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Consumer perceptions of the co-benefits of biosolids and carbon sequestration in a fertiliser aimed at the urban retail market

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ABSTRACT

New markets for biosolids-derived products are urgently required to provide cost-effective solutions for water utilities to address the increasing production of municipal sewage waste. One potential outlet for biosolids is the domestic retail fertiliser market. Biosolids-derived fertilisers could be marketed to consumers by highlighting their environmental benefits, including carbon sequestration potential. This study used a two-part research approach to assess the feasibility of biosolids-derived fertiliser in the current market and to gauge the extent to which retail consumers value carbon sequestration features in fertilisers. First, a hedonic price analysis of existing fertilisers in the market explored consumer preferences and whether they currently pay extra for "sustainable" or "organic-certified" products. Second, a discrete choice experiment was designed to elicit consumers' willingness-to-pay for biosolids-derived fertilisers and those clearly labelled with their carbon sequestration capability. The hedonic price analysis determined that organic or natural fertilisers sell at similar or slightly higher prices than synthetic alternatives. The choice experiment revealed that consumers would pay 17% more for fertilisers labelled with their carbon capture capacity. Purchasers of organic fertilisers perceived biosolids-derived fertilisers as valuable organic alternatives. In contrast, buyers of synthetic fertilisers were willing to pay slightly less for biosolids-derived alternatives. These findings suggest that some consumers are willing to purchase biosolids-derived fertilisers at prices comparable to current alternatives and place higher value on fertilisers offering environmental benefits, such as carbon sequestration. These results indicate that urban retail markets could be a strategic outlet for biosolids by producing biosolids-derived fertilisers.

1. Introduction

The global population is on track to reach 8.5 billion people by 2030. Consequently, waste production is increasing, requiring sustainable, innovative solutions for municipal wastewater treatments (Lahlou et al., 2021). Municipal wastewater treatment, including industrial wastewater, yields two main byproducts: treated wastewater and solid residue, commonly known as biosolids or sewage sludge. While treated wastewater is often discharged into oceans, surface waters, or deep wells for groundwater recharge (Jones, 2021), biosolids face various fates, with some ending up in landfills and others being used as soil fertilisers or agricultural soil amendments (Sharma et al., 2017). In Australia, about two-thirds of the biosolids produced in 2019 were applied to agricultural soils, returning some of the nutrients recovered in wastewater treatment processes (Australian & New Zealand Biosolids Partnership, 2020). The remaining third of biosolids produced in 2019 (roughly 30,000 tonnes) were either stockpiled or directed to landfill (Australian & New Zealand Biosolids Partnership, 2020).

There are opportunities to improve the use of the recovered nutrients in biosolids and reduce disposal costs. Biosolids intended for agricultural use must undergo tertiary wastewater treatment processes to a standard that significantly reduces health risks (EPA, 2021). These treatment processes include anaerobic digestion, aerobic composting, lime stabilisation, incineration, and pyrolysis (Hoang et al., 2022), each of which

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reduces the nutrient content or availability of the biosolids products, diminishing their value. Developing new, high-value markets for biosolids-derived products, such as fertilisers, could minimise nutrient losses from biosolids before land application. Further, water utilities incur considerable costs in disposing of biosolids, failing to capitalise on the recovered nutrients (Torri et al., 2017). However, water utilities could access broader markets by creating more valuable biosolids-derived products, reducing or even eliminating, disposal costs.

This paper explores the feasibility of introducing biosolids-derived fertilisers into the urban retail market, a focus that departs from previous research predominantly concentrated on agricultural applications for biosolids. Marketing biosolids-derived fertilisers to urban consumers could benefit society by reducing landfill usage, mitigating greenhouse gas emissions, and lessening the demand for synthetic fertilisers, particularly those containing finite resources like phosphorus (Pritchard et al., 2010; Qin et al., 2012). Furthermore, since most biosolids are generated in densely populated areas, often distant from agricultural regions, urban markets for biosolids-derived fertilisers could reduce logistical and transportation costs, as biosolids-derived products are typically shipped over 200 km to agricultural users (Darvodelsky, 2011; Pritchard et al., 2010).

Consumer concerns regarding biosolids-derived products could, however, challenge creating new retail markets for these fertilisers. The existing literature has focused on farmer perceptions of using biosolids products or consumer preferences for food produced by agricultural operations using biosolids as an agricultural input. Concerns may be rooted in potential public health risks arising from heavy metals (Haynes et al., 2009), pathogens (King et al., 2011) and other emerging contaminants such as pharmaceuticals (Dalahmeh et al., 2022) and per- and polyfluorinated alkyl substances (PFAS) that can also contaminate groundwater (Moya et al., 2019; Johnson, 2022). While the acceptability of biosolids is well-studied within the agricultural sector, this study addresses a knowledge gap in understanding whether biosolids-derived products can be marketed directly as fertiliser products in the retail market.

The origins of biosolids from human waste and the potential presence of contaminants could adversely affect customer attitudes towards biosolids-derived gardening products. Previous research suggests that the general public tends to disapprove of recycled waste products (Gibson and Burton, 2014; Gwara et al., 2021). However, providing adequate information and increased education about these biosolids-derived products may shift initial apprehensions towards more positive attitudes (Borden et al., 2004; Jones et al., 2020). Moreover, the physical appearance of biosolids-derived products also affects their acceptability; for instance, Malawi farmers perceived composted and granulated fertilisers more favourably than dried sludge (Roxburgh et al., 2020). Given that many factors influence the acceptability of biosolids and biosolids-derived products, further research is needed to elucidate how biosolids-derived products can best align with consumer expectations.

Treating biosolids could dispel some common concerns about pollutants, pathogens, and the appearance of biosolids-derived fertilisers. One method for treating biosolids is composting with additional carbon sources (to meet required C:N composting requirements) via a regulated waste-to-resource transformation process (Lin et al., 2022). Composting biosolids can significantly reduce pathogen load (99% for faecal coliforms, faecal streptococci and Shigella spp.; 100% for Salmonella spp.) (El Hayany et al., 2021), pharmaceutical concentrations (Dalahmeh et al., 2022) and the bioavailability of certain heavy metals (e.g., Pb, Zn and Cd) (Paramashivam et al., 2017). Approximately 8% of biosolids in Australia are composted, primarily for the landscaping sector (Water Corporation, 2021). This urban application of biosolids-derived fertiliser indicates an untapped potential for further exploration in the urban market and the possibility that biosolids remain an underutilised resource for the retail market or domestic home gardeners (Borden et al., 2004; Outwater, 1994).

While some consumers may harbour reservations about biosolids-derived products, others may be drawn to their environmental benefits. For instance, the carbon sequestration potential of fertilisers is a growing area of interest that could influence consumer purchasing behaviour. The addition of biosolids to soil can enhance soil carbon directly through organic matter input and carbon sequestration, increasing crop biomass and rhizodeposition processes. However, the effectiveness of these mechanisms may vary with factors like biosolid input mass, time after application (diminishing over time), soil depth and soil type (Wijesekara et al., 2021). Moreover, optimising the soil humification process, which converts fresh organic matter into soil organic carbon, can be achieved by strategically adding inorganic nutrients to balance the carbon influx from crop residues (Kirkby et al., 2013). Nevertheless, consumer preferences regarding the carbon sequestration potential of fertilisers have not been explored.

The increasing recognition of the potential environmental benefits of biosolids-derived fertilisers and the emergence of prosocial consumer behaviour (Paço et al., 2019) could improve their economic viability in the retail market. Recent investigations into consumer attitudes towards waste-derived fertiliser products have focused primarily on understanding the impact of strategies and raw material descriptions on these attitudes (Dahlin et al., 2016, 2017, 2019; Herbes et al., 2020). The findings of these studies suggest that consumers respond more positively to products featuring pro-environmental labels, translating into a higher willingness-to-pay (WTP) for these products. However, these studies predominantly focused on responses to fertilisers derived from biogas digestates (e.g., liquid byproducts of biogas production), leaving a notable gap in research on urban retail consumer preferences for biosolids-derived gardening products of human origin.

This study has two key research aims:

1) Determine the viability of biosolids-derived fertilisers in the Australian retail market by measuring consumers' WTP for these products.
2) Understand how retail consumers perceive the value of carbon sequestration capabilities in biosolids-derived fertilisers and the influence of environmental labels on fertiliser products more broadly.

By delving into these aspects, we offer valuable insights for the various government and industry decision-makers, including (1) marketers within the fertiliser markets who can gain a deeper understanding of how to target their products to consumers; (2) current and future players in this market who aspire to produce new products that better appeal to customers; and (3) policymaking bodies and utility institutions as they strive to develop sustainable waste management practices to reduce environmental and economic strain, alleviating the strain on landfills, which currently receive 23 million tonnes of materials annually in Australia (Department of Climate Change, Energy, the Environment and Water, 2022). These efforts will reduce conventional waste disposal costs and associated greenhouse gas emissions if the market for biosolids-based products thrives. In addition, (4) consumers themselves may identify a new and valued product not currently available in the market.

2. Methodology

Two non-market valuation methods were used to address the research aims: (1) a hedonic price analysis—relying on observing real sales or pricing data—to examine how different attributes of retail fertilisers, such as nutrient content, bag weight, and organic labelling, affect purchasing price points and (2) a choice experiment—eliciting hypothetical purchase or choice data in surveys—to determine what consumers are willing to pay for novel, biosolids-derived fertilisers that do not yet exist. Both methods are rooted in Lancaster (1966) consumer theory, which posits that a good's value can be broken down into its defining attributes. The hedonic price analysis will reveal whether people generally value fertilisers made from organic material or with "natural" or "organic" labelling differently from synthetic fertilisers to help inform the feasibility of marketing biosolids-derived fertilisers to urban retail consumers. The choice experiment will measure survey respondents' willingness to purchase biosolids-derived fertilisers compared to conventional organic and synthetic alternatives and whether pro-environmental labelling can increase demand or the WTP for these fertilisers. The following sections explain each component of the study.

2.1. Hedonic price analysis

An exploratory hedonic price analysis was conducted as the initial step to understand the Australian retail fertiliser market and inform the subsequent discrete choice experiment (Section 2.2). The results from the hedonic price analysis will also help validate the choice experiment results.

Hedonic price analyses have been used to value product characteristics by drawing inferences from their market price (Gilbert, 2013), such as cars (Goodman, 1983), mobile phones (Dewenter et al., 2007) and food products (Ahmad and Anders, 2012). This method's rationale is based on Rosen's (1974) theoretical hedonic pricing framework, which suggests that the prices of these attributes are implicit through the observed prices of differentiated products. In this study, we model how various characteristics influence the price of retail fertiliser products using a linear regression model.

We gathered data from 116 garden fertiliser products intended for household use, including lawns, fruits and vegetables, and ornamental plants, sourced from Bunnings Warehouse, the largest Australian home, garden, and trade retailer, to determine the marginal monetary values of characteristics such as nutrient content and branding characteristics (Appendix Table A1). Goods considered predominantly soil wetters, potting mixes or hydroponics applications were excluded. The selected fertilisers all contained at least one of the three main macronutrients: nitrogen (N), phosphorus (P) or potassium (K).

For each fertiliser, we noted macronutrient levels, organic certification, and environmental or organic branding (without being formally certified as organic). We also recorded the amount of organic nitrogen, inorganic nitrogen, potassium, and sulphur. Organic certification was based on labelling that indicated compliance with a third-party certification body. Only labels certified by Australian Organic Limited (see https://austorganic.com/) were considered. Organic branding referred to any packaging phrases that associated the fertiliser or its constituents with organic properties, such as "natural", "organic", "blood and bone", "seaweed" or "organically enriched". All raw product data were normalised per kilogram of purchased fertiliser.

2.2. Choice experiment theoretical framework

The choice experiment was used to estimate the WTP for transformed biosolids-derived fertilisers that do not yet exist. In choice experiments, respondents are presented with hypothetical product choices and asked to indicate their preferences. Choice experiments typically include a price variable that allows each attribute's implied ranking and value to become apparent as respondents trade off monetary costs against changes in the levels of other attributes. Choice experiments are widely used in healthcare (Ryan et al., 2008), consumer marketing (Mugera et al., 2017) and the valuation of non-market goods and services, especially in the environmental sphere (Mariel et al., 2021; Mamouni Limnios et al., 2016).

Random utility theory is the underlying foundation for analysing the marginal values associated with changes in product attributes (McFadden, 1986). The theory posits that respondents choose the option that provides them with the most benefit (i.e., utility), with the choice based on a deterministic component that can be measured and an unobserved or random element. Utility (U) can vary randomly across the population in a mixed logit model, expressed as:

$$U_{ij} = \beta_j X_{ij} + \varepsilon_{ij} \tag{1}$$

where X_{ij} is a vector of attributes for a given choice i for an individual j and β_j is a vector of parameters depicting the marginal utilities of these attributes specific to the individual. As we cannot value β_j for every individual, these coefficients are assumed to follow a distribution $f(\beta_j|\theta,$), where θ represents parameters specifying a normal distribution, accounting for heterogeneity across individual preferences (Train, 2003). As a result, the probability that an individual j selects alternative i in a set of I choices is given by:

$$P_{ij} = \int \frac{\exp\left(X_{ij}\beta_j\right)}{\sum_{i=1}^{I} \exp\left(X_{ij}\beta_j\right)} f\left(\beta_j|\theta\right) d\beta \tag{2}$$

This model allows us to estimate the mean marginal utility values β for each observed attribute, along with its standard deviation across the normal distribution. These coefficients can also be used to calculate the mean WTP for non-monetary attributes n using the estimated parameter associated with price β_m:

$$WTP_n = -\frac{\beta_n}{\beta_m} \tag{3}$$

For the two carbon sequestration labels, WTP indicates the increased price individuals are willing to pay for a labelled fertiliser compared to an unlabelled fertiliser. For the different fertiliser types (synthetic, organic, or biosolids-derived), WTP is interpreted as the additional monetary value one would pay relative to the baseline fertiliser type excluded from the model.

Likelihood ratio tests were used to determine whether respondents should be separated into distinct groups (Greene, 2018) based on their most recent fertiliser purchases (Dahlin et al., 2019; Herbes et al., 2020), such as certified organic vs synthetic fertilisers and lawn vs flower, fruit, or vegetable fertilisers. The adopted modelling strategy encompassed three steps: (1) comparing a general model that included all respondents with a split sample of certified organic and synthetic purchasers using a log-likelihood ratio test; (2) within each subsample, evaluating differences between respondents who purchased mainly for lawn versus other uses; (3) incorporating sociodemographic variables into the relevant sub-models.

In addition to estimating the WTP for attributes, we used the probabilistic logit function to calculate the probability of an individual purchasing a particular fertiliser product i from a list of options with X_i attributes, enabling us to estimate the market share of the various fertiliser products. We achieved this through simulation using the mixed logit probability of selecting an item and the population distribution of the parameters (Train, 2003, p. 300).

2.3. Attribute development

In the choice experiment, each respondent was presented with three fertiliser types—synthetic alternative, organic-certified alternative, and biosolids-derived alternative—each with three attributes: whether it was labelled as delivering carbon sequestration benefits, its nutrient content (N, P and K) and the price per 5 kg bag. The attributes of each fertiliser varied between questions, allowing us to understand how these attributes affect purchase decisions. Synthetic fertilisers are artificially derived and typically more effective for plant growth than organic nutrient-based fertilisers due to the higher and more available nutrient contents and other supplementary ingredients such as trace elements and wetting agents. Organic-certified fertilisers, with comparatively fewer nutrients, are produced from plant-derived or animal-derived ingredients. The hypothetical biosolids-derived fertiliser contains human-derived biosolids combined with green waste and composted to produce fertiliser. Consequently, the potential carbon sequestration and nutrient contents differed between the fertiliser types (Tables 1a and 1b).

Two carbon sequestration labels were tested: (1) "environmental carbon capture", focused on the prosocial perspective of carbon sequestration by signifying the fertiliser's ability to remove carbon dioxide from the atmosphere; (2) "soil carbon builder", emphasised how the fertiliser would improve soil quality by increasing soil organic carbon. These attributes were assumed to apply only to synthetic and biosolids-derived fertilisers, as organic-certified fertilisers typically do not contain artificial inputs (Kirkby et al., 2013). While the organic-certified fertilisers may indeed have some soil carbon sequestration capabilities, we assumed their effectiveness would not compare to fertilisers artificially augmented to achieve the desired stoichiometry. Thus, the organic fertiliser alternative could not have a carbon sequestration label, while the synthetic and biosolids alternatives could have no label or one of the two carbon sequestration labels in each choice question.

Nutrient (N, P, K) content levels varied across fertiliser types, with the highest concentrations for synthetic fertiliser, followed by intermediate levels for biosolids-derived fertiliser and the lowest for organic-certified fertiliser. The specific values chosen for this attribute were referenced from the Australian fertiliser market dataset and used to perform the hedonic price analysis. The average nutrient contents from the organic-certified and synthetic fertiliser subsets were used as benchmark attributes. These concentrations (±1 standard deviation) were also used to inform their respective levels.

For authenticity purposes, the nutrient levels depended on the primary use of the fertiliser, as fertilisers targeting lawns typically have higher nutrient contents and variability. As such, two sets of nutrient contents were selected for the three fertiliser types, one representing fertilisers whose principal purpose was for lawns and the other for all other gardening facets such as fruits, flowers, and vegetables. The respondents only saw one version of the choice sets depending on whether they primarily bought fertiliser for lawns or other uses.

Given the variability in reported prices and bag sizes, it was important to scale the prices shown on fertilisers to reflect each respondent's prior purchases, with the standard 5 kg bag used in the choice experiment. Therefore, the vector of prices presented to each respondent was scaled by their most recent fertiliser purchase. A simple price scaling regression model was estimated using the hedonic price analysis dataset to determine the effect of size on the product price.

$$Ln(P) = \beta\, Ln(S) + \alpha \tag{5}$$

where P is price per kilogram of the product, S is size in kilograms, β and α are parameters estimated by the model. The baseline scaled price for an individual respondent was then calculated, with β representing the discount effect observed when purchasing higher-volume products. The scaled price (SP) was calculated within the survey using the respondent's reported price (RP) and size (RS) of their last bought fertiliser product and adjusted for a 5 kg bag in the choice sets as follows:

Table 1a
Survey attribute levels used in discrete choice experiment by fertilizer type (synthetic, organic-certified, biosolids-derived) and nutrient content (N-P-K as mg/kg at three levels for two end-uses – lawn and fruit/vegetable/flower).

Fertiliser use	Nutrient level	Nutrient content (N-P-K) by fertiliser type		
		Synthetic	Organic-certified (ORG)	Biosolids-derived (BIO)
Lawn	Low	8-1-2	4-0-1	6-0.5-2
	Medium	16-1.5-4	6-0.5-2	11-1-3
	High	24-2-6	8-1-3	16-1.5-4
Fruit/vegetable/flower	Low	8-1-3	4-0-1	6-0.5-2
	Medium	12-1.5-6	6-0.5-2	9-1-5
	High	15-2-9	8-1-3	12-1.5-6

Table 1b
Survey attribute levels used in discrete choice experiment by fertilizer type (synthetic, organic-certified, biosolids-derived) with labelling for carbon sequestration, and price of product.

Fertiliser attribute	Fertiliser type		
	Synthetic	Organic-certified (ORG)	Biosolids-derived (BIO)
Carbon sequestration	No label Soil carbon builder Environmental carbon capture	No label No label No label	No label Soil carbon builder Environmental carbon capture
Price of product ($/5 kg)	−20%, −10%, 0, +10%, +20% change from inferred price of respondents' most recent fertiliser purchase		

$$SP = \frac{5RP}{RS} \bullet \left(\frac{5}{RS}\right)^{\beta} \tag{6}$$

In all choice models, alternative-specific dummies were included to identify the fertiliser type (biosolids-derived, organic-certified and synthetic) and treated as a random parameter to account for heterogeneity in preferences.

2.4. Survey design

The survey was structured into four main sections. The first section asked the respondents about the primary gardening purpose of the fertiliser they last bought, how much they paid for it, its size in kilograms and whether it was organic-certified or synthetic. Their selection of the fertiliser's purpose helped tailor the choice sets for improved shopping experience replicability. For example, if they selected "Lawn" as their primary fertiliser purpose, the choice sets would show nutrient contents and images associated with lawn fertilisers. The other questions helped us understand the motives and underlying reasons for a respondent's subsequent answers, including their beliefs on gardening efficacy, understanding of biosolids and carbon sequestration, and attitudes towards environmental issues. The questions related to the respondents' knowledge and predispositions towards biosolids were replicated from an Australian survey by Jones et al. (2020) to compare the two studies.

The second section provided information describing the choice experiment. It included descriptions of the three fertiliser types (biosolids-derived, organic-certified and synthetic), including details on the manufacturing process and ingredients. The role of nutrient values in fertiliser for increasing plant growth was also described. The definition of carbon sequestration was provided again, with the respondents informed that an artificial process could enhance this sequestration potential in the fertiliser. Furthermore, the two labels were explained to assist respondents in understanding that carbon sequestration can benefit soil quality and reduce atmospheric carbon dioxide. This contextual clarification was provided to ensure a consistent understanding among respondents and to aid in interpreting the results. Table S7 in the Supplementary Information provides full descriptions of the information preceding the choice experiment.

In the third section, respondents answered the choice experiment questions. Each respondent answered six choice questions, where they were presented with three hypothetical fertiliser products and asked which one they would buy. For each respondent stream, an experimental design of 24 choice sets split into four blocks of six was created using Ngene software (ChoiceMetrics, 2021). The choice questions were tailored to respondents based on their recent fertiliser purchase. For example, if they reported last purchasing fertiliser for lawn use, they would be randomly directed to one of four possible blocks of questions displaying images and attributes specific to lawn fertilisers. Conversely, if the respondent reported recently purchasing fertiliser for use on flowers, fruits, vegetables, or other plants, they would be randomly directed to one of four possible blocks of questions framed in the context of general-purpose fertilisers (Fig. 1). The apportioning of questions into separate blocks ensured coverage of all possible choice set variations required for analysis and maximised respondent engagement.

The final section of the survey collected sociodemographic information about the respondents, such as income, education level, employment status and area of residence.

2.5. Survey sample

The survey was disseminated through the market research company Dynata (https://www.dynata.com/). This sampling method ensured diversity in respondent demographics, with quotas enforced to include participants from various age groups and genders. To be eligible to participate in the survey, respondents had to be based in metropolitan Perth, Australia, be at least 18 years of age, provide consent to data collection, and have personally purchased fertiliser in the past.

The survey reached 781 respondents; 362 were excluded from the dataset due to ineligibility as they did not purchase fertilisers, with another 74 responses excluded as they completed the survey in less than 5 min, suggesting they might not have answered with sufficient attention or consideration. Of the 345 remaining respondents, the sample was slightly skewed to an older demographic than the Australian population (Table S1), possibly because the survey required participants to be at least 18 years old.

3. Results

3.1. Hedonic price analysis

Table 2 presents the results of two hedonic price models: (1) N as a single variable and (2) N split into inorganic and organic elements. In both models, K and size (bag of fertiliser) had significant positive marginal effects on price (Table 2), P had no significant impact, and S had moderate adverse effects on price.

Nitrogen as a single variable positively influenced the price. However, when divided into inorganic and organic components, organic N (e.g., in a matrix with C) did not significantly affect price, possibly due to the perception that plants do not take up organic N as readily as inorganic N (i.e., NO_3^--N, NH_4^+-N) or the organic branding and certification attributes absorbs the pricing value associated with organic N. Irrespective of whether the model used N as a single or split variable, the price per kilogram increased by about one cent for every extra gram of N per kilogram of total content.

In the hedonic analysis, organic branding and certification had significant but opposite effects. While organic branding had an associated price premium of at least \$2.00 per kilogram, organic certification had a price discount of \$1.43–\$1.92 per kilogram. As the price discount associated with organic certification did not surpass the price premium for organic branding, the fertilisers labelled with an organic association but without certification cost more than those with certification.

3.1.1. Attitudinal questions

Respondents exhibited moderately high levels of understanding about fertiliser (Supplementary Information Table S2), providing assurance that the survey sample had sufficient levels of understanding and experience related to these purchases to answer the valuation questions reliably.

The answers relating to attitudes and awareness of biosolids were similar to the 2020 National Biosolids Survey performed by the ANZBP (Tables S3 and S4), suggesting that our survey sample represents the Australian population. Interestingly, 55% of our respondents had not heard of biosolids, but 25% shifted their negative or uncertain sentiments about biosolids in their gardens to positive attitudes after receiving information about biosolids. Many of those with doubts about using biosolids in their gardens said in follow-up open-ended answers that they would need more information about the fertiliser before using it. Concerns related to pathogens or other contaminants that may pose health risks were also mentioned.

3.1.2. Gardening and fertiliser-purchasing behaviour

Most respondents reported purchasing their last fertiliser from Bunnings (82%), with smaller percentages buying from large supermarket chains (9%) or garden centres (6%) (Table S5). This distribution supports the validity of the choice experiment, which sought to replicate the in-person shopping experience with fertilisers and prices similar to those found in these retail locations. Approximately one-third of respondents (117 respondents) last purchased certified organic fertiliser, while the remainder (228 respondents) purchased synthetic fertiliser. Approximately one-third (34%) reported purchasing fertiliser for lawn use, 23% for flowers, 21% for vegetables, and the remainder for other purposes.

3.1.3. Price scaling model

The price scaling equation (Equation (5)) was used to adjust the respondent's reported prices to a scaled figure for the choice sets. The price scaling regression model revealed a significant negative effect of size on price per unit of weight (Table S6). The size coefficient was used to generate a rescaled price for 5 kg bags, positioned between \$10 and \$25, to prevent extreme values that could occur due to unusual purchases (e.g., very small, high-valued fertilisers).

3.2. Choice experiment models

3.2.1. Likelihood ratio tests

First, we tested whether different sub-groups of respondents had different preferences based on their recent fertiliser purchasing behaviour using likelihood ratio tests. These tests determined that preference parameter estimates significantly differed for people who purchased organic and synthetic fertilisers ($p < 0.001$) but did not significantly differ for those who bought lawn fertilisers versus garden fertilisers.[1] Consequently, separate models were developed for those most recently purchased organic fertiliser and those most recently purchased synthetic fertiliser.

3.2.2. Mixed logit models and willingness-to-pay for fertiliser characteristics

Table 3 presents the choice experiment results for survey respondents who last purchased organic fertilisers. Two specifications are offered—one without respondent-specific characteristics and the other incorporating interactions between respondent characteristics and fertiliser attributes—to determine whether people vary in their fertiliser preferences. The negative coefficients for the price variable indicate that respondents were less likely to select more expensive options. The positive coefficients for medium and high nutrient attributes suggest that respondents favoured these alternatives over those with low nutrient contents. Relative to synthetic fertilisers, this group of respondents were willing to pay \$14.54 more for biosolids-derived fertiliser per 5 kg bag and \$15.20 more for organic-certified fertiliser. Respondents were also willing to pay more for fertilisers with "soil carbon builder" (\$3.70 premium per bag) and "environmental carbon capture" (\$4.67 premium per bag) labels, but these price premiums did not differ from each other ($p = 0.653$). The covariance of random parameters indicated a positive correlation between preferences for biosolids-derived and organic-certified fertilisers.

[1] The null hypothesis that attribute values for the organic certified subsample were the same for those who purchased for lawn use versus all other uses could not be rejected ($p = 0.44$), nor could it be rejected for the synthetic fertiliser subsample ($p = 0.57$).

Fig. 1. Choice set example shown in the survey for respondents who reported last purchasing fertiliser for fruit, flower, or vegetable purposes.

Table 2
Hedonic regression model for price ($/kg) of fertilizer.

Independent variable	Hedonic Pricing Model 1	Hedonic Pricing Model 2
(Intercept)	6.174***	6.910***
Nitrogen (N)	0.012***	–
- Inorganic nitrogen	–	0.010***
- Organic nitrogen	–	−0.013
Phosphorus (P)	0.010	0.008
Potassium (K)	0.011***	0.009**
Sulphur (S)	−0.009**	−0.012**
Organic branding	2.029***	2.398***
Organic certification	−1.919***	−1.343*
Bag size (log transformed)	−2.378***	−2.414***
Observations	116	113
R^2	0.605	0.616

****, ** and * indicate p-values less than 0.01, 0.05 and 0.1, respectively.*
Note: Regression models were estimated using robust standard errors.

Notably, the only respondent characteristic that significantly affected preferences was an interaction term involving a respondent's agreement with the statement "carbon sequestration (CS) is an effective way to combat climate change" (scored −2 to +2, with higher values implying greater agreement) and the biosolids ASC (As this is a labelled experiment, an alternative specific constant e.g. ASC was introduced for the biosolid and organic options, using the synthetic option as the base). The marginal effect was substantial: increasing the WTP for a biosolids-derived fertiliser by $5.46 for each additional point in the scale. At mean CS levels, the organic sample values for the biosolids-derived and organic-certified fertilisers were about the same increment greater than synthetic fertilisers.

Table 4 presents the choice experiment results from the subsample of respondents who last purchased synthetic fertiliser. This group of respondents were not willing to pay significantly more for "soil carbon builder" labelled fertiliser but were willing to pay a $2.73 premium for fertiliser with an "environmental carbon capture" label. On average, respondents were willing to pay $1.55 less for a bag of biosolids-derived fertiliser compared to synthetic fertiliser, though this was only significant at the 10% level. However, there was significant heterogeneity in preferences for biosolids-derived fertilisers, and those concerned about waste management and carbon sequestration were willing to pay more for biosolids-derived products.

3.3. Probabilities of purchasing different fertiliser types

Tables 5 and 6 provide estimates of the probability that individuals will purchase biosolids-derived fertilisers based on their past preferences for organic or synthetic fertilisers, respectively. These probabilities were determined post-estimation using the *mixlpred* command that simulates the expected probability of selecting the item, accounting for the population distribution of the parameters (Hole, 2007). To estimate these probabilities, we mimicked a store situation with seven available products: three synthetic and three organic-certified fertilisers, each with differing nutrient levels, and a biosolids-derived fertiliser. The price is the same across all seven products in each scenario, so only variations in the non-price fertiliser attributes affect utility and, in turn, the probability that each fertiliser will be purchased.

In Table 5, people who last bought organic fertiliser have a 21% chance of selecting a biosolids-derived fertiliser, even with a low nutrient content and no label indicating its carbon sequestration features. As the nutrient contents increase and carbon labels are added, the biosolids-derived fertiliser captures more of the market, becoming the most likely fertiliser purchased in this product line. Adding a label highlighting prosocial or private carbon benefits increases the likelihood of purchasing a biosolids-derived fertiliser by 15% compared to the next most favourable available alternative.

Attitudes about the effectiveness of carbon sequestration in combatting climate change also significantly impact preferences for biosolids-derived fertilisers. Someone who feels very strongly about the effect of carbon sequestration in combating climate change has a 50% probability of choosing a high-nutrient biosolids-derived fertiliser with an "environmental carbon capture" label. On the other hand, consumers who feel that soil carbon sequestration is ineffective in combating climate change would be less likely to buy a biosolids-derived fertiliser. However, individuals already inclined to purchase organic-certified products are unlikely to have a highly negative attitude toward carbon

Table 3
Organic purchasing respondents: Base and Extended mixed logit model, and part-worths (extended model): Coefficients (Coef.), standard error (SE) and 95% confidence interval (CI).

Variable	Base model		Extended model			
	Estimates		Estimates		Part-worths ($)	
	Coef.	SE	Coef.	SE	Coef.	CI
Price	−0.091***	0.026	−0.091***	0.026		
Nutrient content medium	0.079	0.128	0.071	0.128	0.78	[-1.73 to 3.29]
Nutrient content high	0.632***	0.089	0.643***	0.088	7.09***	[2.94 to 11.25]
Soil carbon builder	0.324	0.206	0.336	0.206	3.70**	[0.10 to 7.30]
Environmental carbon capture	0.400***	0.129	0.423***	0.129	4.67***	[1.48 to 7.86]
BIO*CS			0.495***	0.137	5.46**	[1.25 to 9.66]
Random parameters: mean estimates						
Biosolids-derived (BIO)	1.575***	0.213	1.318***	0.202	14.54***	[5.42 to 23.67]
Organic-certified (ORG)	1.328***	0.270	1.378***	0.267	15.20***	[5.96 to 24.46]
Random parameters: standard deviation and covariance estimates						
Biosolids-derived (BIO)	1.447***	0.194	1.451***	0.186		
Organic-certified (ORG)	2.595***	0.310	2.684***	0.261		
BIO:ORG (Covariance)	1.918*	1.063	2.369***	0.744		
McFadden's R^2	0.237		0.241			

***,** and * indicate p-values less than 0.01, 0.05 and 0.1, respectively.
CS = response to: Carbon sequestration is an effective way to combat climate change: see Table S2.

Table 4
Synthetic purchasing respondents: Base and Extended mixed logit model, and part-worths (extended model): Coefficients (Coef.), standard error (SE) and 95% confidence interval (CI).

Variable	Base model		Extended model			
	Estimates		Estimates		Part-worths ($)	
	Coef.	SE	Coef.	SE	Coef.	CI
Price	−0.233***	0.036	−0.236***	0.036		
Nutrient content medium	0.360**	0.173	0.627***	0.218	2.65***	[1.09 to 4.21]
Nutrient content high	0.705***	0.111	0.707***	0.111	2.89***	[1.82 to 3.96]
Soil carbon builder	0.221	0.260	0.24	0.26	1.147	[-0.85 to 3.15]
Environmental carbon capture	0.770***	0.160	0.756***	0.16	2.733***	[1.50 to 3.97]
Nutrient content medium*FV			−0.452**	0.227	−1.914*	[-3.84 to 0.02]
BIO*WM			0.435**	0.173	1.751***	[0.50 to 3.00]
BIO*CS			0.340**	0.167	1.362**	[0.25 to 2.48]
Random parameters: mean estimates						
Biosolids-derived (BIO)	0.358**	0.162	−0.313	0.258	−1.549*	[-3.23 to 0.14]
Organic-certified (ORG)	−0.287	0.254	−0.282	0.252	−1.342	[-3.01 to 0.32]
Random parameter standard deviation (SD) and covariance estimates						
Biosolids-derived (BIO)	1.249***	0.195	1.181***	0.195		
Organic-certified (ORG)	1.464***	0.224	1.437***	0.224		
BIO:ORG (Covariance)	1.232***	0.443	1.236***	0.437		
McFadden's R^2	0.189		0.194			

***, ** and * indicate p-values less than 0.01, 0.05 and 0.1, respectively.
CS = response to: Carbon sequestration is an effective way to combat climate change: see table S2.
WM = response to: Waste management is an important environmental issue: see table S2.
FV = 1 if respondent mainly purchases fertilizer for use on fruit and vegetables, 0 otherwise.

sequestration.

Table 6 shows fertiliser purchasing probabilities among the sample who last purchased synthetic fertiliser for lawn purposes. Individuals with average attitudes towards waste management (attitudinal level of 1.17) and carbon sequestration (attitudinal level of 0.47) are 25% more likely to purchase biosolids-derived fertiliser with high nutrient content and an "environmental carbon capture" label than the next best option. However, when this biosolids-derived fertiliser option has low nutrient content and no carbon sequestration labelling, it is the fourth most likely choice, with a similar market share to an organic-certified fertiliser with high nutrient content.

Attitudes towards waste management and carbon sequestration significantly affected the purchasing probabilities for synthetic fertiliser buyers (Table 6). At one extreme, respondents with negative views about carbon sequestration and waste management had as little as a 2% probability of purchasing a biosolids-derived fertiliser. For average attitude levels among the synthetic fertiliser purchasing survey sample, the biosolids-derived fertiliser captured between 15% and 57% (Table 6) of the market for individuals purchasing fertiliser for lawn purposes, with similar findings (between 17% and 60%) for fruits, flowers, or vegetables (Table A2).

4. Discussion

In this study we aimed to assess the feasibility of marketing biosolids-derived fertilisers to urban retail consumers and determine whether consumers would be willing to pay more for fertilisers with advertised carbon sequestration benefits. The results indicate that biosolids-derived fertilisers could be marketed successfully to urban fertiliser consumers at prices similar to other fertilisers in the market and that consumers are willing to pay more for products with carbon sequestration labels. However, there was significant variation in consumer preferences for fertilisers derived from biosolids or with pro-environmental labels, meaning these products should be marketed to specific consumer

Table 5
Simulated market shares for different fertilizer types using the organic-certified fertiliser subsample model, by fertilizer attribute level and respondent attitudes.

Biosolids product attributes		Attitudinal level	Fertiliser type market shares (%)						
			Synthetic			Organic-certified			Biosolids-derived
Nutrient Content	Carbon sequestration	CS[a]	Nutrient content low	Nutrient content medium	Nutrient content high	Nutrient content low	Nutrient content medium	Nutrient content high	
Low	No label	−2.00	7	8	14	16	17	30	9
		0.59	6	6	11	14	15	26	21
		2.00	5	5	9	12	13	23	32
Medium	Soil carbon builder	−2.00	7	7	13	15	16	29	12
		0.59	5	6	10	13	14	25	27
		2.00	4	5	8	11	12	21	38
High	Environmental carbon capture	−2.00	6	7	12	14	15	27	18
		0.59	4	5	8	11	12	22	37
		2.00	3	3	6	9	10	18	50

Note:
[a] Average attitudinal level among respondents who last purchased organic-certified fertiliser towards the statement "carbon sequestration is an effective way to combat climate change" is 0.59 (−2 = Strongly disagree, 0 = Neither disagree nor agree, 2 = Strongly agree).

Table 6
Simulated market shares for different fertilizer types using the synthetic fertiliser subsample model: lawn use, by fertilizer attribute level and respondent attitudes.

Biosolids product attributes		Attitudinal levels		Fertiliser product market shares (%)						
				Synthetic			Organic-certified			Biosolids-derived
Nutrient Content	Carbon sequestration	WM[a]	CS[b]	Nutrient content low	Nutrient content medium	Nutrient content high	Nutrient content low	Nutrient content medium	Nutrient content high	
Low	No label	−2.00	−2.00	11	21	23	9	17	18	2
		1.17	0.47	10	18	19	8	15	16	15
		2.00	2.00	8	15	16	7	13	14	28
Medium	Soil carbon builder	−2.00	−2.00	11	21	22	9	16	18	4
		1.17	0.47	9	16	17	6	12	13	27
		2.00	2.00	6	12	13	5	9	10	45
High	Environmental carbon capture	−2.00	−2.00	10	19	21	8	16	17	8
		1.17	0.47	7	13	14	5	10	11	40
		2.00	2.00	5	10	10	4	7	7	57

Note:
[a] Average attitudinal level among respondents who last purchased synthetic fertiliser towards the statement "I am conscious/careful of how I dispose of my household waste" is 1.17 (−2 = Strongly disagree, 0 = Neither disagree nor agree, 2 = Strongly agree).
[b] Average attitudinal level among respondents who last purchased synthetic fertiliser towards the statement "carbon sequestration is an effective way to combat climate change" is 0.49 (−2 = Strongly disagree, 0 = neither disagree nor agree, 2 = Strongly agree).

segments.

The hedonic price analysis results revealed that organic-labelled fertilisers are sold at similar or higher prices than synthetic alternatives. This finding is promising for biosolids-derived products and aligns with previous research demonstrating the positive utility of organic labelling (Dahlin et al., 2016, 2019; Herbes et al., 2020). In the choice experiment, past fertiliser purchasing habits significantly affected preferences for biosolids-derived fertilisers. Consumers who typically buy synthetic fertilisers were willing to pay less for biosolids-derived products and were less likely to buy them. In contrast, consumers who typically buy organic fertilisers viewed biosolids-derived fertilisers as equally attractive to organic fertilisers. These results suggest biosolids-derived fertilisers may succeed in the urban retail market, primarily among organic fertiliser consumers.

Our results contradict earlier research suggesting adverse consumer reactions to biosolids-derived fertilisers. For instance, consumers are often averse to foods produced using these fertilisers (Gwara et al., 2021; Simha et al., 2021; Segrè Cohen et al., 2020). Likewise, farmers often prefer not to use biosolids-derived fertilisers in food production (Roxburgh et al., 2020; Moya et al., 2019). However, most prior studies focused on large-scale agricultural applications rather than marketing these products directly to urban consumers. In this study, only synthetic fertiliser consumers demonstrated an aversion to biosolids-derived products on average, and the effect was relatively small. Therefore, retail markets might provide a viable channel to divert biosolids from landfills, particularly by targeting organic fertiliser consumers.

The choice experiment also confirmed that consumers are willing to pay higher amounts for fertilisers with labels that indicate their ability to sequester carbon. Both prosocial (carbon capture) and private (soil carbon builder) messages increased WTP for some segments of consumers, with prosocial messaging increasing WTP for a wider range of people. Labelling the environmental benefits of biosolids-derived fertilisers can improve their acceptance in the marketplace and even command a premium price over alternatives. Positive attitudes about soil carbon sequestration and household responsibility for waste management also significantly increased WTP for biosolids-derived fertilisers. These results highlight that environmentally concerned individuals are highly responsive to pro-environmental labels, significantly increasing individuals' WTP for biosolids-derived products.

This exploratory research offers promise for marketing biosolids-derived fertilisers directly to consumers. However, further research is needed to understand more nuanced factors underlying preferences for biosolids-derived garden products. For instance, exploring theories explaining other pro-environmental purchases, risk perceptions, or uncertainty in consumer behaviour could be beneficial. Moreover, future research could examine the intended use of the fertiliser, distinguishing between edible and ornamental plants, to establish potential markets for biosolids-derived fertilisers for household and commercial horticulture or nursery production systems.

We only offered three fertiliser products in our choice experiments, while in reality, there are many alternatives for synthetic and organic fertilisers. The price discrepancy between the WTP in the choice experiment and the lack of a market price premium in the hedonic analysis may be due to competition in the real market and the possibility that the survey sample did not accurately represent fertiliser consumers. Dahlin et al. (2017) found that men are not often involved in garden product purchases, but our sample had a relatively even split between female and male respondents. Moreover, the sample was taken from a market research company's panel rather than in-store consumers, which may have had more synthetic fertiliser purchasers than organic-certified fertiliser purchasers. Alternatively, consumers may only occasionally purchase organic fertilisers, characterising a much smaller organic fertiliser market than observed in the choice experiment.

Lastly, education and raising awareness about biosolids and their safe use will be critical to building a retail market for biosolids-derived fertilisers (Borden et al., 2004; Jones et al., 2020; Outwater, 1994). Our study suggests that once this information is widespread, there will be great potential for a biosolids-derived fertiliser to penetrate the retail market.

Finally, our study did not consider the costs of producing biosolids-derived fertilisers. We only established that consumers are willing to purchase biosolids-derived fertilisers and that price premiums could be possible with the proper combination of pro-environmental labelling, consumer targeting, and education and marketing to promote the benefits of these fertilisers. Further research is required to understand the cost of producing fertilisers from biosolids and whether urban retail fertilisers will benefit society once the financial, environmental, and social costs of alternative disposal methods or outcomes of biosolids are considered.

CRediT authorship contribution statement

Jacky Lu: Conceptualization, Methodology, Software. **Bede S. Mickan:** Conceptualization, Data curation, Writing – original draft. **Megan H. Ryan:** writing, review and editing. **Heath Okely:** Writing, industry guidence, and, Methodology, setup, analysis, and, interpretation. **Curtis Rollins:** writing, review and editing. **Michael Burton:** Conceptualization, Methodology, Software, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Heath Okely reports financial support was provided by Richgro Garden Products. Heath Okely reports a relationship with Richgro Garden Products that includes: employment. Bede S. Mickan, and Heath Okely.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2023.139728.

Appendix

Table A1
Summary statistics of variables from retail fertiliser data used in hedonic pricing model (N = 116)

Variable	Median	Mean	StDev	Minimum	Maximum
Dependent variable					
Price per kilogram (AUD)	4.012	4.978	2.864	1.187	19.3
Explanatory variables					
Nitrogen (g/kg TP*)	100	117.721	79.221	0	460
Inorganic nitrogen (g/kg TP)	90	99.842	90.909	0	460
Organic nitrogen (g/kg TP)	10	18.137	24.452	0	140
Phosphorous (g/kg TP)	10	12.243	12.481	0	80
Potassium (g/kg TP)	53	63.208	58.712	0	415
Sulphur (g/kg TP)	80	84.322	54.337	0	240
Organic branding (yes = 1, no = 0)	1	0.56	0.498	0	1
Organic certification (yes = 1, no = 0)	0	0.164	0.372	0	1
Product size (kg)	4	5.391	3.937	0.5	20

**g/kg TP = grams per kilogram of total product.*

Table A2
Simulated market shares for different fertilizer types using the synthetic fertiliser subsample model: fruits, flowers and vegetable use, by fertilizer attribute level and respondent attitudes.

Biosolids product attributes	Attitudinal levels	Fertiliser product market shares (%)		
		Synthetic	Organic	Biosolids-derived

(*continued on next page*)

Table A2 (*continued*)

Biosolids product attributes		Attitudinal levels		Fertiliser product market shares (%)						
				Synthetic			Organic			Biosolids-derived
Nutrient content	Carbon sequestration	WM#	CS$	Nutrient content low	Nutrient content medium	Nutrient content high	Nutrient content low	Nutrient content medium	Nutrient content high	Biosolids market share
Nutrient content	Carbon sequestration	WM#	CS$	Nutrient content low	Nutrient content medium	Nutrient content high	Nutrient content low	Nutrient content medium	Nutrient content high	Biosolids market share
Low	None	−2.00	−2.00	13	15	26	10	12	21	**2**
		1.17	0.47	11	13	22	9	11	18	**17**
		2.00	2.00	9	11	18	8	9	15	**31**
Medium	Soil carbon builder	−2.00	−2.00	13	15	26	10	12	21	**3**
		1.17	0.47	11	13	21	8	9	16	**22**
		2.00	2.00	8	10	17	6	7	13	**39**
High	Environmental carbon capture	−2.00	−2.00	12	14	24	10	12	20	**9**
		1.17	0.47	8	9	16	6	7	12	**43**
		2.00	2.00	6	7	11	4	5	8	**60**

Note:
Average attitudinal level among respondents who last purchased synthetic fertiliser towards the statement "I am conscious/careful of how I dispose of my household waste" is 1.17 (−2 = Strongly disagree, 0 = Neither disagree nor agree, 2 = Strongly agree).
$ Average attitudinal level among respondents who last purchased synthetic fertiliser towards the statement "carbon sequestration is an effective way to combat climate change" is 0.49 (−2 = Strongly disagree, 0 = neither disagree nor agree, 2 = Strongly agree).

References

Ahmad, W., Anders, S., 2012. The value of brand and convenience attributes in highly processed food products. Can. J. Agric. Econ. 60 (1), 113–133. https://doi.org/10.1111/j.1744-7976.2011.01234.x.

Australian & New Zealand Biosolids Partnership, 2020. Australian Biosolids Statistics. viewed 15 April 2021 https://www.biosolids.com.au/guidelines/australian-biosolids-statistics/. .

Borden, G.W., Devitt, D.A., Morris, R.L., Robinson, M.L., Lopez, J., 2004. Residential assessment and perception toward biosolids compost use in an urban setting. Compost Sci. Util. 12 (1), 48–54. https://doi.org/10.1080/1065657X.2004.10702157.

ChoiceMetrics, 2021. Ngene 1.3 User Manual & Reference Guide.

Department of Climate Change, Energy, the Environment and Water. 2022. National Waste Report 2022. https://www.dcceew.gov.au/sites/default/files/documents/national-waste-report-2022.pdf.

Dahlin, J., Beuthner, C., Halbherr, V., Kurz, P., Nelles, M., Herbes, C., 2019. Sustainable compost and potting soil marketing: private gardener preferences. J. Clean. Prod. 208, 1603–1612. https://doi.org/10.1016/j.jclepro.2018.10.068.

Dahlin, J., Halbherr, V., Kurz, P., Nelles, M., Herbes, C., 2016. Marketing green fertilizers: insights into consumer preferences. Sustainability 8 (11), 1169. https://doi.org/10.3390/su8111169.

Dahlin, J., Nelles, M., Herbes, C., 2017. Biogas digestate management: evaluating the attitudes and perceptions of German gardeners towards digestate-derived soil amendments. Resour. Conserv. Recycl. 118, 27–38. https://doi.org/10.1016/j.resconrec.2016.11.020.

Dalahmeh, S.S., Thorsén, G., Jönsson, H., 2022. Open-air storage with and without composting as post-treatment methods to degrade pharmaceutical residues in anaerobically digested and dewatered sewage sludge. Sci. Total Environ. 806, 151271.

Darvodelsky, P., 2011. Biosolids Snapshot. E. Department of Sustainability. Water, Population and Communities. https://www.environment.gov.au/system/files/resources/2e8c76c3-0688-47ef-a425-5c89dffc9e04/files/biosolids-snapshot.pdf.

Dewenter, R., Haucap, J., Luther, R., Rötzel, P., 2007. Hedonic prices in the German market for mobile phones. Telecommun. Pol. 31 (1), 4–13. https://doi.org/10.1016/j.telpol.2006.11.002(TelecommunicationsPolicy.

El Hayany, B., El Fels, L., Ouhdouch, Y., Hafidi, M., 2021. Fate of pathogenic microorganisms during lagooning sludge composting and exploration of bacteriophages as indicator of hygienization. Environ. Technol. Innovat. 21, 101268.

EPA, 2021. Basic Information about Biosolids viewed 20 March 2021. https://www.epa.gov/biosolids/basic-information-about-biosolids.

Gibson, F.L., Burton, M., 2014. Salt or sludge? Exploring preferences for potable water sources. Environ. Resour. Econ. 57 (3), 453–476. https://doi.org/10.1007/s10640-013-9672-9.

Gilbert, S.W., 2013. Applying the Hedonic Method. U.S. Department of Commerce. National Institute of Standards and Technology. https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1811.pdf.

Goodman, A.C., 1983. Willingness to pay for car efficiency: a hedonic price approach. J. Transport Econ. Pol. 17 (3), 247–266.

Greene, W.H., 2018. Econometric Analysis, eighth ed. Pearson.

Gwara, S., Wale, E., Odindo, A., Buckley, C., 2021. Attitudes and perceptions on the agricultural use of human excreta and human excreta derived materials: a scoping review. Agriculture (Basel) 11 (2), 153. https://doi.org/10.3390/agriculture11020153.

Haynes, R.J., Murtaza, G., Naidu, R., 2009. Inorganic and organic constituents and contaminants of biosolids: implications for land application. Adv. Agron. 104, 165–267.

Herbes, C., Dahlin, J., Kurz, P., 2020. Consumer willingness to pay for proenvironmental attributes of biogas digestate-derived potting soil. Sustainability 12 (16), 6405. https://doi.org/10.3390/su12166405.

Hoang, S.A., Bolan, N., Madhubashani, A.M.P., Vithanage, M., Perera, V., Wijesekara, H., Wang, H., Srivastava, P., Kirkham, M.B., Mickan, B.S., Rinklebe, J., Siddique, K.H., 2022. Treatment processes to eliminate potential environmental hazards and restore agronomic value of sewage sludge: a review. Environ. Pollut. 293, 118564.

Hole, A., 2007. Fitting mixed logit models by using maximum simulated likelihood. STATA J. 7 (3), 388–401.

Johnson, G.R., 2022. PFAS in soil and groundwater following historical land application of biosolids. Water Res. 211, 118035.

Jones, H., Banks, C., Vo, L., 2020. Community attitudes to the use and management of biosolids - 2020 community public report. Newgate Research. https://www.biosolids.com.au/wp-content/uploads/NGR-1906009-Community-Attitudes-Survey-PUBLIC-REPORT.pdf.

Jones, E.R., 2021. Country-level and gridded estimates of wastewater production, collection, treatment and reuse. Earth Syst. Sci. Data 13 (2), 237–254.

King, G., Brooks, J.P., Brown, S., Gerba, C., O'Connor, G.A., Pepper, I.L., 2011. Land Application of Organic Residuals: Public Health Threat or Environmental Benefit. American Society for Microbiology, Washington, DC, USA.

Kirkby, C.A., Richardson, A.E., Wade, L.J., Batten, G.D., Blanchard, C., Kirkegaard, J.A., 2013. Carbon-nutrient stoichiometry to increase soil carbon sequestration. Soil Biol. Biochem. 60, 77–86. https://doi.org/10.1016/j.soilbio.2013.01.011.

Lahlou, F.Z., Mackey, H.R., Al-Ansari, T., 2021. Wastewater reuse for livestock feed irrigation as a sustainable practice: a socio-environmental-economic review. J. Clean. Prod. 294, 126331.

Lancaster, J.K., 1966. A new approach to consumer theory. J. Polit. Econ. 74 (2), 132–157.

Lin, Z., Price, G.W., Burton, D.L., Clark, O.G., 2022. Effects on soil nitrogen and plant production from land applying three types of biosolids to an agricultural field for three consecutive years. Soil Tillage Res. 223, 105458.

Mamouni Limnios, E., Schilizzi, S.G.M., Burton, M., Ong, A., Hynes, N., 2016. Willingness to pay for product ecological footprint: organic vs non-organic consumers. Technol. Forecast. Soc. Change 111, 338–348. https://doi.org/10.1016/j.techfore.2016.05.009.

Mariel, P., Hoyos, D., Meyerhoff, J., Czajkowski, M., Dekker, T., et al., 2021. Environmental Valuation with Discrete Choice Experiments: Guidance on Design, Implementation and Data Analysis. Springer Nature, Cham, Switz.

McFadden, D., 1986. The choice theory approach to market research. Market. Sci. 5 (4), 275–297. https://doi.org/10.1287/mksc.5.4.275.

Moya, B., Parker, A., Sakrabani, R., 2019. Challenges to the use of fertilisers derived from human excreta: the case of vegetable exports from Kenya to Europe and influence of certification systems. Food Pol. 85, 72–78. https://doi.org/10.1016/j.foodpol.2019.05.001.

Mugera, A., Burton, M., Downsborough, E., 2017. Consumer preference and willingness to pay for a local label attribute in Western Australian fresh and processed food products. J. Food Prod. Market. 23 (4), 452–472. https://doi.org/10.1080/10454446.2015.1048019.

Outwater, A.B., 1994. Reuse of Sludge and Minor Wastewater Residuals. Lewis Publishers.
Paço, A.d., Shiel, C., Alves, H., 2019. A new model for testing green consumer behaviour. J. Clean. Prod. 207, 998–1006. https://doi.org/10.1016/j.jclepro.2018.10.105.
Paramashivam, D., Dickinson, N.M., Clough, T.J., Horswell, J., Robinson, B.H., 2017. Potential environmental benefits from blending biosolids with other organic amendments before application to land. J. Environ. Qual. 46 (3), 481–489.
Pritchard, D.L., Penney, N., McLaughlin, M.J., Rigby, H., Schwarz, K., 2010. Land application of sewage sludge (biosolids) in Australia: risks to the environment and food crops. Water Sci. Technol. 62 (1), 48–57. https://doi.org/10.2166/wst.2010.274.
Qin, L., Zhenli, L.H., Peter, J.S., 2012. Land application of biosolids in the USA: a review. Applied and Environmental Soil Science 2012, 1–11. https://doi.org/10.1155/2012/201462.
Rosen, S., 1974. Hedonic prices and implicit markets: product differentiation in pure competition. J. Polit. Econ. 82 (1), 34–55. https://doi.org/10.1086/260169.
Roxburgh, H., Hampshire, K., Tilley, E.A., Oliver, D.M., Quiliam, R.S., 2020. Being shown samples of composted, granulated faecal sludge strongly influences acceptability of its use in peri-urban subsistence agriculture. Resour. Conserv. Recycl. 7, 100041.
Ryan, M., Amaya-Amaya, M., Gerard, K., 2008. *Using Discrete Choice Experiments to Value Health and Health Care* (1. Aufl, Vol. 11. Springer Netherlands.
Segrè Cohen, A., Love, N.G., Nace, K.K., Árvai, J., 2020. Consumers' acceptance of agricultural fertilizers derived from diverted and recycled human urine. Environ. Sci. Technol. 54 (8), 5297–5305.
Sharma, B., Sarkar, A., Singh, P., Singh, R.P., 2017. Agricultural utilization of biosolids: a review on potential effects on soil and plant grown. Waste Manag. 64, 117–132.
Simha, P., Barton, M.A., Perez-Mercado, L.F., McConville, J.R., Lalander, C., Magri, M.E., Dutta, S., Kabir, H., Selvakumar, A., Zhou, X., Martin, T., Kizos, T., Kataki, R., Gerchman, Y., Herscu-Kluska, R., Alrousan, D., Goh, E.G., Elenciuc, D., Glowacka, A., Korculanin, L., Tzeng, R.V., Ray, S.S., Niwagaba, C., Prouty, C., Mihelcic, J.R., Vinnerås, B., 2021. Willingness among food consumers to recycle human urine as crop fertiliser: evidence from a multinational survey. Sci. Total Environ. 765, 144438.
Torri, S.I., Correa, R.S., Renella, G., 2017. Biosolid application to agricultural land a contribution to global phosphorus recycle: a review. Pedosphere 27 (1), 1–16. https://doi.org/10.1016/S1002-0160(15)60106-0.
Train, K., 2003. Discrete Choice Methods with Simulation. Cambridge University Press, New York.
Water Corporation, 2021. Biosolids. viewed 6 May 2021 https://www.watercorporation.com.au/Our-water/Wastewater/Biosolids. .
Wijesekara, H., Colyvas, K., Rippon, P., Hoang, S.A., Bolan, N.S., Manna, M.C., Thangavel, R., Seshadri, B., Vithanage, M., Awad, Y.M., Surapaneni, A., Saint, C., Tian, G., Torri, S., Om, Y.S., Kirkham, M.B., 2021. Carbon sequestration value of biosolids applied to soil: a global meta-analysis. J. Environ. Manag. 284, 112008.