Farmers' Preferences for Fertilizers derived from Domestic Sewage and Kitchen Waste – A Discrete Choice Experiment in Germany

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Abstract

In view of increasing energy and resource scarcities, nutrient recycling from domestic wastewater is a promising way to obtain mineral fertilizers. Given the lacking evidence about the acceptance of recycling fertilizers by the farming sector, we elicited farmer preferences and willingness to pay (WTP) for selected attributes of mineral fertilizers made from domestic sewage and kitchen waste. We conducted a Discrete Choice Experiment with 206 German farmers and fitted a Random Parameter Logit (RPL) model. Assuming an average market price level of around 300 euros per tonne of N-P-K fertilizer, the choice experiment revealed that farmers not engaged in non-food production such as forage cultivation or renewable energies activities and without farmer-to-consumer direct marketing would accept a recycling fertilizer only together with a financial compensation via price discount of approximately 10%. The average WTP drops considerably if a fertilizer's heavy metal contents are relatively high and if the absence of drug residues cannot be guaranteed, whereas a customizable nutrient composition and a constant supply availability would have a sales promoting effect. Farmers' characteristics can only partly explain the notable heterogeneity of the WTP for the considered fertilizer attributes. Even though the WTP for a recycling fertilizer is on average less than that for a conventional mineral fertilizer, the estimated WTP standard deviations suggest that not all farmers expect a financial compensation via price discount when purchasing recycling fertilizers.

Keywords

recycling fertilizer; Discrete Choice Experiment; preferences; willingness to pay; Random Parameter Logit Model

1 Introduction

The current high-yielding European agriculture strongly relies upon the intensive use of synthetic mineral fertilizers that, amongst others, supply crops with the major plant nutrients nitrogen (N), phosphorus (P) and potassium (K). The extensive production of mineral nitrogen fertilizers via the energy-intensive Haber-Bosch synthesis causes several negative environmental externalities (BILLEN et al., 2021). Further problems relate to the future depletion of non-renewable resources and the European Union's dependence on phosphate rock imports (EUROSTAT, 2021), which are often contaminated with heavy metals (KRÜGER, 2016). Thus, closing nutrient cycles and recycling nutrient-rich organic waste materials in form of fertilizers are increasingly important strategies to mitigate climate change and for moving toward a more sustainable resource use (KRÜGER, 2016; STEINMETZ, 2012; SMOL, 2019). Different projects investigated the technical feasibility of nutrient recycling from human wastewater with the objective of replacing synthetic mineral fertilizers (see WALD, 2022; HILTON et al., 2020). In Germany, current interdisciplinary research focuses on analyzing the recovery of N, P and K from domestic sewage and kitchen waste (RUN project, 2021). The recovered nutrients are used to produce mineral fertilizers that the project partners have termed *design fertilizers* as these fertilizers are supposed to be readily customizable for farm specific needs. The overall aim is to contribute to the future closing of nutrient cycles between urban and rural regions (RUN, 2021). Moreover, the recently amended German Sewage Sludge Ordinance (ABFKLÄRV, 2017) stipulates that, from 2029 on, phosphorus recovery in sewage treatment plants with a capacity for more than 100,000 inhabitants will be mandatory.

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From 2032 on, this will also hold for treatment plants for more than 50,000 inhabitants. STEINMETZ (2016) assumes that, in Germany, the recovery of phosphorus from wastewater can potentially substitute 30 to 50% of conventional P fertilizers.

From a technical and environmental point of view, nutrient recycling from human wastewater is seen as a rather promising way to obtain sustainably produced mineral fertilizers (WALD, 2022; HILTON et al., 2020). Nevertheless, the question arises whether farmers will accept such recycling fertilizers. This question is all the more relevant as "[f]ertilizer and food companies, farmers, toilet manufacturers and regulators are [supposed being] slow to make big changes to their practices" (WALD, 2022: 206). In this context, and because of lacking scientific insights into farmers' views on nutrient recycling from domestic wastewater, the main objective of our study is to investigate the attitudes and preferences of German farmers regarding the use of design fertilizers. A further objective is to provide estimates for prices at which the farming sector would demand different fertilizers from recycled anthropogenic nutrients.

Our analysis of farmers' preferences and willingness to pay (WTP) is based on an online survey, including a Discrete Choice Experiment (DCE), conducted in November 2020. In agricultural economics, DCEs to analyze farmers' preferences for innovations or new farming practices are a well-established method as, amongst others, illustrated for the German context by the studies by BREUSTEDT et al. (2007), BREUSTEDT et al. (2013), SCHULZ et al. (2014), SAUTHOFF et al. (2016), GILLICH et al. (2017), LATACZ-LOHMANN and SCHREINER (2018), DANNE et al. (2019) and BUSCHMANN and RÖDER (2019).

As discrete choice modelling allows for the evaluation of hypothetical situations and products, it is a particularly suited research method for this study because mineral design fertilizers from domestic wastewater are not yet produced and supplied on markets. It is important to know which properties such fertilizers should have in the future to be broadly accepted and purchased by farmers. In this regard, a DCE helps identifying specific preferences and WTP for different product attributes simultaneously.

There have been attempts to elicit preferences for concentrated fertilizers obtained from livestock manure (TUR-CARDONA et al., 2018; HILLS et al., 2020). However, to our best knowledge, no DCE so far has tried to capture farmers' preferences for fertilizers produced from *human* wastewater. Thus, with our research, we aim at enriching the state of knowledge about the acceptance of future design fertilizers and analyze the WTP for specific properties of the latter. The corresponding hypotheses underlying our DCE have been drawn from both the literature and a focus group discussion with German farmers. We fitted a Random Parameter Logit (RPL) model to the collected discrete choice data to account for the rather likely heterogeneity in farmers' preferences and WTP.

The remainder of the article is structured as follows: After deriving the research hypotheses on farmers' attitudes toward design fertilizers in Section 2 and outlining our choice modelling approach in Section 3, we present the hypothesis testing results and the estimated WTP in Section 4 and conclude with a discussion in Section 5.

2 Hypotheses

There is only little published evidence regarding farmers' acceptance of nutrient recycling from sewage. One reference is JEDELHAUSER et al. (2015), who had carried out a focus group study with eight organic farmers in Germany and, by means of an analytic hierarchy process, identified criteria for the acceptance of phosphate fertilizers recycled from wastewater and sewage sludge. In their study, the 'absence of hazardous substances' turned out to be the most important among nine criteria for the acceptance of such fertilizers.

Similarly, LIENERT et al.'s (2003) email survey with 467 Swiss vegetable and non-vegetable crop farmers, with either organic or integrated agricultural production, exhibited an overall high acceptance for urine-based fertilizers. 57% of the sampled farmers explicitly stated that it is a good idea to apply urine-based fertilizers and 42% stated that they would be willing to buy such a product. The absence of harmful substances was also a relevant criterion for the acceptance of the product in this study.

In a written survey of farmers from the German federal state of Brandenburg on the willingness to replace common mineral phosphorus fertilizers by P-containing struvite recycled from wastewater, about two-thirds of the farmers would use struvite. Many of them would apply it for the production of energy crops (MAAß et al., 2014).

There are two DCEs dealing with manure-based fertilizers that are quite interesting in the context of our research. HILLS et al. (2020) conducted a study on bio-based fertilizers derived from dairy manure in the federal state of Washington (USA). TUR-CARDONA et al. (2018) analyzed farmers' preferences in different parts of Europe regarding processed concentrated fertilizers that are also obtained from livestock manure. The latter identified an overall WTP for a bio-based fertilizer at about 77% of the price of a conventional chemical fertilizer with similar nutrient contents. This was on condition that the fertilizer configuration consisted of the farmers' preferred attribute levels (i.e., granular form, fast nutrient release, certainty of nitrogen content and hygienic condition).

In addition to these literature references, our hypotheses are based on the expert views expressed in a focus group discussion at a workshop with 18 farmers that took place in the Heidelberg district of Kirchheim in February 2020. After briefly informing the farmers about the possibilities of small-scale nutrient recycling, the aim of this workshop was to gain insights into their attitudes and the factors that possibly determine the acceptance of design fertilizers from local sewage and kitchen waste. In four small groups, the participants were asked to elaborate criteria that matter for the acceptance of novel design fertilizers.

Table 1. Hypotheses for the econometric analysis with their origins and operationalization in the Discrete Choice Model

Hypothesis	Motivation by
Main hypotheses translating into non-zero part-worth utilities of fertilizer attributes On average, **German farmers ceteris paribus assign** a …	
H1: … **negative utility** to the use of a **design fertilizer** derived from domestic sewage and kitchen waste instead of a conventional mineral fertilizer	LIENERT et al. (2003); farmers' workshop[a)]
H2: … **negative utility** to the prospect of a **heavy metal exposure close to the legal limit**	JEDELHAUSER et al. (2015); LIENERT et al. (2003); farmers' workshop
H3: … **negative utility** to the possible **exposure to drug residues** (as an example for organic pollutants)	JEDELHAUSER et al. (2015); LIENERT et al. (2003); TUR-CARDONA et al. (2018); farmers' workshop
H4: … **positive utility** to an **individually customizable nutrient composition**	RUN project[b)] (fertilizer feature investigated in the project)
H5: … **positive utility** to a **permanent retail availability** of the design fertilizer	Farmers' workshop
H6: … **negative utility** to a **higher purchase price** of the fertilizer	Farmers' workshop; plausibility
Hypotheses translating into non-zero part-worth utilities of interactions between farmers' characteristics and the design fertilizer generic constant	
H7: A **professional qualification** awarded with a higher education or university degree has an effect on a farmer's preference for design fertilizers	Plausibility consideration[c)]
H8a: **Forage producing farmers**, whose land use is not directly linked to human consumption are likelier to choose a design fertilizer *H8b:* Farmers with activities classified as ***renewable energies***[d)] are likelier to choose a design fertilizer	MAAß et al. (2014); farmers' work-shop
H9: **Farmer-to-consumer direct marketing**, e.g., through a farm store reduces the likelihood of a farmer to choose a design fertilizer	Farmers' workshop
H10: **Younger farmers** are likelier to choose a design fertilizer	Plausibility consideration[e)]
H11: Farmers who already gained **experience with recycled nutrients** or compost are likelier to choose a design fertilizer	Plausibility consideration
H12a: The **participation in agri-environmental schemes** increases the likelihood that a farmer will choose a design fertilizer *H12b:* Farmers who have **volunteered in the field of landscape maintenance** are likelier to choose a design fertilizer	Plausibility consideration[f)]
Hypothesis translating into a non-zero part-worth utility of an interaction between a farmers' characteristic and a fertilizer attribute	
H13: Farmers involved in ***renewable energy***[d)] activities are likelier to accept a rare, yet possible presence of drug residues	MAAß et al. (2014)

[a)]Not all farmers in the farmers' workshop held in Heidelberg in 2020 could imagine the use of design fertilizers on their farm. – [b)]The acronym RUN stands for *Rural Urban Nutrient Partnership* research project. – [c)]The attitude toward nutrient recycling and its risks may be positively or negatively influenced by the educational level. – [d)]In the *agri EXPERTS* panel, the category *renewable energies* includes farms generating energy through biogas, photovoltaics and/or wind energy. Thus, farmers under this category may also grow energy crops that are not intended for human consumption. – [e)]Younger farmers are supposedly less reluctant to innovations. – [f)]Farmers engaged in activities to improve the environment are supposedly more inclined to implement nutrient recycling.
Source: own representation

The majority of participants appreciated the idea of recycling nutrients from sewage and kitchen waste. Fertilizer quality and price were given as the most important determinants for their buying decisions. A uniform fertilizer quality and permanent market availability were considered prerequisites for a constant use of design fertilizers. Although most of them could imagine making use of such fertilizers on their farm, there were concerns about the general social acceptance of corresponding practices. In particular, the potentially low consumer acceptance in case of farmer-to-consumer direct marketing was seen as a problem. Most of the farmers were against using design fertilizers on malting barley and vegetables, which are crops subject to high quality standards. Farmers identified possible residues of harmful substances, unclear liability rules in the occurrence of a damage and poor nutrient availability for crops as reasons against the use of design fertilizers.

We derived the ex-ante hypotheses outlined in Table 1 from the cited publications and the expert views expressed in the workshop along with some further plausible reasoning. The table presents the sources and plausibility considerations that motivate the respective hypotheses and illustrates their operationalization in the subsequent econometric analysis.

Besides eliciting preferences for the different fertilizer attributes, an additional aim of the hypothesis testing is to identify farm types or farmers who may be particularly inclined to use design fertilizers. Thus, further hypotheses relate to the assumption that the perceived utility of fertilizer attributes is dependent on certain farmer characteristics. In other words, here we hypothesize influences of farmer-specific variables on the preferences for a design fertilizer. The fertilizer attribute supposed to interact with a farmer characteristic can be the overarching feature "design fertilizer", as in the case of hypotheses *H7* through *H12* in Table 1, or any other fertilizer attribute (see hypothesis *H13* in Table 1). The feature *design fertilizer* is represented by the generic constant of the estimated logit model.

3 Choice Modelling Approach

3.1 Data Collection and Experimental Design of the Discrete Choice Experiment (DCE)

We conducted an online survey including a DCE that was carried out in November 2020 by *agri EXPERTS*, a market research institute for the agricultural sector affiliated to the publisher *Deutscher Landwirtschaftsverlag (DLV)*. To assure understandability and to obtain prior part-worth utilities of the attributes for the DCE design, the questionnaire was pretested in a small pilot study with eight selected farmers. The invitation to take part in the survey was addressed to conventional farmers[1] and distributed through the already existent panel, which covers farms from all over Germany. However, the panel farmers were not obliged to participate. Anonymized data on the characteristics of farmers and their farm operations from the panel were linked to the individual DCE responses and used for statistical inference. In addition to the DCE, our survey included questions about the respondents' attitudes toward recycled design fertilizers and their preferences regarding specific properties of such fertilizers. Due to the Covid-19 pandemic, we had to cancel the initially planned DCEs on farmer workshops in different parts of Germany.

The main aim of this study's DCE was to evaluate farmers' preferences for specific fertilizer attributes that, bundled in different combinations, always described three hypothetical mineral fertilizer alternatives (A, B and C). The respondents had to choose one of the three alternatives in each of the six different choice situations (i.e., choice sets) they were confronted with. All mineral fertilizers were presented as legally approved fertilizers, containing the three macronutrients N, P_2O_5 and K_2O in granular form and sharing the same qualities regarding spreadability, storage suitability, and nutrient content and availability to the plants. However, in each choice situation, the three fertilizer alternatives differed in these study's attributes of interest (i.e., the combination of attribute levels outlined in Table 2). Table 2 displays the attributes and their corresponding levels translated from the original version of the questionnaire presented in German language.

The DCE's attributes were determined based on the main hypotheses outlined in Section 2 (see hypotheses *H2* through *H6* in Table 1 along with the attribute descriptions in Table 2), and then specified with plausible attribute levels that could be easily understood by the DCE participants.

The attribute *Heavy metal content* was set at either "close to the legal limit" or at "well below the legal limit". We deliberately opted for this somewhat

[1] The survey targeted farmers, who manage their farm conventionally, as the recycling fertilizers discussed here have not yet been approved for organic farming in the EU (see ANNEX I of the COMMISSION REGULATION (EC) No 889/2008: L 250 / 34f.).

Table 2. Choice alternative attributes and their corresponding levels

Attribute	Description	Attribute's DCE design levels
Heavy metal content	Heavy metals (e.g., cadmium) contained in fertilizers can accumulate in the soil over time. As a result, the fertilized area may be rendered unusable for the cultivation of human food in the distant future.	The heavy metals content of both the design fertilizers and the conventional fertilizers may be either: • **close to the legal limit,** *or* • **well below the legal limit**.
Drug residues	Drug residues contained in fertilizers can leach into the groundwater or transfer into the food chain.	In the design fertilizer alternatives, drug residues may be either: • **absent** *or*, • **present in rare cases**. No such residues are present in the conventional fertilizer alternatives.
Individual nutrient composition		• **Customizable:** Farmers may order customized design fertilizers, which can be varied in the composition shares of the main nutrients N, P_2O_5 and K_2O within a range of ± 15%, from the manufacturer. For example, the N content may be increased by up to 15% and the P_2O_5 content reduced accordingly. This feature does not change the specified price. *or* • **Fixed:** The nutrient composition cannot be varied and corresponds to the fixed N-P-K ratio of common commercial fertilizers.
Retail availability		Design fertilizers may be either • **subject to possible delivery delays** of several weeks, *or*, • **readily available**, like conventional commercial fertilizers.
Price (euros/tonne)		The price is given without VAT and varies between **250**, **300** and **350** euros per tonne

Source: own representation

fuzzy wording as farmers are not used to contextualize corresponding residue limits. Similarly, we renounced to assign an exact probability to the attribute level "present in rare cases" with regard to *Drug residues*, considering the lack of past observations from which probabilities could have been derived. When defining the level "customizable" of the attribute *Individual nutrient composition* we considered the technical constraints underlying the variation of nutrient composition in the production of conventional fertilizers. As in the case of the other attributes, we preferred a single dummy variable for the attribute *Retail availability* (see Table 2) instead of using a continuous variable depicting possible delivery delays. This facilitates capturing the attribute dependent variability in the latent utility, which depends on the strength of the trade-offs underlying the respondents' choices. Adding further levels for each attribute would have increased the necessary number of choice observations and the complexity of the statistical analysis. In contrast, the levels of the *Price* attribute were specified at equally spaced levels that spanned observed (at the time of the survey plausible) fertilizer retail price fluctuations.

Each participant was confronted with six choice sets like the one presented in Table 3 and in each set had to select her/his most preferred alternative by pondering the trade-offs that result from comparing the presented attribute levels. In each choice set, the alternatives A and B described a design fertilizer consisting of recycled nutrients obtained from domestic wastewater and kitchen waste of neighboring residential areas. Alternative C, in contrast, described a commercially available fertilizer that contains nutrients from conventionally sourced raw materials.[2]

A D-efficient design with six choice sets was generated with Ngene 1.2.1 software (ChoiceMetrics Pty Ltd), using the prior part-worth utilities that were obtained from fitting a conditional logit model to the discrete choice data from the aforementioned pilot study. The attribute levels were thus systematically varied between the six choice situations to minimize

[2] We did not offer a "no fertilizer" opt-out option as this is no realistic alternative for a conventional farmer. The conventional mineral fertilizer C thus served as the status quo alternative. – In every choice set we offered two design fertilizer alternatives (instead of only one), plus the status quo option to increase the amount of information drawn from a sample of unknown limited size. – Six repetitions of the choice situation (i.e., six choice sets per participant) were supposed to yield enough data for our econometric analysis. More repetitions would have been problematic because of the online survey's time constraint.

Table 3. A translated example choice set as presented in the online survey, 2020

	Fertilizer A (Design Fertilizer)	Fertilizer B (Design Fertilizer)	Fertilizer C (Conventional Fertilizer)
Heavy metal content	**well below the legal limit**	**well below the legal limit**	**close to the legal limit**
Drug residues	**present in rare cases**	**absent**	**absent**
Individual nutrient composition	**customizable**	**fixed**	**fixed**
Retail availability	**readily available**	**subject to possible delivery delays**	**readily available**
Price (euros / tonne)	**350**	**250**	**350**
I choose	☐	☐	☐

Source: own representation

the standard errors of the expected model parameters, while accentuating the simulated trade-offs faced by the interviewed farmers.

3.2 Econometric Analysis

Our econometric analysis is based on the work by MCFADDEN (1974), and LOUVIERE and WOODWORTH (1983): Following the random utility approach, in our case it can be assumed that a farmer *i* will choose the fertilizer alternative *j* that gives her/him the greatest utility U_{ij}. The utility U_{ij} is formed by an explained component V_{ij} and a random component ε_{ij}:

$$U_{ij} = V_{ij} + \varepsilon_{ij} = \beta' x_j + \varepsilon_{ij} \quad (1)$$

The first component V_{ij} is a linear utility function of the observed attribute levels including a generic constant (dis-)utility for the feature *Design fertilizer*. The explained component V_{ij} can be expressed as the product of the row vector of part-worth utility parameters β' and the column vector x_j that contains the utility generating attribute levels of the fertilizer alternative *j*. The unexplained random component ε_{ij} of the utility is assumed to be independently and identically distributed (IID), following an extreme value type 1 (EV1) distribution (see MCFADDEN, 1974; BEN-AKIVA and LERMAN, 1994; HENSHER et al., 2015).

In our case, the main hypotheses *H1* through *H6* (see Table 1) translate into a negative or a positive average part-worth utility of a fertilizer attribute (i.e., the parameters β_k (k = 1, …, 6) in the vector β' being non-zero). The vector x_j consists of the alternative specific values of the five dummy variables *Design fertilizer* (yes or no), *Heavy metal content*, *Drug residues*, *Individual nutrient composition*, *Retail availability* and the value of the *Price* variable in alternative *j* (see Table 2). The part-worth utility parameters β' are estimated via a logistic regression by maximizing the likelihood of the observed farmers' choices (TEMME, 2009).

Provided that one attribute $k = c$ is a monetary variable (here, the per-tonne fertilizer price), the marginal WTP for individual fertilizer attributes, i.e., the monetary value assigned to a ceteris paribus change in the level of attribute $k \neq c$ can be calculated as the negative ratio of the corresponding estimated parameter β_k to the cost parameter β_c (HENSHER et al., 2015):

$$WTP_k = -\frac{\beta_k}{\beta_c} \quad (2)$$

The Random Parameter Logit (RPL) model is an extension of the standard logit model. It decomposes the stochastic utility portion into two parts: One part that can be modelled, as the researcher may assign any distribution to the part-worth utility parameters, and another part that remains ~ IID EV1. This mixed distribution allows capturing the (quite realistic) heterogeneity in the part-worth utility parameters β_{ki} among the respondent population. In addition, the RPL model allows for interactions of respondent-specific variables (e.g., age) with attribute levels to partly explain estimated heterogeneous part-worth utilities (TRAIN, 2009; HENSHER et al., 2015). In this study we assigned a normal distribution to the random part-worth utility parameters (including the parameter for the generic constant). For an attribute *k*, the part-worth utility β_{ki} of a single farmer *i* in the RPL specification is then given by:

$$\beta_{ki} = \beta_k + \delta_k' w_i + \sigma_k v_i, \qquad v_i \sim N(0,1) \quad (3)$$

The parameter β_k, the row vector δ_k' and the standard deviation σ_k are to be estimated. The parameters contained in the vector δ_k' then explain the part of the deviations from the average random parameter β_k that is due to the eight farmer-specific characteristics (see Table 4b) expressed by the variables in column vector w_i.

When the perceived utility of fertilizer attributes is dependent on certain farmer characteristics, this should result in non-zero part-worth utilities for the interactions between these characteristics and the fertilizer attributes (i.e., the corresponding parameters in δ_k' being non-zero). With one exception (i.e., hypothesis *H13*), our analysis only included interaction terms of farmer characteristics with the generic constant. This was done to test whether individual characteristics of the farmers influence their overall preference for design fertilizers (e.g., to see whether a farmer's age influences the (dis-)utility of using a design fertilizer). Note that our model specification also allowed for correlation in v_i, i.e., the i-specific unobserved deviations from the different means β_k of the random part-worth utility parameters β_{ki} (see Annexes 1 and 2 for the resulting correlation matrices).

The software NLOGIT 6 (Econometric Software, Inc.) was used to analyze the discrete choice data by means of maximum likelihood estimation. The model goodness of fit was determined with McFadden's pseudo-R^2 (McFadden, 1974), which according to McFadden (1979: 307) corresponds to a very good model fit between the values of 0.2 and 0.4.

Rejecting the hypotheses for which we did not find a statistically significant interaction term in the full model (see Table 5) and based on the remaining hypotheses that we preliminarily keep, we finally estimated a restricted model to elicit farmers' average WTP for the investigated fertilizer attributes (Table 6). In the corresponding RPL specification, the estimated cost parameter β_c was kept constant (i.e., its standard deviation σ_c set to zero) in order to obtain WTP point estimates.

4 Results

4.1 Sample and Descriptive Statistics

Of the 211 conventional German farms that took part in the online survey, 82.5% are classified as individual enterprises, 14.2% as business partnerships and 3.3% as legal entities (i.e., for the most part registered cooperatives or limited liability companies). These results largely coincide with the legal structure of German farming operations in 2020 as reported by Germany's latest Farm Structure Survey, according to which 86.9% were individual enterprises, 10.9% were business partnerships, and 2.2% were legal entities (Statistisches Bundesamt, 2021a). The share of part-time farmers, however, is underrepresented in our sample (36.2%) compared to 56.5% part-time farmers in Germany's (individual enterprise) farmer population (Statistisches Bundesamt, 2021a). The per farm utilized agricultural area (UAA) managed by the respondents averages 147 hectares and is therefore more than double the national average of 63 hectares UAA (Statistisches Bundesamt, 2021b). Thus, larger holdings are overrepresented in our survey. The share of leased land among surveyed farmers is 54.2%, which is slightly lower than the national average of 60.1% (Statistisches Bundesamt, 2021a). The share of arable land in total UAA is 86.0% in the farm survey and 70.3% in Germany in 2020 (Statistisches Bundesamt, 2021b). According to the 2019 statistics of the Federal Information Center for Agriculture (BLE, 2020), three-quarters of Germany's total arable land were used for the cultivation of the following six crops: wheat (cultivated on one quarter of total arable land and thus the dominant field crop), silage maize, barley, canola, grain maize, and sugar beet. In our sample, wheat is the dominant field crop as well and cultivated by 177 farmers, while 149 and 107 of our sample's farms cultivate barley and canola, respectively (Table 4a).

Table 4a. Counts of crops grown on respondents' arable land (2020 online survey, n = 204, multiple choice)

Crop	Number of mentions (i.e., farms)
Wheat	177
Barley	149
Canola	107
Silage maize	105
Sugar beet	61
Rye	49
Triticale	45
Grain maize	38
Potato	28
Oats	21

Source: count results of this study's 2020 online survey, based on *agri EXPERTS*' pre-surveyed structural data

Of the 91 surveyed farmers with declared livestock husbandry activities on their farm (43.1% of the sample), 67 raise cattle, 33 raise pigs, and 23 raise poultry. The combined total of cattle (9,643), pigs (29,435), and poultry birds (63,924) translates to an average of 144 cattle per cattle holding, 892 pigs and 2,779 poultry birds on the average pig and poultry holding, respectively. In contrast, Germany's 2016 farm census reported 102 cattle, 694 pigs, and 3,535 poultry birds on average per farm (Statistisches Bundesamt, 2019).

In summary, large holdings and full-time farming are overrepresented in our sample. With respect to the legal structure of farm operations and crop shares in total arable land, there are, however, only minor differences between our sample and Germany's last Farm Structure Survey.

Table 4b shows the means and standard deviations for the variables used to explain the heterogeneity of the estimated part-worth utilities in our RPL models. Five of the 211 respondents were excluded from the statistical analysis because part of the required information was not available. For instance, one of the respondents did not provide their age. 26% of the remaining 206 respondents had a higher education degree (i.e., a degree from a university of applied sciences, a school of engineering or a university). 40% of the considered farms produced forage and 27% of them were engaged in some kind of renewable energy production. 9% showed activities like marketing via a farm store. The average age of the retained respondents was 47 years. 24% had already experience with recycled nutrients or compost on their farm. 53% participated in agri-environmental schemes or were engaged in nature conservation via contractual commitments and 15% volunteered in landscape maintenance and/or nature protection activities.

Table 4b. Descriptive statistics for the farmer specific variables used to explain heterogeneity in part-worth utilities in the RPL models (see Tables 5 and 6)

Variable	Mean	SD
Professional qualification: has higher education degree (yes = 1)	0.26	0.44
Forage production (yes = 1)	0.40	0.49
Renewable energy production (yes = 1)	0.27	0.44
Farm store (yes = 1)	0.09	0.28
Age (in years)	46.94	12.41
Experience with recycled nutrients or compost (yes = 1)	0.24	0.43
Has participated in agri-environmental schemes (yes = 1)	0.53	0.50
Volunteer work (yes = 1)	0.15	0.35

Source: own calculation based on the results of our 2020 online survey and on *agri EXPERTS*' pre-surveyed structural data (*N* = 206 respondents)

Multi-collinearity of the farmer-specific characteristics displayed in Table 4b could be ruled out as the variance inflation factors (VIF) were all relatively low (see Annex 3).

4.2 Hypothesis Testing

Estimating a random parameter logit (RPL) model with the explanatory variables corresponding to the hypotheses postulated in Section 2 yields the results presented in Table 5. The results suggest that all considered fertilizer attributes have a notable influence on the respondents' choice decisions. Their estimated *average* part-worth utilities (i.e., the mean random parameters β_k according to Equation (3)) are – except for the generic constant – statistically significant at least at the usual 5%-level and show the expected signs (see the z-test results displayed in Table 5).

However, the maximum likelihood estimation results in relevant *heterogeneity* of these part-worth utilities as illustrated by the statistically significant notable standard deviations. The mean part-worth utility of the generic constant hints at an average disutility resulting from a fertilizer being a design fertilizer, at least for those farmers who are not represented with the characteristics captured by the interaction terms (i.e., as described by a vector of zeros for the interactions between farmers' characteristics and the generic constant; see Table 5). The mean part-worth utilities of the interaction terms (parameters δ_k' in Equation (3)) with the generic constant produce an upwards or downwards shift of the average design fertilizer utility.

To demonstrate the interpretation of our results, we consider a 47 years old farmer, who has no higher educational degree, does not produce fodder nor renewable energy, does not engage in farmer-to-consumer direct marketing, has no previous nutrient recycling experiences and does not engage in agri-environmental schemes nor in voluntary landscape maintenance. On average, such farmer would perceive a design-fertilizer induced partial disutility of -1.82 (= -1.94702 + 0.00264*47).

Given the results displayed in Table 5, we keep our hypotheses *H1* through *H6* along with hypotheses *H8* and *H9* and drop hypothesis *H7* as well as hypotheses *H10* through *H13*. Note that due to its high standard error, the mean of the generic constant is only statistically significant at the 10% level.

The proximity of the farm production to direct human consumption seems to matter, as the preferences for recycling fertilizers are positively affected by farm activities not linked to food production (see hypotheses *H8*), whereas direct marketing has a negative impact. Farmer-to-consumer direct marketing, e.g., through a farm store ceteris paribus changes the

Table 5. Results of a Random Parameter Logit (RPL) model: estimated part-worth utilities for design fertilizer attributes and all tested interaction term specifications, according to the hypotheses postulated in Section 2

Attribute		Part-worth Utility [a)]	SE
H1: Generic constant (design fertilizer)	Mean	-1.94702	1.12140
	SD	2.37321**	0.41866
H2: Heavy metal content close to legal limit (yes = 1)	Mean	-2.48097**	0.35981
	SD	2.03393**	0.35191
H3: Drug residues present in rare cases (yes = 1)	Mean	-3.84673**	0.57968
	SD	2.51480**	0.40736
H4: Individually customizable nutrient composition (yes = 1)	Mean	1.02554*	0.46098
	SD	1.23163**	0.39298
H5: Readily available in retail (yes = 1)	Mean	1.31337**	0.24557
	SD	1.44612**	0.28560
H6: Price (Euro/tonne) [b)]	Mean	-0.03648**	0.00530
	SD	0.03412**	0.00537
Interactions between farmers' characteristics and design fertilizer generic constant			
H7: Professional qualification: higher education degree (yes = 1)	Mean	0.59191	0.47341
H8a: Forage production (yes = 1)	Mean	1.46234**	0.47715
H8b: Renewable energy production (yes = 1)	Mean	1.19342*	0.49533
H9: Farm store (yes = 1)	Mean	-1.60603**	0.61029
H10: Age (in years)	Mean	0.00264	0.01658
H11: Experience with recycled nutrients or compost (yes = 1)	Mean	0.52974	0.44671
H12a: Participation in agri-environmental schemes (yes = 1)	Mean	0.80579	0.41223
H12b: Volunteer work (yes = 1)	Mean	0.53046	0.53907
Interaction of renewable energies branch in the presence of drug residues			
H13:	Mean	0.54932	0.40703
Log Likelihood (LL)	-976.30882		
LL Ratio-Test $\chi^2(df)$	763.15193** (36)		
Adjusted Pseudo-R^2 (McFadden)	0.2664		
AIC/N	1.638		

[a)]Significance levels: * $p < 0.05$, ** $p < 0.01$ based on a two-sided z-test with z = estimated coefficient/SE; the indicated significance level is reached when $|z| > z_p$. - [b)]Fertilizer price in euro/tonne before VAT.
Abbreviations: *H* = hypothesis (see hypotheses in Table 1, Section 2), SE = standard error, SD = standard deviation (σ_k in Equation (3)), AIC = Akaike information criterion
Source: own calculation based on the results of our 2020 online survey (*N* = 1,236 observations from 206 respondents)

average design fertilizer related disutility by – 1.61 (supporting hypothesis *H9*).

As expected, the potential, yet rare presence of drug residues in recycling fertilizers causes a smaller disutility to farmers, who are engaged in renewable energy production than to those without such activities (see hypothesis *H13*). However, the corresponding effect was not statistically significant at the conventional 5% level (see the z-test result in Table 5).

4.3 Farmers' Willingness to Pay (WTP)

To estimate farmers' WTP we fitted a restricted RPL model, i.e., with all statistically non-significant interaction terms from the full model (see Section 4.2) removed, and set the standard deviation of the price attribute's part-worth utility equal to zero. The latter allows applying Equation (2) to calculate the attributes' mean WTP point estimates along with their standard deviations (see Table 6).

A farmer would on average expect a price discount of 32.81 euros per tonne of a design fertilizer to perceive the same utility that she would derive from a conventional N-P-K fertilizer with otherwise same properties. This discount corresponds to about 10% of the average price level of around 300 euros per tonne that the respondents had to face in the DCE's choice sets. The, at the 1% level statistically significant, ±67.69 euro/tonne WTP standard deviation estimate for the generic constant (see Table 6), however, suggests that there are also farmers who show a positive WTP (or expect no price reduction) for fertilizers derived from domestic sewage and kitchen waste.

According to the parameter estimates, approximately two thirds of the farmers, who do not share the characteristics captured by the interaction terms in Table 6, are willing to pay for the feature *design fertilizer* a price premium ranging between minus 100.50 and plus 34.88 euros per tonne (i.e., -32.81 ± 67.69).

Most farmers would ceteris paribus only be willing to purchase fertilizers with heavy metal contents that are close to the legal limit if they were granted a price reduction of 72.11 (±69.20) euros per tonne. Similarly, for farmers to purchase a fertilizer that nonetheless rarely may contain drug residues, they would ceteris paribus expect a discount of 120.53 (±79.73) euros per tonne.

However, German farmers would accept a mark-up of 44.50 (±53.01) euros per tonne for the option of customizing the individual nutrient composition that is offered with a design fertilizer. What is more, they would be willing to pay additional 37.21 (±23.46) euros per tonne for a permanent retail availability of their preferred fertilizer.

Again, our results hint at a pronounced preference heterogeneity among German farmers regarding design fertilizers and their constituting attributes. Notwithstanding an overall negative attitude toward such fertilizers, the estimates suggest that there are farmers, who would even be willing to pay a higher price for design fertilizers when compared to conventional fertilizer prices.

The average WTP for a design fertilizer considerably increases (i.e., by 31.23 euros per tonne) if the farmer produces forages, and by additional 27.76 euros per tonne if the farmer operates in the renewable energies branch, here taken as a proxy for the production of energy crops. In contrast, farmer-to-consumer direct marketing, e.g., through a farm store results in a substantially lower WTP (-47.63 euros per tonne) compared with other farmers (see Table 6). Hence, farmer-to-consumer direct marketing considerably increases the average price discount expected by farmers before accepting a design fertilizer which is otherwise comparable to conventional mineral fertilizers. This latter result is not surprising. If the offered farm commodities were only once contaminated with drug residues or germs, the farmer would very likely be held accountable and could expect large sales losses and a damaged reputation in the long term.

Table 6. Results of Random Parameter Logit (RPL) model: estimated part-worth utilities for design fertilizer attributes and statistically significant interaction terms along with corresponding willingness to pay (WTP) point estimates

Attribute		Part-worth Utility[a)]	SE	WTP in €[c)]	SE
Generic constant (design fertilizer)	Mean	-0.99166**	0.32504	-32.8122**	9.57924
	SD	2.04579**	0.29147	67.6910**	11.61732
Heavy metal content close to legal limit (yes = 1)	Mean	-2.17929**	0.25152	-72.1082**	6.16729
	SD	2.09151**	0.26613	69.2037**	11.01751
Drug residues present in rare cases (yes = 1)	Mean	-3.64257**	0.38637	-120.526**	10.54537
	SD	2.40961**	0.36235	79.7293**	14.21073
Individually customizable nutrient composition (yes = 1)	Mean	1.34479**	0.31274	44.4965**	7.80327
	SD	1.60211**	0.21970	53.0105**	8.86413
Readily available in retail (yes = 1)	Mean	1.12464**	0.16354	37.2122**	4.60451
	SD	0.70890**	0.19404	23.4562**	6.80131
Price (euro/tonne)[b)]	Mean	-0.03022**	0.00289	---	---
	SD	Parameter fixed to zero			
Interactions between farmers' characteristics and design fertilizer generic constant					
Forage production (yes = 1)	Mean	0.94389**	0.31099	31.2313**	10.47040
Renewable energy production (yes = 1)	Mean	0.83883*	0.35019	27.7551*	11.60512
Farm store (yes = 1)	Mean	-1.43940**	0.51257	-47.6270**	17.22957
Log-Likelihood (LL)	-1009.84844				
LL Ratio-Test $\chi^2(df)$	696.07271** (24)				
Adjusted Pseudo-R^2 (McFadden)	0.2449				
AIC/N	1.673				

[a)]Significance levels: * $p < 0.05$, ** $p < 0.01$ based on a two-sided z-test with z = estimated coefficient/SE; the indicated significance level is reached when $|z| > z_p$. - [b)]Fertilizer price in euro/tonne before VAT. - [c)]Rounding differences.
Abbreviations: SE = standard error, SD = standard deviation, WTP = willingness to pay, AIC = Akaike information criterion
Source: own calculation based on the results of our 2020 online survey (*N* = 1,236 observations from 206 respondents)

5 Discussion and Conclusions

By conducting a DCE, we tried to elicit the preferences of German farmers for various mineral fertilizer attributes and analyzed a convenience sample with 206 respondents by fitting a random parameter logit model to the resulting choice data. Thereby, we obtained a first empirical evidence of active farmers' WTP for (not yet available) so-called design fertilizers obtained from domestic sewage and kitchen waste. Finally, we want to discuss the caveats of our methodological approach and the major conclusions one may draw from the presented results.

5.1 Methodological Limitations

Definitely, the parameter estimates for the part-worth utilities and deduced WTP cannot be considered stable approximations of immutable (constant) parameters, but should rather be seen as rough indicators of farmers' preferences at the time when the survey took place. With this in mind, our model estimates can be considered a preferences snapshot that is likely to change over time along with further knowledge, changing habits and resource scarcities, but possibly also as a consequence of possible future events like scandals due to accidentally contaminated products, etc.

One should further be aware that, although DCEs overcome some of the potential biases linked to other stated preference valuation approaches (e.g., the *strategic*, *yea-saying* and *starting-point* biases inherent to contingent valuation studies), this method–like every other attempt to directly elicit preferences by means of surveys–is still prone to *information* and *hypothetical* biases. These biases arise from the information given in the survey (e.g., when introducing the DCE), the formulation and framing of the choice sets, and the kind and levels of the DCE attributes. For instance, in the context of this study, an information bias may have been introduced when presenting the choice of alternatives regarding the risks of heavy metal contamination and drug residues that come along with the use of recycling fertilizers. The way the corresponding information is given could influence farmers' choices. A hypothetical bias is concerned with the hypothetical nature of the presented experiment, which may produce discrepancies between the estimated preferences and those that would be embedded in actual market transactions.

One should also note that, for reasons of feasibility, we applied a non-random cost coefficient specification in our restricted random parameter logit model in order to obtain WTP point estimates. Relying upon Equation (2) for calculating the WTP of attribute levels implies a linear utility function of money and the marginal utility of one euro being identical for all farmers (see MARIEL et al., 2021: 72, 84). This restriction might lead to biased estimates that, although avoidable with a sophisticated yet complex WTP space specification, are likely negligible. This is suggested by studies that have compared WTP results obtained from fitting both WTP space and preference space (i.e., this study's approach) models on the same data (e.g., NARJES and LIPPERT, 2021).

Moreover, to conduct the survey, we used an existent panel of active farmers, who volunteered for participating. Thus, the survey respondents' farms are not necessarily representative for all farms in Germany.

Finally, it should be mentioned that the relatively large standard deviation estimates of the part-worth utilities and the derived WTP may not only reflect heterogeneity of farmers' preferences. They might also be a result of different interpretations of the attribute levels by the respondents when completing the choice tasks.

Notwithstanding these caveats, the estimated average part-worth utilities and WTP give valuable insights in farmers' attitudes toward nutrient recycling fertilizers. At any rate, this study is an attempt at providing order of magnitude estimates of the relative importance of preferences and WTP for the considered fertilizer attributes.

5.2 Discussion of the Results and Concluding Remarks

It should be emphasized that, in spite of a negative attitude that many German farmers seem to exhibit toward design fertilizers from domestic sewage and kitchen waste, the statistically significant preference heterogeneity in our results suggests that there are also farmers, who would take such fertilizers at common market prices. Some farmers may even pay a price premium to acquire them. The considerable preference heterogeneity could only partly be explained by differences between individual farmers and farm operations. Hence, apart from those who are engaged in farmer-to-consumer direct marketing, it is difficult to tell which type of farmer in need of mineral fertilizers is particularly reluctant to use design fertilizers in the future. Not only because of our WTP estimates, but also for food safety reasons, one may initially restrict the use of newly introduced design fertilizers to non-food farm production like forage and bioenergy crops.

On the one hand, the price discounts that most German farmers would expect to consider purchasing a design fertilizer could be overcompensated by the perceived value of guaranteed low heavy metal contents compared to conventional fertilizers without such warranty. This aspect is interesting, considering that recycling fertilizers such as struvite, a phosphate-containing mineral recovered from wastewater, have notably lower heavy metal contents than conventional rock-phosphate-based mineral fertilizers (WOLLMANN and MÖLLER, 2015).

On the other hand, being unable to warrant absence of drug residues would substantially increase the average price discounts that German farmers expect before committing to purchase a design fertilizer. Overall, our results suggest that a negative predisposition of German farmers toward design fertilizers would be largely caused by their concern that recycled nutrients could compromise the product safety of their food crops through contamination, particularly with organic pollutants. Of less importance with regard to farmers' WTP are the option of customizing the fertilizer's individual nutrient composition and its permanent retail availability.

The high importance of the fertilizer being uncontaminated with harmful residues corroborates the results by TUR-CARDONA et al. (2018: 414). They reported a relatively high WTP for the attribute "hygienic condition" of a concentrated fertilizer from livestock manure in most of the European countries that they surveyed with a DCE. In view of this, operators of recycling plants must ensure that their production yields fertilizers free from substances, which could pose a risk to public health or to the environment.

If damages due to the application of design fertilizers occurred, the question of liability would arise. To promote design fertilizers in the future, the liability for potential contaminations could either be taken over by the state, covered by insurance policies, or be legally transferred to recycling plant operators and/or fertilizer manufacturers. However, the latter becomes more difficult the more decentralized and small-scale the new recycling systems will be set up, as is the case for the several connected residential units that are planned in the RUN project.

Cost estimates by KRAUS et al. (2019) show that cost-covering decentralized P-recycling from wastewater is unlikely to be possible without additional financial support. The estimated average price discount (relative to a comparable conventional fertilizer) that farmers would expect for a design fertilizer also hints at the need for subsidies if design fertilizers are to be broadly introduced in practice.

Recycling fertilizers could also be promoted by setting quality standards and creating a trustworthy label. In this way, policy makers could increase farmers' confidence in a recycling product that has the potential to contribute to a more sustainable and circular farming system.

Finally, recycling nutrients from domestic wastewater and kitchen waste on a large scale in the future requires both farmers' willingness to apply such fertilizers and consumers' trust in farm products made with such fertilizers. Therefore, besides trying to influence farmers' attitudes and demand, consumers' understanding and acceptance should be likewise promoted. The estimated price discount of farmers directly marketing (part of) their produce suggests that a fundamentally positive consumer attitude toward recycling fertilizers can increase farmers' acceptance of these inputs once they are no longer seen as a risk for the sale of their farm products.

Pointing out the social benefits of saving energy and using own phosphorous sources when producing design fertilizers could improve the overall social acceptance of design fertilizers. Currently, mineral fertilizers of the three major plant nutrients are to a large extent supplied either via mining activities (P and K) or via the highly energy-intensive Haber-Bosch process (N). Regarding potassium and nitrogen, supply shortages due to market distortions and rocketing energy prices notably in the aftermath of the 2022 Russian invasion of Ukraine have raised serious concerns in the European Union about supply security (AGRA-EUROPE, 2022)[3]. Hence, higher energy prices in the future may incentivize the recycling of mineralized nitrogen from sewage and organic waste. In addition, there is an obvious need to develop alternative phosphorous sources as the finite nature of (uncontaminated) global phosphorous reserves and likely future shortages have been broadly discussed (GILBERT, 2009).

Theoretically, the P-recycling from farmyard manure, domestic waste and the wastes of the food-processing industry could cover approximately 80% of the phosphorus needs of German primary crop pro-

[3] Recently, in Germany, France, Poland and other EU member states fertilizer prices strongly increased, exacerbated by the war in Ukraine. France, Czech Republic and Latvia even experienced a deficit in fertilizer supply.

duction (WISSENSCHAFTLICHER BEIRAT FÜR DÜNGUNGSFRAGEN, 2011). Exploiting this potential, however, requires the acceptance by the farming sector. In contrast to the idea that farmers are "[…] slow to make big changes to their practices" (WALD, 2022: 206) and notwithstanding the dynamic character of their preferences, farmers' attitudes elicited by our choice experiment suggest that there is currently sufficient scope for the establishment of customized recycling fertilizers once the concomitant technical and hygienic challenges can be handled.

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Software

Ngene 1.2.1 (ChoiceMetrics Pty Ltd)
NLOGIT 6 (Econometric Software, Inc.)
IBM® SPSS® Statistics 26

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Annex

Annex 1. Correlation matrix for the estimated part-worth utility means of the RPL model presented in Table 5

	Constant	Heavy metal content	Drug residues	Individually customizable	Readily available	Price
Constant	1	-0.20485	-0.36926	0.13745	0.17046	0.24099
Heavy metal content	-0.20485	1	-0.43450	0.64508	0.03607	0.21369
Drug residues	-0.36926	-0.43450	1	0.05918	0.24819	-0.30899
Individually customizable	0.13745	0.64508	0.05918	1	0.66867	-0.38017
Readily available	0.17046	0.03607	0.24819	0.66867	1	-0.71903
Price	0.24099	0.21369	-0.30899	-0.38017	-0.71903	1

Source: own estimation

Annex 2. Correlation matrix for the estimated part-worth utility means of the RPL model presented in Table 6

	Constant	Heavy metal content	Drug residues	Individually customizable	Readily available
Constant	1	-0.56574	-0.74836	0.60846	0.28857
Heavy metal content	-0.56574	1	0.66762	-0.94820	-0.50151
Drug residues	-0.74836	0.66762	1	-0.49666	-0.25945
Individually customizable	0.60846	-0.94820	-0.49666	1	0.45079
Readily available	0.28857	-0.50151	-0.25945	0.45079	1

Source: own estimation

Annex 3. Collinearity tests for independence of the farmer specific variables considered in the RPL models

Variables	R-sq from OLS regression of the respective variable on all the other variables	VIF[a)]
Professional qualification (higher education degree) (yes = 1)	0.101	1.112
Forage production (yes = 1)	0.082	1.089
Renewable energy production (yes = 1)	0.043	1.045
Farm store (yes = 1)	0.022	1.023
Age (in years)	0.114	1.128
Experience with recycled nutrients or compost (yes = 1)	0.028	1.028
Participation in agri-environmental schemes (yes = 1)	0.058	1.062
Volunteer work (yes = 1)	0.044	1.046

[a)]Variance inflation factor
Source: own calculation