Farmer Preferences and Willingness to Pay for Soil Amendment Attributes

Abstract

Improving soil health is increasingly viewed as a means of enhancing agricultural productivity and resilience, yet relatively little is known about which specific soil improvements producers value when evaluating technologies that generate multiple agronomic benefits. This study examines producer preferences and willingness to pay for soil improvements among farmland owners and operators in the High Plains Aquifer portions of Nebraska, Kansas, and Oklahoma. We combine an object-case best-worst scaling experiment with a discrete choice experiment to distinguish the relative importance of soil attributes from their economic value under explicit tradeoffs. The best-worst experiment evaluates six potential soil improvements, while the choice experiment estimates willingness to pay for incremental improvements in nutrient uptake, water retention, and soil organic matter. Water retention is the most important attribute in the best-worst experiment, accounting for 38.2% of total attribute importance, followed by soil organic matter (23.9%) and nutrient uptake (21.9%). Among respondents who attend to all attributes, willingness to pay for a 10% improvement in soil organic matter is $20.75 per acre, compared with $22.26 per acre for a 20% improvement in water retention and $17.83 per acre for a 10% increase in nutrient uptake.

Keywords: Soil health; Water retention; Choice experiment; Willingness to pay; Soil moisture; Producer preferences

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1. Introduction

Declining groundwater availability across the High Plains Aquifer and elsewhere has increased interest in technologies that improve agricultural water use efficiency while maintaining crop productivity (Cameron-Harp & Hendricks, 2025). Groundwater withdrawals continue to exceed recharge across large portions of western Kansas, eastern Colorado, Oklahoma, and the Texas Panhandle, threatening the long-run sustainability of irrigated agriculture in the High Plains Aquifer region (Scanlon et al., 2012). In response, considerable research has been dedicated to soil management practices and biological soil amendments, including microbial inoculants and biochar, in efforts to improve soil water retention, nutrient availability, and overall soil functioning (Ali et al., 2018; Prokopy et al., 2019; Sarkar et al., 2021; Thao et al., 2023).

Recent advances in microbial inoculants (e.g., *Bacillus subtilis*) and other biological amendments illustrate this trend in soil management. Research on soil and biological amendments has documented effects on soil moisture, water retention, nutrient availability, and soil structure, with potential implications for water-use efficiency and crop productivity (Ali et al., 2018; Bi et al., 2024; Ren et al., 2025; B. Zhang et al., 2021). Unlike conventional inputs that are often applied to address individual production constraints (e.g., fertilizer to alleviate nutrient deficiency or pesticides to control pests), biological soil amendments may generate multiple agronomic benefits simultaneously (Fenibo et al., 2019; Sarkar et al., 2021). Consequently, producers evaluating this new wave of soil products must implicitly trade off improvements across several dimensions of soil functioning, including soil water retention.

Despite growing interest in soil-health technologies, relatively little is known about which soil improvements producers value most. The existing literature has focused predominantly on the adoption of conservation practices or irrigation technologies and the socioeconomic factors associated with adoption, including producer demographics, farm characteristics, risk preferences, access to information, and institutional constraints (Abdulai & Huffman, 2005; e.g., Caswell et al., 2001; Koundouri et al., 2006; Prokopy et al., 2019; Sampson & Perry, 2019). A related literature has used stated-preference methods to quantify producer willingness to pay (WTP) for improvements in water management (G. Gardner et al., 2021; Guerrero-Baena et al., 2019; Knapp et al., 2018; Martey et al., 2023; Suter et al., 2021). While this literature has substantially improved our understanding of the determinants of technology adoption, it provides limited insight into how producers value the individual agronomic outcomes embodied in soil technologies. Because many technologies bundle multiple agronomic benefits into a single adoption decision, observed adoption behavior cannot disentangle the value producers place on individual soil improvements. One recent exception is Mavroutsikos et al. (2025), who examine WTP for bundled ecosystem services associated with soil health improvements, but the relative value producers place on specific soil attributes remains largely unexamined.

This distinction is increasingly important for the development of biological soil amendments and other emerging soil-health technologies. Technologies that simultaneously improve water retention, nutrient uptake, and soil organic matter may ultimately be adopted or rejected for very different reasons depending on which underlying soil improvements producers value most. Consequently, understanding producer preferences is important not only for predicting adoption patterns and designing extension programs, but also for guiding the direction of technology development itself. Information on the relative value producers place on different soil improvements can help public and private research prioritize product characteristics that are the most agronomically effective and economically attractive to producers.

To address this gap, we combine two stated-preference methods to examine how agricultural producers in Nebraska, Kansas, and Oklahoma value different soil improvements. First, an object-case best-worst scaling (BWS) experiment measures the relative importance producers assign to six soil improvement attributes without introducing monetary tradeoffs. Second, a discrete choice experiment (DCE) estimates WTP for incremental improvements in water retention, nutrient uptake, and soil organic matter under explicit price tradeoffs. Together, the two experiments provide a more comprehensive assessment of producer preferences than either approach alone. Additionally, by explicitly valuing improvements in soil water retention alongside other soil functions, this study provides evidence on producer demand for soil amendments as a potential component of broader agricultural water management.

The results indicate that producers place the greatest importance on improvements in water retention, followed by soil organic matter and nutrient uptake. The BWS reveals that water retention accounts for the largest share of relative attribute importance (38.2%). The DCE provides evidence of positive WTP for improvements in all three attributes, with estimated WTP varying across attributes and improvement levels. WTP for a 10% improvement in soil organic matter was $20.75 per acre, while WTP for a 20% improvement in water retention was $22.26 per acre. In contrast, reduced soil compaction, soilborne pathogens, and metal contamination receive comparatively little weight, indicating that producers place greater importance on improvements to core soil functions than on more context-dependent soil conditions.

This paper contributes to the literature in three ways. First, rather than evaluating the adoption of conservation practices or soil technologies as bundled innovations, it estimates producer preferences for the underlying soil improvements those technologies are ultimately intended to generate. By identifying the improvements producers value most, the results can inform private-sector product development, extension messaging, and public investments related to technologies that improve water use efficiency and soil health. Second, by combining BWS with a DCE, this paper distinguishes between the relative importance of soil attributes in producer decision-making and their economic value under explicit tradeoffs, providing information that neither method alone can capture. Third, the results provide insight into how producers value broad soil functions, such as water retention, nutrient uptake, and soil organic matter, relative to more context-dependent soil conditions, including compaction, soilborne pathogens, and metal contamination. This distinction is particularly relevant in water-limited agricultural systems, where soil improvements may affect crop productivity and water management.

2. Background

Soil amendment technologies, including materials such as biochar and compost as well as microbial products and other biological amendments, are increasingly promoted as tools for supporting long-term soil health (Matisic et al., 2024; Singh et al., 2024; Thapa et al., 2025). Public policy also encourages the use of soil amendments to improve soil health and enhance carbon sequestration. Programs such as the Environmental Quality Incentives Program provide producers with cost-sharing to adopt amendments such as compost and biochar (U.S. Department of Agriculture, 2022). As reviewed by Matisic et al. (2024) and Oyebiyi et al. (2026), soil amendments can affect multiple aspects of soil functioning, including organic matter accumulation, water infiltration and retention, microbial activity, soil structure, nutrient availability, and erosion control. Biological amendments, including microbial inoculants, represent a related class of technologies that are increasingly promoted for their potential to influence several of these soil functions simultaneously (O'Callaghan et al., 2022).

Realizing these benefits, however, often incurs additional capital and variable costs, and the benefits themselves are uncertain, depending on soil type, climate, and management practices (Bowman et al., 2025). Soil amendments also differ in several measurable dimensions, including expected yield effects and environmental co-benefits, requiring producers to weigh trade-offs among these characteristics when evaluating alternative technologies (Matisic et al., 2024; S. Zhang et al., 2023). Prior research has examined whether producers adopt soil health practices, but less attention has gone to which technology attributes producers prioritize when choosing among them. Understanding these decisions requires identifying the characteristics producers value and the trade-offs they make among competing attributes.

Researchers commonly use contingent valuation methods to measure what farmers value by asking respondents how much they would be willing to pay for a specified product or improvement (McGurk et al., 2020; Olum et al., 2020; Opdenbosch & Hansson, 2023). This approach yields an overall WTP but does not reveal how producers value individual attributes relative to one another when a technology bundles multiple attributes. DCEs address this limitation by requiring respondents to choose among alternatives that differ in multiple attributes and have been used to study soil-health attributes (Black et al., 2025), soil carbon programs (Block et al., 2024; G. E. Gardner et al., 2026), soil amendments such as biochar (S. Zhang et al., 2023), and water access reliability (Guerrero-Baena et al., 2019; Suter et al., 2021). Together, this literature demonstrates the usefulness of stated-preference methods for valuing agricultural technologies, but less is known about how producers value improvements in soil water retention relative to other soil functions

Our study combines BWS, which measures the relative importance producers assign to individual soil attributes, with a DCE, which estimates the economic value producers place on incremental improvements in selected attributes. In the BWS, introduced by Finn and Louviere (1992), respondents identify the most and least important attributes within sets of soil improvements, providing a direct measure of relative attribute importance. BWS is an approach that has performed well in prior food and agricultural applications (Gondos et al., 2026; Lusk & Briggeman, 2009; Mueller et al., 2010). In the DCE, respondents choose among hypothetical alternatives that vary in attribute levels and price, allowing WTP for specific soil improvements to be estimated from the trade-offs reflected in their choices (Mueller et al., 2010). Combining the two provides complementary evidence: BWS identifies which soil improvements producers consider most important, while the DCE estimates the economic value producers place on incremental improvements in selected attributes.

3. Sampling Strategy and Experimental Design

This section describes the survey sampling strategy and the experimental designs used to elicit producer preferences for soil amendment attributes.

3.1 Survey Design

The target population consisted of farmland owners and owner-operators in Nebraska, Kansas, and Oklahoma. Mailing addresses and farm characteristics for these states were obtained from DTN. We restricted the sampling frame to counties overlying the High Plains Aquifer, yielding six counties in Oklahoma and 35 counties in Kansas. Because our survey budget could not support mailings across the full set of aquifer-overlying counties in Nebraska, we further restricted the Nebraska sample to 23 counties that also experienced either groundwater-table declines or nitrogen loss, prioritizing areas where soil amendment adoption decisions were most policy-relevant. The geographic distribution of sample counties is shown in Figure 1.

We further restricted the sampling frame to farms with at least 320 planted acres and excluded addresses referencing apartments or post office boxes, because these were more likely to represent landowners residing off-farm rather than active farm operators. Given our overall survey budget, we targeted 3,000 mailings, stratified by county in proportion to each county's share of the farm population, with farms randomly selected within each county.

The 3,000 surveys were mailed in mid-to-late March 2026. Of these, 24 were returned as undeliverable, leaving an effective sample of 2,976 delivered surveys. Each sampled farm received a presurvey postcard introducing the study, followed by a single mailed questionnaire. By June 1, 2026, 224 completed surveys had been returned, yielding a response rate of 7.5% (224/2,976 delivered surveys). The questionnaire collected information on farm practices and respondents' perceptions of drought severity and included both a DCE and a BWS exercise.

3.2 Best-Worst Scaling

Producer preferences for soil amendment attributes were elicited using an object case BWS experiment administered alongside the DCE. Object case BWS presents respondents with a set of attributes and asks them to identify the most and least important item in each choice set. This approach yields richer preference information than a simple ranking task by exploiting both best and worst selections (Louviere et al., 2015) and complements the DCE by establishing attribute salience independently of the price-tradeoff context embedded in the choice experiment.

The BWS experiment included six soil amendment attributes: increased nutrient uptake, increased water retention, increased soil organic matter, reduced soil compaction, reduced concentration of metal contaminants, and reduced populations of soilborne pathogens. Attributes were identified through consultations with agronomy faculty and agricultural producers to ensure relevance to soil amendment adoption decisions in the study region. To construct the choice sets, a balanced incomplete block design was employed with six attributes, ten choice sets, three attributes per choice set, five appearances per attribute, and two co-occurrences per attribute pair. This design satisfies the balance condition in which each pair of attributes appears together in the same number of choice sets, supporting efficient estimation of relative attribute utilities (Louviere et al., 2015).

The ten choice sets were divided into two survey versions of five choice sets each, with respondents randomly assigned to one version at the time of mailing. Within each choice set, respondents were presented with three attributes and asked to identify which attribute they considered most important and which they considered least important when evaluating a soil amendment product. A total of 123 producers completed the BWS instrument, with approximately equal numbers assigned to each survey version.

3.3 Choice Experiment

Attribute levels for the DCE were motivated by empirical evidence on the agronomic effects of *Bacillus subtilis*, a microbial soil amendment with documented effects on plant nutrient acquisition, soil water dynamics, and soil organic matter accumulation (Fenibo et al., 2019; Sarkar et al., 2021 review the literature on biosurfactants). The attributes and levels used in the choice experiment are presented in Table 1. Respondents were asked to choose amongst two products containing different combinations of attribute levels, or a no-cost opt-out option.[1]

The nutrient uptake attribute was informed by evidence that *B. subtilis* can improve nitrogen availability and the efficiency with which plants use nitrogen. Ren et al. (2025) report that *B. subtilis* increased nitrogen use efficiency by approximately 9%, while Xia et al. (2025) find that *B. subtilis* increased available soil nitrogen by approximately 25%. Together, these findings suggest that microbial soil amendments can generate measurable

[1] Attributes were expressed relative to the respondent's most recent crop cycle. The opt-out would maintain the same soil condition as the most recent crop cycle.

improvements in nitrogen cycling and plant nutrient acquisition, supporting the nutrient uptake levels used in the experiment (+5%, +10%) as plausible representations of improvement in nutrient delivery to crops.

The water retention attribute was based on evidence that *B. subtilis* can improve the availability and stability of soil water. For example, Bi et al. (2024) find that *B. subtilis* reduced soil-moisture variability by approximately 7% to 59% across soil depths, indicating more stable moisture conditions. Ren et al. (2025) report increases in soil water retention of approximately 1% to 33% following *B. subtilis* application. These studies provide empirical support for the ability of microbial soil amendments to improve soil water dynamics and informed the range of water retention improvements (+10%, +20%) considered in the experiment.

The soil organic matter attribute was informed by recent evidence that microbial inoculation can affect soil carbon and organic matter accumulation. Timmermann et al. (2025) report an approximately 12% increase in organic matter and a 13% increase in total carbon in *B. subtilis*-treated soil relative to untreated controls, suggesting that improvements in soil organic matter of the magnitude considered in the experiment (+5%, +10%) are plausible relative to the baseline condition.

Price levels were informed by both commercial product costs and benchmarks from alternative soil management practices. Discussions with producers indicated that commercial soil inoculants can cost approximately $5–$10 per acre. Because direct cost estimates for achieving the specific soil improvements considered in this study are limited, plausible per-acre costs were also benchmarked against costs associated with other soil management practices. Che et al. (2023) find that no-till practices increase chemical input costs by approximately $17 per acre, while K-State's 2025 crop budget projections[2] report fertilizer costs ranging from approximately $93 per acre for non-irrigated corn to $150 per acre for irrigated corn. Against these benchmarks, the $10 per acre price level represents approximately 7% of fertilizer costs for irrigated corn, while the $30 per acre level represents approximately 32% of fertilizer costs for non-irrigated corn. Based on these benchmarks, the experiment included price levels of $10, $20, and $30 per acre.

A main effects design was used to determine choice scenarios. The final design resulted in 36 choice sets that were blocked into six groups of six choice sets. Each respondent was thus presented with six choice sets,

[2] https://agmanager.info/farm-budgets

each containing two alternative products with varying levels of their attributes and a no-cost opt-out option. A total of 180 producers completed the DCE instrument, with approximately equal numbers for each block.

The choice sets were constructed in SAS, version 9.4. With four attributes at three levels each, the full factorial design yielded 81 possible profiles (3×3×3×3 = 81). Pairing two alternatives from this set produced 6,561 possible choice sets (81 × 81). The %MktRuns macro was used to identify efficient design sizes, and a 36-run design was selected because it achieved 100% efficiency, with no violations of orthogonality or balance. This design was then generated for the four attributes, producing 36 choice sets, each containing two design alternatives plus an opt-out option. Profiles with zero levels across all three non-price attributes were excluded, as were choice sets containing identical alternatives or an alternative that strictly dominated the other. The final design was divided into six blocks of six choice sets each to reduce respondent burden, using a fixed random seed to ensure reproducibility.

4. Methods

The survey included two stated-preference experiments designed to elicit complementary measures of producer preferences for soil amendment attributes. The BWS and DCE methodologies are described below.

4.1 Discrete Choice Experiment

The DCE is grounded in the random utility framework of McFadden (1972). In this framework, a producer is assumed to choose the alternative that provides the highest utility among the alternatives presented in a choice situation. Utility depends on the attributes of each alternative and includes both a systematic component that can be observed by the researcher and an unobserved component. Thus, the utility that producer i obtains from alternative j in choice situation t is:

$$U_{ijt} = V(x_{ijt}) + \epsilon_{ijt} \tag{1}$$

where $V(x_{ijt})$ is the systematic component of utility, specified as a function of the attributes of alternative j, and ϵ_{ijt} is the unobserved component. In our application, x_{ijt} contains price, nutrient uptake, water retention, and soil organic matter. For a particular choice situation and alternative, the j and t indices can be suppressed for notational convenience. Utility is then specified as:

$$V_i = \alpha OPT_i + \beta_{11} NU_i^5 + \beta_{12} NU_i^{10} + \beta_{21} WR_i^{10} + \beta_{22} WR_i^{20} + \beta_{31} SOM_i^5 + \beta_{32} SOM_i^{10} + \gamma p_i. \tag{2}$$

In equation (2), the term OPT_i is an indicator for the no-purchase opt-out alternative, NU_i^5 and NU_i^{10} are indicators for 5% and 10% increases in nutrient uptake respectively, WR_i^{10} and WR_i^{20} are indicators for 10% and 20% increase in water retention, SOM_i^5 and SOM_i^{10} are indicators for 5% and 10% increase in soil organic matter, and p_i is the per-acre price of the product (i.e., annual input cost). The baseline level for each attribute, no improvement relative to the status quo, is the omitted category.

The model is estimated in WTP space following Scarpa et al. (2008), which reparameterizes each attribute coefficient as $WTP = \frac{\beta}{\gamma}$, yielding mean WTP expressed in dollars per acre. Coefficients on the six soil attribute level indicators are treated as random to accommodate preference heterogeneity across producers in the valuation of each attribute level. The price coefficient γ and the opt-out coefficient α are treated as fixed. The model is estimated as a mixed logit (McFadden & Train, 2000) using 1,000 Halton draws with 50 burn-in draws, with robust standard errors.

Attribute non-attendance is addressed following Hess and Hensher (2010). Individual-level posterior means of each respondent's attribute-specific coefficients are recovered after estimation on the full sample. Respondents whose ratio of the posterior standard deviation to the posterior mean for a given attribute exceeds 2.0 are classified as non-attendees for that attribute, and WTP estimates are re-estimated on the subsample of full-attendee respondents.

4.2 Best-Worst Scaling

Following Louviere et al. (2015), the object case best-worst scaling presents respondents with a set of attributes and asks them to identify the most and least important item in each choice set. Let U_{iat} denote the latent utility that producer i associates with attribute a in choice set t. The latent utility associated with selecting attribute a as best and attribute b as worst is:

$$I_{iabt} = U_{iat} - U_{ibt} + \epsilon_{iabt} \quad (3)$$

The observed best-worst pair is assumed to be the ordered pair whose latent utility exceeds that of all other feasible best-worst pairs within the choice set. Assuming ϵ_{iabt} is independently and identically distributed Type I extreme value, the probability of observing attribute a as best and attribute b as worst is the probability that the latent utility associated with the ordered pair (a, b) exceeds that of all other feasible best-worst pairs in the choice set (Lusk & Briggeman, 2009), which yields a conditional logit likelihood.

Estimation follows the sequential approach of Flynn et al. (2007), in which each best-worst task is treated as two linked choice tasks. First, respondents choose the most important attribute from the full choice set. The attribute selected as best is then removed, and respondents choose the least important attribute from the remaining alternatives. The best and worst choices are combined into a single dataset. Attribute indicators enter the model with a positive sign for the best choice and a negative sign for the worst choice, so that the same utility parameters apply to both tasks. The model is estimated using conditional logit, with each respondent-choice-set-task combination defining a separate choice group.

The estimated coefficients indicate the relative importance of the attributes. To express these differences as shares of total importance (Lusk & Briggeman, 2009), the exponentiated coefficient for each attribute k is divided by the sum of all exponentiated coefficients:

$$w_k = \frac{\exp(\widehat{U}_k)}{\sum_n \exp(\widehat{U}_n)} \tag{4}$$

where w_k is the relative importance weight for attribute k and $\widehat{U}_k$ is its estimated logit coefficient. Confidence intervals for importance weights are constructed via cluster bootstrap with 1,000 replications, resampling at the respondent level to account for within-respondent correlation across repeated choice tasks.

5. Results

In this section we present information collected from the mail survey. We first present summary statistics from questions collecting information on farm characteristics, producer practices, and perceptions of soil moisture risk to different farm activities for study area context. We then present results from the BWS and DCE.

5.1 Producer Perceptions of Soil and Water Management

Summary characteristics of the producers are provided in Table 2. Operation size varies considerably: 33.9% farm more than 3,000 acres, while 29.8% operate 500–1,500 acres and just 9.2% farm less than 500 acres. Irrigation is also variable, with 30.3% having no irrigated cropland, while 16.1% irrigate more than 75% of their cropland. Soil testing is common but heterogeneous across test types: 68.9% test for soil organic matter and

52.6% test plant-available water, compared with only 23.9% who test for soil compaction, and 16.3% who do not test their soil at all.

We asked a set of questions to gauge how likely respondents believed low soil moisture during a drought would be to cause problems with the viability of different farm activities. Responses to these questions are summarized in Figure 2. Respondents perceive low moisture threats as most severe for row crop farming, with 95.8% rating it likely or very likely, including 70.8% selecting "very likely." Concern was similarly high for livestock farming, with 90.9% rating the threat as likely or very likely, though less concentrated at the extreme (51.4% "very likely"). Perceived risk to the viability of living in a rural community was notably lower, with 72.7% rating it likely or very likely and 27.3% considering it unlikely. This pattern suggests respondents view drought-driven soil moisture problems as most directly threatening to production activities, with effects on rural community viability perceived as somewhat less certain.

5.2 Best-Worst Scaling Results

The raw best-worst scores presented in Figure 3 provide a first-order overview of respondents' preferences across soil attributes. Attributes rated best in the BWS are assigned a value of one while attributes rated worst are assigned a value of minus one. These values are then aggregated across all choice sets and respondents. A value of zero in Figure 3 would indicate offsetting chosen-bests and chosen-worsts. Water retention has the largest positive score, followed by soil organic matter and nutrient uptake. Reduced soil compaction is approximately neutral, whereas reduced soilborne pathogen populations and reduced metal contamination have negative scores. The descriptive results therefore indicate a clear preference for attributes associated with productive soil functions over attributes associated with pathogen and contaminant reduction.

Results from the stacked best-worst model are reported as log-odds in Table 3. Relative to reduced metal contamination, the least-preferred attribute and reference category, all other soil attributes generate significantly higher utility. Water retention has the largest utility coefficient ($\beta = 3.215$, $p < 0.001$), followed by soil organic matter ($\beta = 2.746$, $p < 0.001$) and nutrient uptake ($\beta = 2.656$, $p < 0.001$). The coefficients for soil organic matter and nutrient uptake are similar in magnitude, indicating comparable preferences for these two attributes. Respondents were about 25 times more likely to select water retention as best than reduced metals when both attributes appeared in the same choice set. Respondents were about 14-16 times more likely to select soil organic matter or nutrient uptake than reduced metals when appearing in the same choice set.

Reduced soil compaction (β = 1.907, $p < 0.001$) and reduced soilborne pathogen populations (β = 0.996, $p < 0.001$) rank fourth and fifth, respectively. These two attributes were about 3-7 times more likely to be selected than reduced metals when appearing in the same choice set. The similar ordering of attributes across best-only and worst-only choices supports the common utility scale imposed by the stacked specification.

Figure 4 presents normalized importance scores and bootstrapped 95% confidence intervals for the six soil attributes. Water retention accounts for 38.2% of total attribute importance, making it the dominant attribute in the best-worst experiment. Its importance exceeds that of soil organic matter (23.9%) and nutrient uptake (21.9%). The remaining attributes account for comparatively little total importance: reduced soil compaction represents 10.3%, while reduced soilborne pathogens and reduced metal contamination account for 4.2% and 1.5%, respectively. Thus, the model-based results reinforce the descriptive ordering in Figure 3 and indicate that respondents place substantially greater importance on productivity-related soil functions, particularly water retention, than on pathogen and contaminant reduction.

5.2 Discrete Choice Experiment Results

Mixed logit estimates in willingness-to-pay space are reported in Table 4 and Figure 5 for the pooled sample (n = 180) and the attribute-attendant subsample (n=103). Attribute non-attendance (ANA) was identified at the individual level using posterior mean attribute-specific coefficients and a threshold of 2 for the coefficient of variation (Gramig & Widmar, 2018; Hess & Hensher, 2010). ANA rates for specific attributes range from 20.5% for soil organic matter to 25.9% for nutrient uptake. Depending on the attribute, between 134 and 143 respondents are classified as attribute attendants. Restricting the sample to respondents who attend to all three attributes yields 103 respondents. Because ANA correction produces systematically larger WTP estimates across all attributes and levels, we treat the ANA-corrected results as the preferred specification, as these estimates more closely reflect the preferences of respondents who actively considered each attribute when making their choices rather than averaging in respondents who effectively ignored one or more attributes.

In the pooled sample, WTP increases with the level of improvement for all three attributes. Mean WTP for a 10% increase in water retention is $14.68 per acre (95% CI: $10.15–$19.21), increasing to $16.40 per acre (95% CI: $10.30–$22.50) for a 20% increase. For nutrient uptake, WTP increases from $5.51 per acre (95% CI: $1.01–$10.01) for a 5% improvement to $11.75 per acre (95% CI: $7.04–$16.45) for a 10% improvement. Soil organic matter exhibits a similar pattern, with WTP increasing from $4.86 per acre (95% CI: $1.04–$8.68) to

$14.38 per acre (95% CI: $9.74–$19.01) as the improvement increases from 5% to 10%. All pooled WTP estimates are positive and statistically significant at the 5% level or better.

ANA-corrected estimates are substantially larger (Table 4, Figure 5). WTP for a 10% increase in water retention is $21.10 per acre (95% CI: $14.24–$27.97), increasing only modestly to $22.26 per acre (95% CI: $13.20–$31.32) for a 20% improvement. WTP for nutrient uptake increases from $11.49 per acre (95% CI: $6.21–$16.77) for a 5% improvement to $17.83 per acre (95% CI: $11.99–$23.68) for a 10% improvement. Soil organic matter generates WTP of $10.97 per acre (95% CI: $5.84–$16.09) at the 5% improvement level and $20.75 per acre (95% CI: $14.00–$27.50) at the 10% level. All ANA-corrected estimates are statistically significant at the 0.1% level.

The WTP results reveal a pattern of diminishing marginal value for larger improvements in water retention and nutrient uptake. Expressed per percentage point of improvement, ANA-corrected WTP for the medium improvement level is similar across attributes, ranging from $2.11 per acre for water retention to $2.30 per acre for nutrient uptake. At the high improvement level, however, WTP per percentage point falls to $1.11 for water retention and $1.78 for nutrient uptake. Soil organic matter exhibits somewhat of a different pattern: per-percentage-point WTP remains relatively stable at $2.19 for a 5% improvement and $2.08 for a 10% improvement. Thus, the DCE suggests that respondents place relatively stable marginal value on soil organic matter improvements across the range of levels examined, whereas the marginal value of larger water-retention and nutrient-uptake improvements declines.

5.3 Synthesis

The BWS and DCE results reveal a consistent preference ordering while providing different information about producer preferences. Water retention is the dominant attribute in the BWS, accounting for 38.2% of total importance, and generates the highest WTP at the largest improvement level in the DCE. Soil organic matter and nutrient uptake also rank highly in both experiments. In contrast, reduced soilborne pathogens and reduced metal contamination receive relatively little weight in the BWS.

The comparison of the two experiments nevertheless highlights an important distinction between relative attribute importance and marginal economic value. Water retention accounts for substantially more BWS importance than soil organic matter or nutrient uptake, but ANA-corrected WTP per percentage point of improvement is similar across the three attributes at the medium improvement level. Thus, the attribute receiving the greatest relative weight in a forced ranking is not necessarily the attribute with the highest marginal economic value for a given incremental improvement. This distinction reflects the different information provided by the two experiments: BWS measures the relative prominence of attributes in forced best-worst choices, whereas the DCE measures the value of specific changes in attribute levels under explicit tradeoffs. The greater BWS importance of water retention therefore indicates greater relative prominence in the ranking exercise (independent of cost), while the DCE results indicate similar marginal WTP for moderate improvements in water retention, nutrient uptake, and soil organic matter.

The DCE also reveals differences in how respondents value larger improvements within attributes. Marginal WTP declines for larger improvements in water retention and nutrient uptake but remains stable for soil organic matter, with WTP per percentage point of improvement nearly unchanged between the 5% and 10% levels. This pattern is particularly notable when the two experiments are considered together: soil organic matter ranks second in the BWS, while WTP for a 10% improvement ($20.75 per acre) is similar to WTP for a 20% improvement in water retention ($22.26 per acre). One possible interpretation is that respondents view soil organic matter as a broad indicator of overall soil condition rather than as a single soil function, given its connections to water retention, nutrient cycling, and soil structure (Murphy, 2015). This interpretation is necessarily speculative, however, and the survey data do not allow us to determine whether producers value soil organic matter specifically because they associate it with improvements across multiple dimensions of soil functioning.

Finally, reduced soil compaction, soilborne pathogens, and metal contaminants received relatively little weight in the BWS compared with water retention, nutrient uptake, and soil organic matter. Collectively, these three attributes account for less than 16% of total BWS importance. They were not included in the DCE because the choice experiment was designed to evaluate the key soil properties for which biological soil amendments, including *B. subtilis*, have documented effects and that could be represented as economically meaningful incremental improvements. The lower BWS importance assigned to these attributes may reflect differences in their production relevance and the extent to which their benefits are broadly applicable across production settings in the study region. Water retention, nutrient uptake, and soil organic matter are directly related to fundamental soil functions and can affect crop growth and resource use. In contrast, the relevance of soil compaction, soilborne pathogens, and metal contamination is more dependent on specific production conditions, which may be spatially localized. Soilborne pathogen impacts, for example, are often crop- and disease-specific, while metal contamination may be spatially concentrated (e.g., Arkansas River watershed) and of limited relevance in some production areas. Thus, the relatively low importance assigned to these attributes may reflect their more context-dependent nature rather than a general lack of producer concern. Overall, the BWS results suggest that respondents placed greater relative importance on broad soil functions and nutrient-related productivity than on reducing specific adverse soil conditions such as compaction, pathogens, and contaminants.

6. Discussion and Conclusion

This study combines best-worst scaling and a discrete choice experiment to examine which soil improvements agricultural producers value and how those preferences translate into economic values. The results identify water retention, soil organic matter, and nutrient uptake as the most salient attributes of soil improvement technologies. Water retention was the most prominent attribute in the BWS, accounting for 38.2% of total importance, while the DCE indicates positive and economically meaningful WTP for improvements in water retention, soil organic matter, and nutrient uptake. WTP increased with the magnitude of improvement for each attribute, although the marginal value of larger improvements differed across attributes. In particular, marginal WTP declined for larger improvements in water retention and nutrient uptake but remained relatively stable for soil organic matter. Soil compaction, soilborne pathogens, and metal contamination received substantially less weight in the BWS and were not included in the DCE, which was designed a priori around water retention, nutrient uptake, and soil organic matter as key agronomic outcomes of biological soil amendments.

The valuation pattern for soil organic matter merits further discussion. WTP for a 10% improvement in soil organic matter was approximately twice the WTP for a 5% improvement. One possible explanation is that soil organic matter represents a broader indicator of soil condition, as it is associated with water retention, nutrient cycling, biological activity, and other soil processes (Murphy, 2015). Consequently, producers may view improvements in soil organic matter as reflecting broader improvements in soil functioning rather than an improvement in a single production function. Although this interpretation is consistent with the observed valuation pattern, the survey data do not provide direct evidence that producers made this connection when evaluating the alternatives.

The relatively low importance assigned to soil compaction, soilborne pathogens, and metal contamination should also be interpreted in the context of their production relevance. These attributes are not necessarily unimportant agronomically. Rather, their value may depend more strongly on whether a particular constraint is present and relevant to production on a particular farm. Soilborne pathogen impacts vary across crops and disease environments; metal contamination tends to be spatially concentrated; and the effects of soil compaction depend on field conditions, machinery use, soil characteristics, and management history. In contrast, water availability and nutrient acquisition are fundamental to crop production across a broader range of production environments. The BWS results therefore suggest that producers place greater general importance on soil functions directly connected to crop production than on improvements addressing specific soil conditions whose relevance may vary considerably across farms.

These findings have implications for firms, extension programs, and public conservation efforts seeking to promote soil-health technologies. For firms developing products that affect multiple dimensions of soil functioning, water retention, nutrient uptake, and soil organic matter represent benefits that are particularly salient to producers. Product development and communication may therefore benefit from emphasizing specific, measurable agronomic outcomes rather than broadly describing products as improving soil health. Extension programs can similarly use information on producer preferences to prioritize the soil functions most likely to resonate with producers in technical demonstrations and educational materials. For public conservation programs, the findings provide information on the soil functions producers value that can inform outreach and communication about soil-improving technologies.

More broadly, the results suggest that understanding which agronomic outcomes producers value is important for anticipating demand for emerging soil technologies. Biological amendments and other soil-health practices can influence multiple physical, chemical, and biological soil functions through a single management decision, creating potential value across several dimensions of crop production (Ghimire et al., 2023). This multifunctionality makes it important to identify which outcomes producers value most, rather than treating soil health as a single, undifferentiated benefit. Although the WTP estimates are specific to producers in Nebraska, Kansas, and Oklahoma, the underlying preference patterns may have broader relevance to water-limited agricultural regions, particularly the Great Plains and western United States, where water availability is a critical constraint on crop production and soil management.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process.

Statement: During the preparation of this work the authors used ChatGPT to improve the clarity, organization, and readability of the manuscript and to identify and reduce redundancy. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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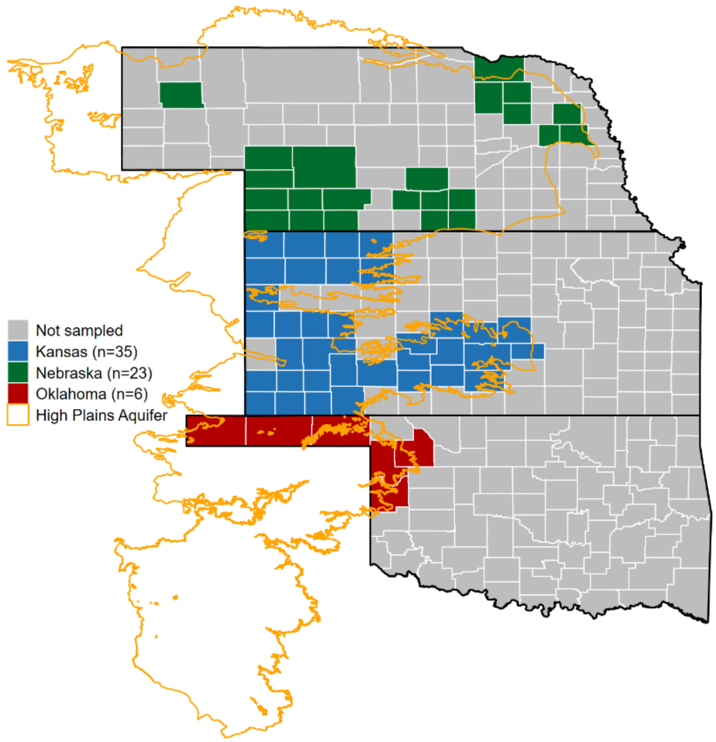

Figure 1. Geographic distribution of sampled agricultural producers across the High Plains Aquifer region. Colored counties indicate sampled counties by state; gray counties were not sampled. The orange outline denotes the extent of the High Plains Aquifer.

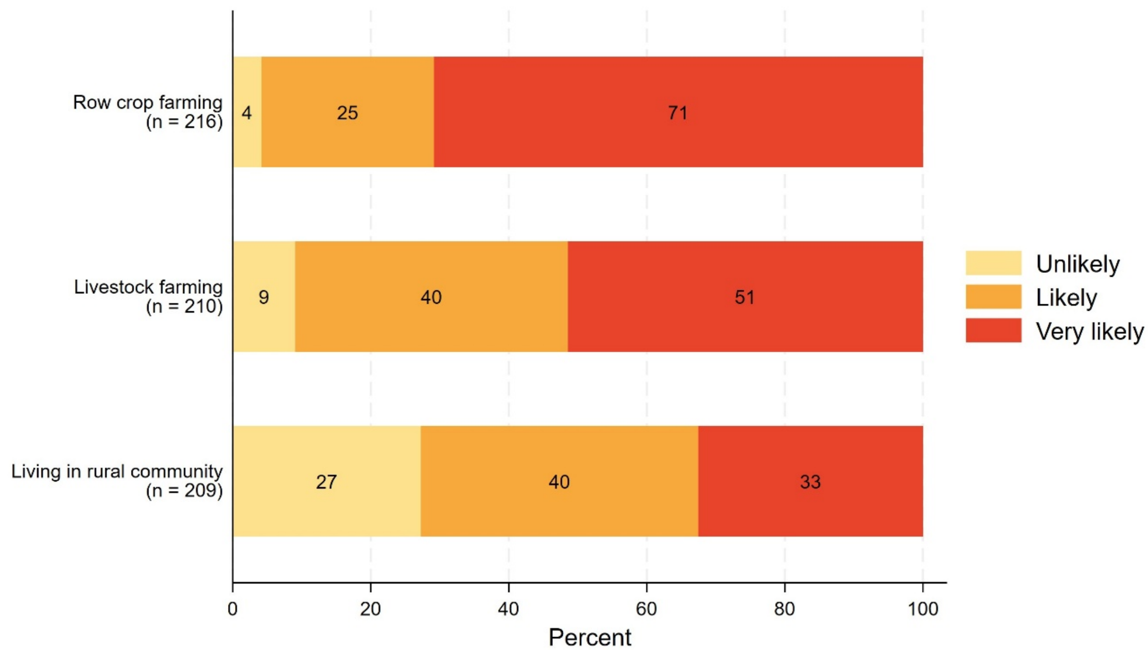

Figure 2. Perceived likelihood for low moisture during drought to cause problems to farm activities. Specific n is reported in parentheses; percentages are calculated on the number of respondents answering each item and excluding non-responses. Responses were measured on a 3-point scale (1=unlikely, 2=likely, 3=very likely).

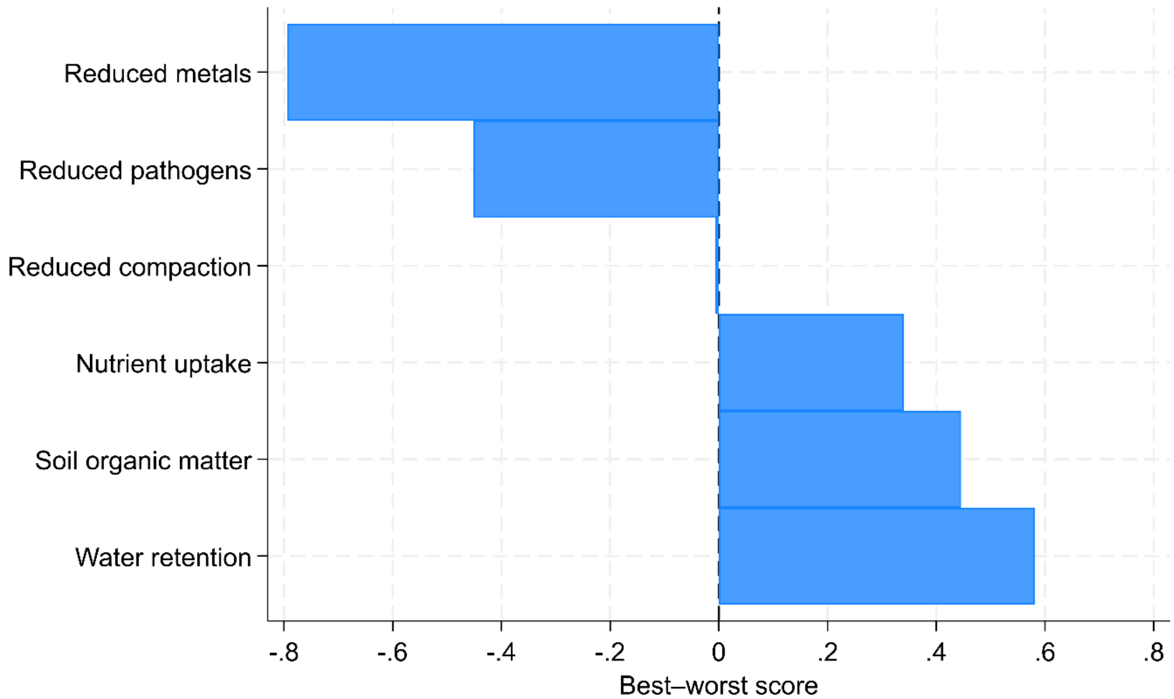

Figure 3. Raw best-worst scores for soil attributes. Scores represent the aggregate difference between the number of times an attribute was selected as best and worst across respondents and choice sets. Positive (negative) values indicate that an attribute was selected as best more (less) frequently than worst.

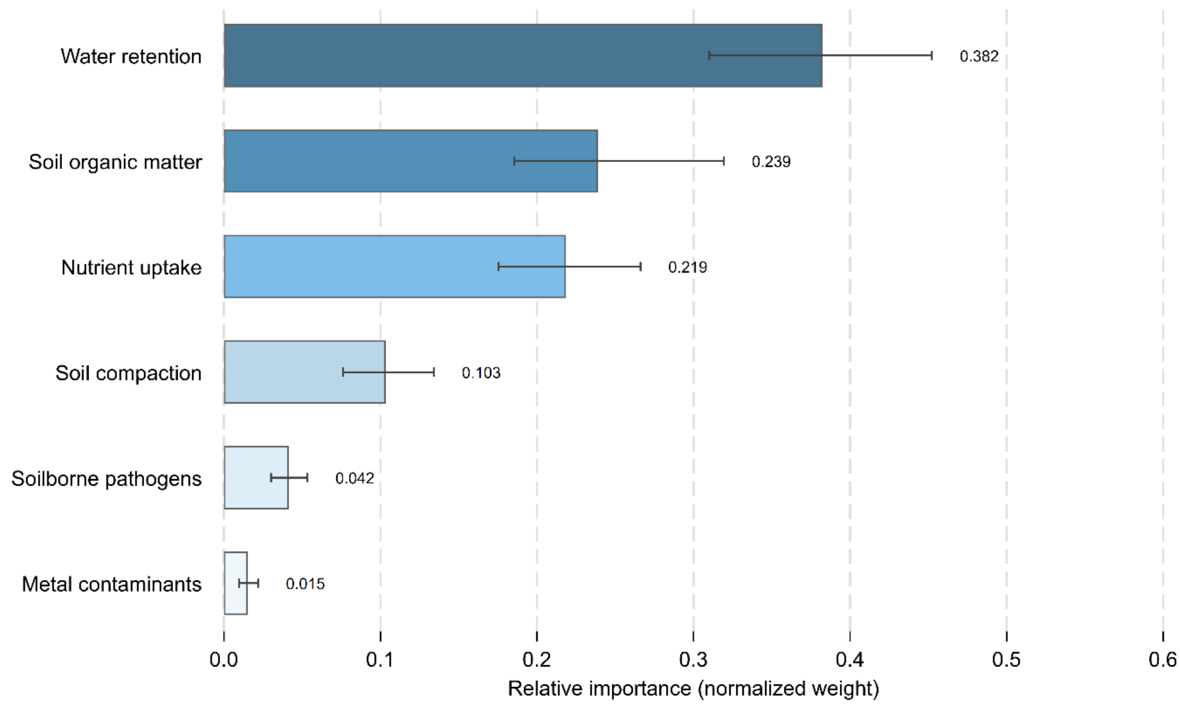

Figure 4. Relative importance of soil attributes based on the stacked best-worst model. Bars represent normalized attribute importance scores, and whiskers denote bootstrapped 95% confidence intervals.

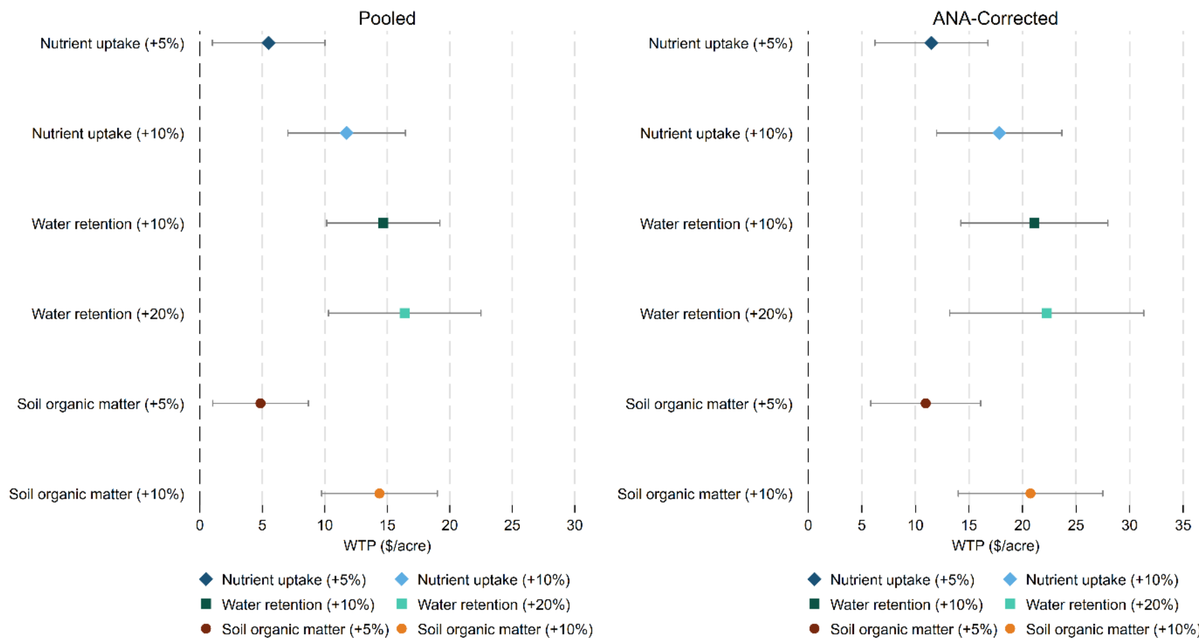

Figure 5. Willingness to pay for soil attribute improvements in the pooled and attribute-nonattendance-corrected samples. Points represent mean WTP per acre and whiskers denote 95% confidence intervals.

Table 1. Attributes and Levels Used in the Discrete Choice Experiment

Attribute	Attribute Levels
Nutrient uptake	0%
	5%
	10%
Water retention	0%
	10%
	20%
Soil organic matter	0%
	5%
	10%
Input cost	$0/acre
	$10/acre
	$20/acre
	$30/acre

Table 2. Characteristics of Survey Respondents and Their Farm Operations

Variable	Frequency	Percent
Total size of operation - single response (n = 218)		
Less than 500 acres	20	9.2
500 – 1,500 acres	65	29.8
1,501 – 3,000 acres	59	27.1
More than 3,000 acres	74	33.9
Portion of total cropland irrigated - single response (n = 218)		
None	66	30.3
1% - 25%	50	22.9
26% - 50%	38	17.4
51% - 75%	29	13.3
More than 75%	35	16.1
Soil characteristics tested - multiple response (valid n = 209)		
Soil organic matter	144	68.9
Water available in soil for crop use (plant available water)	110	52.6
Nutrient recovery rate	92	44.0
Soil compaction	50	23.9
Do not test soil	34	16.3

Note: Size of operation, portion of total cropland irrigated, and the drought related problems sub-items are single-response items; percentages are of valid responses and sum to 100 within each item. Soil characteristics tested is multiple responses ("check all that apply"); percentages are of cases and therefore sum to more than 100.

Table 3. Best-Worst Scaling Estimates of Producer Preferences for Soil Amendment Attributes

Soil attribute	Stacked best-worst	Best-only	Worst-only
Water retention	3.215***	3.820***	−3.677***
Soil organic matter	2.746***	3.451***	−2.954***
Nutrient uptake	2.656***	3.191***	−3.170***
Reduced compaction	1.907***	2.576***	−1.941***
Reduced pathogens	0.996***	1.202**	−1.056***
Reduced metal contaminants	Reference	Reference	Reference
Observations	3,075	1,845	1,845

Notes: Coefficients from conditional logit estimation. Best and worst models estimated separately; stacked model pools best and worst choices into a single likelihood with signed attribute dummies. All models estimated with robust standard errors. Reference category is reduced metal contaminant concentration, the least-preferred attribute. Attributes ordered by stacked model coefficient magnitude within group.

*** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$

Table 4. Willingness to Pay for Soil Amendment Attributes and Attribute Non-Attendance

Variable	Percentage Change	Pooled Data (n=180)		Rate of Attribute Non-Attendance	ANA-Corrected Data (n=103)	
		Mean WTP ($/acre)	Mean WTP ($/1% change/acre)		Mean WTP ($/acre)	Mean WTP ($/1% change/acre)
Nutrient uptake	5	5.51* [1.01, 10.01]	1.10* [0.20, 2.00]	25.9%	11.49*** [6.21, 16.77]	2.30*** [1.24, 3.35]
	10	11.75*** [7.04, 16.45]	1.18* [0.70, 1.65]		17.83*** [11.99, 23.68]	1.78*** [1.20, 2.37]
Water retention	10	14.68*** [10.15, 19.21]	1.47*** [1.02, 1.92]	23.2%	21.10*** [14.24, 27.97]	2.11*** [1.42, 2.82]
	20	16.40*** [10.30, 22.50]	0.82*** [0.52, 1.13]		22.26*** [13.20, 31.32]	1.11*** [0.66, 1.57]
Soil organic matter	5	4.86* [1.04, 8.68]	0.97* [0.21, 1.74]	20.5%	10.97*** [5.84, 16.09]	2.19*** [1.17, 3.22]
	10	14.38*** [9.74, 19.01]	1.44*** [0.97, 1.90]		20.75*** [14.00, 27.50]	2.08*** [1.40, 2.75]

Notes: Coefficients from conditional logit estimation. ANA-Corrected sample based on full attribute attendance using the metric of Hess and Hensher (2010).

*** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$