked survey respondents to circle a number indicating their WTP for a product.

A previous study explored consumers WTP higher prices for potting mix containing biochar (Thomas et al. 2021), but it only considered the climate change benefits because the biomass feedstock was not specified. This study specifically measured WTP for biochar made from ERC in a setting where the consumer was informed about the benefits of both sequestering carbon and controlling a weedy species.

Materials and methods

A nationwide survey of Americans was conducted using an online survey whereby participants were presented with different bags of potting mix and were asked their likelihood of purchasing them. A stated preference survey model was used because participant responses were based on hypothetical purchasing scenarios. A revealed survey model could not be conducted because no commercial potting mixes contain ERC biochar. Additionally, stated preference survey models are more amenable to online surveys and can be administered to a larger respondent pool with little to no additional costs.

The participant sample was acquired from Qualtrics (Provo, UT, USA), which maintains a panel of United States denizens who volunteer to take surveys in return for various compensations like gift cards, cash, or airline miles. Although the sample demographics were deliberately chosen to mimic those of the United States as a whole, because it was an opt-in sample, it may not be as robust or representative of the general population as other sampling methods. The survey design and implementation were approved by the Institutional Review Board at Oklahoma State University (under application IRB-22–207).

The first two questions of the survey were designed to narrow the respondent pool to those who had purchased potting soil. Then, the remaining respondents were presented with visual illustrations of potting mix bags (containing information that mimicked common marketing practices) and asked to rate their likelihood to purchase using a scale of 0 to 100, with a higher number indicating a higher likelihood.

Three scenarios (i.e., contexts) were presented to each respondent. The first context (set A, shown in Fig. 1) measured respondents' initial reaction to potting mix containing ERC biochar without presenting any information about the qualities of biochar. Each respondent was presented with four bags in a randomized order. All bags in the survey contained the claim "designed for optimal plant growth." The price of each bag was either $3 or $9 per cubic foot; half the bags indicated it contained 20% ERC biochar and the other half did not. Together, the four bags represented all possible combinations of the varying price and biochar attributes, allowing a measure of how respondents react to ERC biochar as an ingredient before being provided with

Fig. 1. Three information exposures, price levels, and potting mix attributes used in the survey to measure willingness to pay for eastern redcedar biochar as a potting mix ingredient. The survey was conducted online in 2022 and included 496 respondents who purchase potting mix. $1/ft^3 = $35.3147/m^3.

information about its qualities. The second context (set B) was similar to set A, except that the label indicating "20% ERC biochar" was replaced with "Is environmentally friendly."

The third context (set C) included a larger number of varieties and represented the purchasing patterns of consumers who were informed about ERC biochar. Before set C, respondents were presented with questions regarding ERC itself. First, they were asked about their familiarity with a list of nine different trees, including ERC. Then, respondents were told that at least one tree on the list was invasive, and they were asked to identify which one. Then, respondents were exposed to information designed to ensure that they understood that ERC invades regions where it is not wanted, how harvesting it for biochar can help contain its spread, and the benefits of replacing other potting mix supplements like peat with biochar.

After providing this information, the respondent was asked to rate potting mix bags in set C. To avoid a potential instrument-induced bias (Norwood and Lusk 2005), two additional attributes were randomly included with ERC biochar. One was the bag type containing either no label regarding bag type or the verbiage "durable yet easy-to-open packaging." The other attribute concerned whether it was produced locally. The bags either said "produced locally" or did not mention the production location.

Bags in set C had 0%, 10%, or 20% ERC biochar (if 0%, then there was no label referring to the biochar). Figure 1 shows the following bag labels: "contains 10% ERC biochar," "durable yet easy-to-open packaging," and "produced locally" (in addition to "designed for optimal plant growth," which was always present). If the potting bag did not include information such as produced locally or durable yet easy-to-open packaging, then the respondents were told to assume that the bag was not produced locally and that the packaging was neither durable nor easy to open. There were 60 different combinations of labels (three ERC levels × five biochar price levels × two packaging levels × two regions of production levels = 60), and each respondent was presented with five randomly chosen combinations to rate.

Statistical procedures

The respondent ratings of different types of potting mix were used to measure price premiums consumers would pay for potting mix containing ERC biochar. This involved first statistically documenting how the likelihood of purchasing any mix varies with its attributes, and then using those estimates to calculate the maximum additional amount the average respondent would pay for a mix containing ERC biochar relative to a mix containing none.

The ratings of the potting mix types were estimated using a Tobit model (Tobin 1958). Several WTP studies have used the Tobit model for analyses (Carlsson and Martinsson 2007; Donaldson et al. 1998; Fuller et al. 2022; Halstead et al. 1991; Saz-Salazar et al. 2020; Wang et al. 1997). Khachatryan et al. (2014) used an ordered probit model to analyze a similar rating variable, but that requires estimating dozens (up to 100) of additional threshold parameters, and each additional parameter estimated detracts from the statistical degrees of freedom. Conversely, the use of a Tobit model allowed us to estimate the same latent construct with no additional parameters.

For each context (set A, set B, and set C), a Tobit model was estimated, where the rating (R_{ij}) respondent i assigned to a potting mix bag j was determined by a vector of potting mix attributes (X_j), a parameter vector articulating the contribution of each attribute to ratings (β), an error term specific to each respondent (μ_i), and an idiosyncratic error term (ϵ_{ij}). The term μ_i accounted for the fact that some respondents may tend to provide lower or higher ratings than others; incorporating this information in the model helped to provide more accurate parameter estimates. Both μ_i and ϵ_{ij} were assumed to be normally distributed with a zero mean and constant variance. The difference between μ_i and ϵ_{ij} was that ϵ_{ij} was the same for each respondent, whereas ϵ_{ij} varied across each respondent and bag being evaluated. The model is shown in Eq. [1] and was estimated as a Tobit model with the lower and upper bounds for R_{ij} being 0 and 100, respectively.

$$R_{ij} = X_j\beta + \mu_i + \epsilon_{ij} \qquad [1]$$

In set A, the bag had only two attributes: an indicator variable for the presence of ERC biochar (denoted ERC_j) and a variable for price (P_j); therefore, the vector $X_j = [1 \ ERC_j \ P_j]$ and $\beta = [\beta_0 \ \beta_{ERC} \ \beta_P]'$. The variable $ERC_j = 1$ when the bag indicated it contained ERC biochar and zero otherwise. The maximum premium that the average respondent would pay for a mix containing ERC biochar relative to an otherwise identical bag that did not was the change in price (ΔP) that set $\beta_0 + \beta_{ERC} + \beta_P(P_j + \Delta P) = \beta_0 + \beta_P(P_j)$. This maximum premium was $\Delta P = -\frac{\beta_{ERC}}{\beta_P}$. To obtain a confidence interval for this statistic, the Krinsky and Robb (1986) method was used. A similar model structure was used for set B and set C, but with different explanatory variables in X_j.

Results and discussion

Characteristics of respondents. Of 1023 respondents, only 715 indicated that they had purchased potting mix in the past; therefore, 715 respondents were retained for analysis. Participants who haphazardly answered survey questions were filtered out by providing a follow-up question after each piece of information. After each piece of information, the respondent was presented with a one-question quiz to determine if they paid attention. These questions are useful for identifying people who are answering questions haphazardly and, thus, should not be considered "informed" consumers. Eliminating the subjects who did not answer all three questions correctly reduced the sample size from 715 to 496. Characteristics of the 496 respondents are shown in Table 1. Most purchased potting mix approximately once per year. The frequency of purchases was used as an approximate and indirect proxy for the amount of potting mix purchased (it was believed that households would not be able to accurately estimate the amount of potting mix or dollars spent on potting mix). Approximately half the respondents were female, and this was the same for all frequencies of purchases, and a little less than half of the respondents belonged to households with more than $100,000 in annual income. Most respondents grew plants inside, and potting mix was used more for ornamentals than edible plants. The greater the frequency of purchases, the greater the variety of plants grown. This survey did not target a representative sample of Americans; instead, it was concerned with people who purchased potting mix. Therefore, no comparison

Table 1. Sex, income, type of plants grown, and frequency of potting mix purchases of an internet sample of 496 respondents who purchase potting mix.

	Approximately every other yr (n = 85)	Approximately once per yr (n = 271)	More than once per yr (n = 140)
Female (%)	43	52	47
Household income >$100,000 (%)	31	42	43
	Proportion (%) of households that grow		
Plants indoors	74	73	89
Outdoor ornamentals in pots	64	72	81
Outdoor ornamentals in ground	52	56	66
Outdoor fruit, vegetables, or herbs in pots	34	41	66
Outdoor fruit, vegetables, or herbs in ground	32	36	52

of sample demographics with those of the population was performed.

Knowledge about ERC. Of the 715 respondents, 262 had heard of ERC and 93 identified it as invasive. Of course, as a native plant, ERC does not meet the United States Department of Agriculture, Forestry Services' definition of an invasive species, but the public often informally and colloquially terms it "invasive" in this region. Therefore, we used this more informal definition during the survey to better identify with the target audience. This suggested that approximately 13% of potting mix customers not only knew of ERC but also were aware that it is considered a nuisance. Then, a picture of an ERC tree was provided, and the respondents were asked if they had seen it before; 56% indicated that they had, but there are numerous trees that could be mistaken for it.

Tobit WTP estimates for potting mix. The Tobit model estimates for each set are shown in Table 2. A potting mix containing ERC biochar as an ingredient is not currently a commercial product; therefore, measuring its potential on the market is difficult because consumers are not familiar with the product. The success of the product will depend on its performance in growing plants, how it is marketed, and the extent to which consumers are informed about the qualities of ERC biochar. To accommodate various marketing strategies and consumer information, respondents were asked to rate the bags in three different contexts.

Set A was considered first to capture a scenario in which a consumer confronts a potting mix containing 20% ERC biochar but with no information about the biochar. The coefficient of price was statistically significant at the 5% level, with a point estimate of −5.17. This means that for every \$1/ft^3 increase in price, the rating of the mix decreased 5.17 points. The coefficient corresponding to the biochar was negative and statistically significant at the 10% level, but not the 5% level, suggesting that the presence of ERC biochar as an ingredient either did not change the rating or, if it did, reduced the likelihood of the mix being purchased. The point estimate suggested that the potting mix containing ERC biochar was valued \$0.37/ft^3 less than a bag without ERC biochar, but the standard deviation of this estimate was \$0.22/ft^3, suggesting that the discount assigned to potting mix with ERC biochar was not statistically significant at the 5% level. This suggested that the average respondent has difficulty understanding the use of biochar in the potting mix, and that if it changed their perception of the product, then it made it less desirable.

The model for set B describes a scenario in which the consumer sees a potting mix bag claiming to be environmentally friendly. A company selling this product will likely tout its environmental benefits; therefore, this set of bags was intended to gauge respondents' reactions to potting mixes with such claims. Both sets A and B represented situations in which consumers were making uninformed decisions based on limited information provided on the potting mix labels. The coefficient for the environmentally friendly label was positive and statistically significant. The WTP estimate of 0.618 meant that the average consumer will pay up to \$0.618 more for potting mix bags with an "environmentally friendly" label than for any otherwise identical bag without the label. Considering that a reasonable estimate of a standard potting mix bag is \$6/ft^3 (based on observations in our area), this represents a 10% increase in value.

Next, we considered the estimates for set C, which represented a scenario in which the customer was informed about the environmental benefits of using ERC biochar as a potting mix ingredient. The respondents were asked to assume that the potting mix with this ingredient was equally effective at growing plants as a potting mix without it. The coefficients for both 10% and 20% ERC biochar were positive, statistically significant, and larger in magnitude than the "Is environmentally friendly" coefficient from set B. This meant that for every 1-ft^3 bag of potting mix with the label "Is environmentally friendly," the rating of the mix increased by 3.92 points, whereas for bags containing 10% and 20% ERC biochar, the rating of the mix increased by 5.70 points and 8.51 points, respectively. This suggested that the information about the use of ERC biochar did cause respondents to increase their WTP for potting mix containing it as an ingredient. The WTP estimates showed that respondents will pay \$1.63/ft^3 and \$2.42/ft^3 more for potting mix containing 10% and 20% ERC biochar, respectively. Moreover, the \$2.42/ft^3 premium was statistically different from the \$1.63/ft^3 premium; therefore, increasing the amount of biochar at this range did enhance the value of the potting mix.

It is interesting that this premium was smaller than that measured by Thomas et al. (2021), who assumed a biochar with fewer environmental benefits than biochar made from ERC. They estimated a premium of \$3.53 per 9.31-qt bag of potting mix containing 25% biochar, which is equivalent to approximately \$11/ft^3. It is unclear what drives these differences because there are multiple differences, with the Thomas et al. (2021) study sample being representative of Tennessee, whereas our study was representative of the contiguous United States. Furthermore,

Table 2. Tobit model and willingness to pay (WTP) estimates for potting soil containing eastern redcedar (ERC) biochar under three information exposures in a 2022 survey of 496 respondents who purchase potting mix.

	Set A: Initial uninformed exposure	Set B: Second uninformed exposure	Set C: Informed exposure
Tobit model variable	**Coefficient estimate (*P* value)**		
Intercept	95.05876 (0.000)	102.0808 (0.000)	82.71972 (0.000)
Is environmentally friendly		3.92163 (0.000)	
Contains 10% ERC biochar			5.698569[i] (0.000)
Contains 20% ERC biochar	−1.90131 (0.091)		8.507019[i] (0.000)
Durable yet easy-to-open packaging			3.673709 (0.000)
Produced locally			0.491403 (0.607)
Price[ii]	−5.174612 (0.000)	−6.359562 (0.000)	−3.511827 (0.000)
$\sqrt{V(\mu_i)}$	22.19785 (0.000)	19.60959 (0.000)	24.75092 (0.000)
$\sqrt{V(\epsilon_{ij})}$	23.75288 (0.000)	23.90129 (0.000)	20.70571 (0.000)
Sample size	473	483	478

WTP ($/ft^3) for[iii]	**ERC biochar**	**Environmentally friendly**	**10% ERC biochar**
	Point estimate (*SD*)[iv]		
	−0.366 (0.216)	0.618 (0.176)	1.627 (0.335)

20% ERC biochar
2.422 (0.349)

[i] A likelihood ratio test in which the coefficients for 10% ERC biochar and 20% ERC biochar in set C were equal was rejected at the 5% level.

[ii] V represents the variance, μ_i is an error term unique to each respondent, and ϵ_{ij} is an error term unique to each respondent and potting mix combination.

[iii] \$1/ft^3= \$35.3147/m^3.

[iv] The *SD* for the WTP estimates was calculated using the Krinsky-Robb method with 10,000 simulations. These simulations showed that the WTP for 20% ERC biochar was statistically higher than the WTP for 10% at the 5% level.

they used a logit model, and our study used a Tobit model.

The magnitude of our premiums, assuming a \$6/ft^3 price for potting mix without the biochar, was approximately 30% to 40%. If these estimates were subject to hypothetical bias, then when respondents overstated the actual amount they would pay, previous studies showed that the average hypothetical value was approximately twice the actual value (Penn and Hu 2018). Even if the WTP estimates were reduced by half to correct for hypothetical bias, the premiums of 15% to 20% might be considered substantial to potting mix manufacturers.

The coefficient pertaining to a durable yet easy-to-open bag was positive and statistically significant, although it was not as high as that pertaining to the ERC biochar reference. Bags indicating that the products were produced locally did not have a statistically significant impact on the ratings at the 5% level. This is contrary to other studies that often found premiums are associated with locally produced goods, especially foods (Darby et al. 2008; Yang et al. 2019). This might be because potting mix is not a product whose quality is perceived as higher when produced locally. Alternatively, it might be because the survey focused more on the environmental impacts of the potting mix than its production location, naturally inducing respondents to focus less attention on its production location.

Some variations of the Tobit model using set C were estimated to provide information about how potting mix containing ERC biochar should be marketed. First, the estimated model included an indicator variable for whether the respondent was located in a state where ERC is widely described as invasive. These states are Iowa, Kansas, Missouri, Nebraska, Oklahoma, and Texas. Respondents in this area might be more informed about its invasive nature and more motivated to contain it. However, the indicator variable was not significant at the 5% level.

Second, the estimated model included an indicator variable for respondents who correctly identified ERC as invasive (before the survey told them it was). This variable was significant at the 1% level; therefore, a marketing strategy that distributes it to areas where customers are more likely to know about the tree could increase sales and/or allow a firm to charge a higher premium. In this model, the WTP for respondents who correctly identified it as invading areas where it is not wanted was \$3.58; however, the WTP was \$2.28 for those who did not (when the mix contains 20% ERC biochar). This increase in WTP suggests that a marketing strategy might include distributing the mix to stores in the United States Great Plains, which has a high population of farmers and ranchers, because they are more likely to know more about the invasive nature of ERC from personal experience than, for example, the average "big box" shopper.

Conclusions

Eastern redcedar is sometimes referred to as a "green glacier" because of its slow but relentless expansion into the United States Great Plains. Scientists may not technically consider it an invasive species because it is indigenous to the area, but that is the common

adjective applied to the tree. In Oklahoma, the tree has increased its cover area by ~8% each year between 1984 and 2010 (Wang et al. 2017). Its ubiquitous presence provides an opportunity because valuable products can be made from the plant. The more land it covers, the easier it will be to harvest, and the more producers will pay to have their fields cleared. Supply chain models have already been constructed and how to harvest the trees as biomass has been demonstrated (Craige et al. 2016). This biomass could be used to produce a variety of value-added products, such as biofuel and mulch. The product considered during this study was ERC biochar used as an ingredient in potting mix.

If consumers recognize the clearing of ERCs as an environmentally friendly practice, then producers of such potting mix may be able to charge a premium. This study used a nationwide internet survey of potting mix customers to measure the potential size of this premium. Of the 496 individuals surveyed, approximately 13% recognized ERC as invasive before completing the survey. The survey results showed that most respondents needed education about ERC before they were willing to pay a premium for potting mix containing it as an ingredient. This can be achieved by making the claim that the mix is environmentally friendly, but an even greater premium can be earned by informing consumers that its use as an ingredient helps contain its spread and protect natural habitats.

Informed consumers indicated that they would pay 30% to 40% more for potting mix containing ERC. This is a large premium even if it is reduced by 50% to account for possible hypothetical bias. The premium is even larger for individuals who were aware of ERC before taking the survey. If firms can properly identify people who understand the tree's aggressive nature and find an inexpensive method of informing potting mix customers, then this survey suggests they should be able to sell potting mix containing ERC biochar at a higher price than that of standard potting mix types.

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