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# How do farmers value organic fertilisers? An exploratory study on conventional and innovative products

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ABSTRACT

Current trends in the adoption of agricultural innovations aimed at replacing mineral fertilisers with organic fertilisers such as biochar and biochar-compost blends made from various organic wastes have recently been recognised as an important innovation to restore and improve soil fertility and mitigate environmental impacts while implementing the circular economy. A survey was designed to capture socio-economic characteristics and attitudes of farmers towards the use of organic fertilisers. Attitudinal data from 176 farmers were analysed using exploratory principal component analysis (PCA) to identify the components associated with their acceptance. Subsequently, the components and socio-economic data were used to delineate clusters of farmers that were matched with the willingness-to-pay (WTP) for a novel organic fertiliser, a biochar-compost blend. WTP was tasted using a dichotomous choice contingent valuation within the range of €1–300 per tonne. A positive WTP for BCmix was expressed by 63.1 % of farmers, with average preferred application rates exceeding 11 t/ha. Five main farmer clusters with different attitudes and appreciation levels for organic fertilisers were identified -*The Neutral, The Unready, The Opposed, The Sceptic,* and *The Engaged*-highlighting a range of attitudes and appreciation levels towards organic fertilisers. Interestingly, clusters with a neutral stance towards organic fertilisers showed significantly higher WTP than clusters more actively committed to sustainability, such as *The Engaged*, a finding that contrasts with prior studies where environmentally committed farmers typically show greater adoption willingness. The study's insights support targeted market segmentation and inform policy and communication strategies to promote the early adoption of organic fertilisers.

## 1. Introduction

Synthetic fertilisers play a crucial role in enhancing human prosperity, offering universal availability in diverse forms such as granules, liquids, and sprays, facilitating easy transport, storage, and application (Erisman et al., 2008). Despite their ability to provide precise nutrient control tailored to specific crop and soil requirements, thereby optimising nutrient delivery and maximising crop yields, many regions face a surplus of fertilisers, particularly nitrogen (N) and phosphorus (P) (Bouwman et al., 2017). This surplus, encompassing plant harvest excess N input over N export, depends on mineral fertilisers, symbiotic N fixation, manure application, and atmospheric deposition onto cropland. While this overuse is often justified in terms of food security and farmers' income, the cost-benefit balance is becoming increasingly disproportionate.

Replacing mineral fertilisers with organic fertilisers presents a multifaceted challenge rooted in innovation, with distinct aspects on both the demand and supply sides. On the supply side, resistance to change pervades the fertiliser industry and its associated supply chain, primarily due to the technological and logistical complexities involved in converting agricultural residues into organic fertilisers (Molina-Guerrero et al., 2020). The inherent variability in composition,

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availability, and quality of organic fertilisers necessitates substantial investments to reorganise the value chain, encompassing upstream processes such as delivery, storage, and feedstock provision, as well as downstream aspects like adopting new practices, application protocols, and equipment. However, the adoption and diffusion of innovation in the realm of fertilisers are primarily influenced by farmers' attitudes towards innovative products or technologies—a demand-pull dynamic. Various factors, including product features, farm characteristics, farmer attitudes, and broader social and environmental considerations, contribute to the adoption landscape (Prokopy et al., 2008; Case et al., 2017; Canavari et al., 2021; Gabriel and Gandorfer, 2023). For instance, studies on fertiliser management reveal that farm location, size, and income are key determinants of adoption likelihood (Pedersen et al., 2019; Qi et al., 2021; Gao and Arbuckle, 2022). Nonetheless, empirical evidence challenges the prevailing notion that demand-side factors predominantly drive adoption. Hasler et al. (2016) propose that farmers' adoption of innovation is largely influenced by the supply side, particularly technological advancements, rather than strong market pull factors, with the retail sector exerting significant influence. This assertion is bolstered by many farmers' relatively limited bargaining power within the supply chain, highlighting substantial disparities between stakeholder expectations and farmers' perspectives, needs, and opportunities (Totin et al., 2012).

The use of organic fertilisers is hampered by a number of factors, despite the growing interest in organic alternatives. The high initial cost of production, transportation, and application, which frequently calls for specialised equipment, is one major obstacle (Case et al., 2017). Compared to mineral fertilisers, organic fertilisers are less practical due to their bulk and compositional variability, which make storage and logistics more difficult (Asai et al., 2014). Furthermore, farmers often lack sufficient knowledge about appropriate rates of application and possible long-term advantages, which frequently take longer to materialise than the instant results of synthetic fertilisers. The appeal of organic fertilisers may vary depending on local availability. Innovative products like biochar and biochar-compost blend are characterised by limited market availability.

This study aimed to identify socio-economic and attitudinal factors illustrating adoption patterns for organic fertilisers to better understand farmer interests in relation to agricultural innovations. Two research questions were formulated to reach this goal:

1. Which farmer attitudes and characteristics influence the intention to use organic fertilisers?
2. How much an innovative organic fertiliser, specifically a biochar-compost blend, could be appreciated by farmers?

A statistical exploratory approach was used to reveal relationships between variables describing farm production systems and farmer attitudes. First, a farmer questionnaire was designed to capture main farm figures (e.g., type of crops, cultivated area, adopted practices) and farmer attitudes towards using organic fertilisers in a broad sense. The observations collected were used to conduct a principal component analysis (PCA) aimed at identifying the components that determine the acceptability of innovative organic fertiliser products. These components were thus used in hierarchical clustering to identify farmers with similar patterns in the combination of socio-attitudinal characteristics. Last, final clusters were used as explanatory variables in an interval regression analysis towards the willingness-to-pay (WTP) for a biochar-compost blend (hereinafter BCmix), a heterogeneous mixture composed by biochar and compost further described in Section 1.2, measuring the value that homogeneous groups of farmers attributed to such specific innovative organic fertiliser. It is worth highlighting that while PCA and clustering were based on positions relative to organic fertilisers in general, the WTP and regression analysis referred to a novel type of fertiliser, i.e. the BCmix.

The originality of this study lies in the investigation of the intention to adopt a novel and promising innovative fertiliser like the BCmix, with initial analyses based on farmers' general viewpoints and opinions on traditional organic fertilisers to capture broader adoption patterns. While many studies in developed countries tend to focus on farmer uptake of new technologies, it is not as prevalent to concentrate on the uptake of fertilising innovations.

### 1.1. Literature review

Long-term studies demonstrate that over-fertilisation disrupts carbon (C) and N cycling (Mulvaney et al., 2009). Specifically, evidence indicates that mineral N fertilisers lead to soil N depletion after 40–50 years of continuous application, leading to decreases in soil productivity and agronomic efficiency. Lassaletta et al. (2014) found that only 47 % of the reactive N added onto cropland is converted into harvested products, compared to 68 % in the early 1960s, while mineral N fertiliser input increased by a factor of 9 over the same period. More recently, it was observed that although intensive N fertilisation can substantially increase the productivity of low-fertility soils, resulting effects promote C mineralisation rather than sequestration (Jesmin et al., 2023). Such degradation of soil C and organic N resources necessarily increases, in turn, reliance on mineral N fertilisation. The practice of over-fertilisation is currently an issue in Europe. Excess N in croplands is quickly leached as nitrate and emitted as ammonia or $N_2O$, hence contributing to the N cascade of environmental contamination, such as eutrophication, ozone depletion, and particulate formation. For nearly two-thirds of agricultural soils, nitrogen values exceeded critical values beyond which eutrophication can be expected (de Vries et al., 2021), with a surplus of nutrients in the range of 20–90 kg/ha (Eurostat, 2024). Also, the mineral N fertiliser supply chain was responsible for estimated emissions of 1.13 Gt $CO_{2eq}$ in 2018, representing 10.6 % of agricultural emissions and 2.1 % of global GHG emissions (Menegat et al., 2022). Other disadvantages of the excessive use of fertilisers deal with the increased availability and activity of naturally occurring heavy metals such as lead, mercury, chromium, arsenic and above all, in terms of frequency and danger, cadmium (Cd) (Khan et al., 2018), a toxic contaminant that may have serious and often irreversible consequences on human health and the natural ecosystems. Several studies have confirmed the impact of mineral fertilisers as a main source to Cd contamination levels in agricultural soils: P fertilisers were found to contribute to 45 % of the total load of Cd in European croplands and 55 % of the total dietary intake of Cd by average consumers are related to Cd accumulation in soil (Rietra et al., 2017; Römkens et al., 2018).

In light of this, the Regulation (EU) 2019/1009 (European Council, 2019 aims i) to reduce the presence of Cd within all types of fertilisers, ii) to reduce the increased import of mineral fertilisers from outside the EU, and iii) to encourage the large-scale use of organic fertilisers (Marini et al., 2020). Furthermore, numerous actions are expected, including a reduction in the use of mineral fertilisers, use of organic fertilisers along with precision agriculture techniques, use of $N_2O$ stabilisers/inhibitors to enhance fertiliser efficiency and reduce nitrogen losses, ultimately lowering nitrous oxide emissions, and replacing mineral fertilisers with organic fertilisers.

Organic fertilisers comprise a wide range of products consisting of various source materials. Table 1 contains a non-exhaustive list of the component material categories and product function categories based on the the Regulation (EU) 2019/1009 (European Council, 2019) definitions. Various chemical, microbiological and biochemical processes are used to recover macro- and micronutrients from fertiliser source materials. These include anaerobic digestion, composting, vermicomposting, gasification, incineration, and pyrolysis (Chojnacka et al., 2024). Considering the wide variety of raw materials and provided that the product properties vary accordingly, the treatment of agricultural residues to obtain fertilisers from organic waste generally offers a wide range of opportunities. Organic fertilisers can help to mitigate the negative and controversial effects of mineral fertilisers (Mulvaney et al.,

**Table 1**
Exemplified categories of organic fertilisers. Source: Regulation (EU) 2019/1009.

| | |
|---|---|
| Material component categories | Plants, plant parts or plant extracts<br>Fresh crop digestate<br>Digestate other than fresh crop digestate<br>Food industry by-products<br>Composts: composted plant materials, animal materials, or mixtures thereof<br>Microorganisms: bacteria, fungi, yeasts, etc.<br>Minerals (used as additives): rock phosphate, greensand, bentonite, etc.<br>Pyrolysis and gasification material (e.g. biochar) |
| Product function categories | Organic fertilisers: organic carbon ($C_{org}$) and nutrients of solely biological origin [a]<br>Organo-mineral fertilisers: one or more inorganic fertilisers and nutrients of solely biological origin [a]<br>Plant biostimulants: increase plant nutrition efficiency or tolerance to abiotic stress; consist of material 95 % of which is of solely biological origin [a]<br>Organic soil improvers: improve physical and biological properties of soil<br>Growing media: mixtures containing various organic and inorganic materials [b]<br>Fertilising product blend: fertilising product composed of two or more of the previous categories, including mineral additives and inorganic fertilisers [b] |

[a] May contain peat, leonardite and lignite, but no other material which is fossilised or embedded in geological formations.
[b] Inorganic fertilisers functional categories and related material component categories not included here.

2009; Medici et al., 2019; Zhang et al., 2021; Gamage et al., 2023). For example, organic fertilisers can retain substantial amounts of nutrients and lead to a general increase in bacterial, fungal, and total microbial biomass in soils (Case et al., 2017; Morugán-Coronado et al., 2022). This counteracts the promotion of C mineralisation and soil N depletion, which emerged as a significant concern in mineral fertiliser application to soils, as already discussed. A meta-analysis of compliant reviewed experiments revealed significantly lower $N_2O$ emissions for organic compared to mineral fertilisers (23 % reduction) (Aguilera et al., 2013). Organic fertilisers were found also to increase the cation exchange capacity, to regulate pH, and balance macro- and micronutrients enrichments with benefits for soil health and crops productivity (Sharma et al., 2019). The increased biodiversity and the increased soil quality explains a limited C mineralisation a reduction in soil N depletion and a reduction in P leaching (Zhang et al., 2021; Llovet et al., 2023). More importantly, it was pointed out that while recovery of organic fertiliser N (manure, green manure, compost, etc.) in crops is lower than synthetic fertilisers, N recovery in subsequent years is greater (Yan et al., 2020; You et al., 2023). Yan et al. (2020) suggests a rethink of fertilisers - whether mineral or organic - as inputs that enhance ongoing soil organic N turnover. In this respect organic fertilisers provides a source of residual-N greater than synthetic counterparts and persistent over time.

At a microeconomic level, fertiliser price is a key aspect that may drive a wider adoption of organic fertilisers. Fertilisers are a major expense for farmers, ranging from 15 % to 35 % of crop production costs. Since the beginning of 2022, fertiliser prices have increased by almost 30 % because of increased resource costs, supply chain interruptions in Eastern Europe, and trade restrictions from China (Uçak et al., 2022; Rodríguez-Espinosa et al., 2023). Structural phenomena such as the rise of natural gas prices and the geopolitical crisis in Ukraine have made the mineral fertiliser industry's dependence on the fossil fuels market volatility a point of vulnerability.

### 1.2. *The biochar-compost blend*

The BCmix is a heterogeneous mixture composed by biochar and compost developed and tested in the EIT Food project "Black to the future". Its constituents qualify as "compost" and "pyrolysis and gasification material" according to the definitions in the Regulation (EU) 2019/1009 (Table 1). Depending on its material composition (biochar-compost ratio, N-P-K content) and processing method (material blending before or after qualification/labelling), its formulation would allow it to be classified as "organic fertiliser", "organic soil improver", or "fertilising product blend". Recently, the use of biochar and biochar-compost blends from various organic sources has proven to be functional in restoring and improving soil fertility, mitigating environmental impacts (Cao et al., 2017; Garau et al., 2024), and potentially enhancing farmers' socio-economic gains (Chang et al., 2015). This approach capitalises on biochar's enduring physical and chemical attributes, including its stability, water retention capacity, and nutrient retention capabilities, in conjunction with the provision of labile organic carbon and nutrients by compost. Furthermore, studies have highlighted a synergistic interplay between biochar and compost, facilitating soil microbial processes and fostering carbon stabilisation by forming organo-mineral complexes. This process improves nutrient retention and ultimately supports enhanced plant growth (Sánchez-Monedero et al., 2019).

## 2. Methods

An online questionnaire, developed using the Qualtrics platform, was distributed throughout Italy, from August to December 2021, to farmers with viticulture and fruit-growing as their main orientation. Data collection was included in a large-scale survey conducted in the EIT Food project "Black to the future". Invitation letters were sent to 1500 farmers specialised in grapes and fruits-growing across Italy, with a total of 198 observations (13.2 %) collected, which, after data cleaning, were reduced to 176. Table A.1 provides an overview of the questionnaire's structure, divided into three sections. The first section encompasses information related to the farm's production system, including details about the standards and practices employed, the types and quantities of fertilisers utilised, as well as demographic data concerning the farmers themselves. The second part of the survey comprised a series of questions exploring farmers' attitudes toward using organic fertilisers. These questions included various statements regarding the advantages and obstacles associated with organic fertiliser usage, adapted from a previous study by Case et al. (2017), which investigated farmers' perceptions of organic fertilisers (statements are reported in Supplementary Material). These attributes summarise what other survey campaigns have highlighted as the most important attributes for fertilisers, including fertiliser content and composition, cost, and ease of use and application (Case et al., 2017). The third section of the survey focused on providing information about the BCmix and recorded respondents' value perception, expressed in monetary terms as their WTP for purchasing it.

Farmers' perceptions expressing various viewpoints concerning the acceptability of organic fertilisers were measured using a questionnaire divided into 12 advantages and 16 barriers. Principal component analysis (PCA) was carried out to reduce the relatively large number of statements concerning organic fertilisers into a few meaningful constructs (available in Supplementary Material). Survey statements were shaped in terms of equidistant scale points and organised into four response categories, from "not relevant" to "very relevant", making them suitable for a PCA (Mooi et al., 2018). The components retained from the PCA, and the variables discarded from PCA were used as input to cluster farmers into homogeneous groups. Clusters have been found via hierarchical clustering. Ward's linkage has been chosen as linkage algorithm due to its good performance and Euclidean distance has been chosen as distance method due to its wide acceptance (Mooi et al., 2018). Similar approaches using factor analyses and clustering to characterise farm typologies and adoption factors have been recently proposed in the literature (Hyland et al., 2018; Paresys et al., 2018; Kong and Castella, 2021; Silveira et al., 2022).

Participants' WTP was elicited using a dichotomous choice contingent valuation on BCmix, used as sample innovative fertiliser: they were firstly asked how much BCmix they would approximately use during an entire fertilisation campaign (quintals per hectare) and on how many hectares. Then, they were asked whether they would buy the BCmix at a given price, randomly selected between € 1 and € 30 per quintal, highlighting at the same time the total potential expenditure based on the area and on the fertilising rate they previously indicated. An interval regression based on single-censored data was performed considering the WTP as the dependent variable. Statistical analyses for PCA and cluster analysis were performed with Stata/SE 17 (StataCorp, 2021), while interval regression against WTP was measured using R v.4.3.1, specifically the "survival" package (R Core Team, 2023). Details about the statistical analysis and data treatment are reported in the Supplementary Material.

## 3. Results and discussion

### 3.1. Sample description

Table 2 displays descriptive statistics for the 176 subjects who completed the survey. Respondents were geographically distributed as follows: 62.5 % from the north, 17.1 % from the centre, and 20.4 % from the south of Italy. It is unsurprising that almost three-quarters of respondents cultivated fruit trees (70.5 %), less than half cereals (42 %), and one quarter grow vegetables (25 %), as the most representative region was Emilia-Romagna, often regarded as the orchard of Italy; industrial crops, leguminous and other crops are present, respectively in the 19.9 %, 15.9 %, and 12.5 % of cases. On average, nearly two types of crops are grown on the same farm. Most of the farms (64.8 %) are conventional, while 21.6 % comply with organic standards and 16.6 % are under conversion. On average, 27 % of the surveyed farmers' total cultivated area is dedicated to organic production, suggesting that the study sample may have a slightly higher representation of organic production compared to the national level, where organic farmland accounts for approximately one fifth of the total. Nearly 9 respondents out of 10 used at least one type of organic fertiliser at the time of the survey. Half of the farmers used cattle manure (51.1 %), nearly one-third (35.8 %) used compost, whereas fewer used poultry manure (18.2 %), organo-mineral (6.1 %), digestate (3.0 %), green manure (2.5 %) or other (10.6 %). Regarding the WTP, 63.1 % of respondents answered 'yes', while 36.9 % answered 'no', indicating a significant appreciation for the BCmix, especially at prices below 200 €/t (Fig. 1). This reflects the overall satisfaction with circular products found in literature (Fu et al., 2024). Such WTP is 3–5 times higher with respect to the study of Tur-Cardona et al. (2018) who found that the WTP for composted-pelletised manure was around ¾ of the price of the equivalent N content in the synthetic corresponding products. Results are in line with the WTP for biochar-based fertilisers ranging in between 183 and 400 € per tonne observed by Moshkin et al. (2023).

### 3.2. Exploratory principal component analysis

Farmers' perceptions concerning the 12 advantages (*adv*) and 16 barriers (*barr*) concerning the acceptability of organic fertilisers resulted in a 5-component structure (Table 3), characterised by a communality

**Table 2**
Main farm characteristics (n = 176).

| Variable | Min | Max | Mean | Median | Sd |
|---|---|---|---|---|---|
| Farmer age | 18 | 86 | 53 | 55 | 12.60 |
| Agricultural area (ha) | 0.25 | 1000 | 41.14 | 12.5 | 110.57 |
| No. cropping systems | 1 | 5 | 1.86 | 2.00 | 1.02 |
| Organic fertiliser quantity (t/ha) | 0 | 75 | 17.16 | 10.00 | 18.37 |
| No. sustainable practices | 0 | 5 | 3.03 | 3.00 | 1.13 |
| Organic production (% of total area) | 0 | 1 | 0.27 | 0.00 | 0.42 |

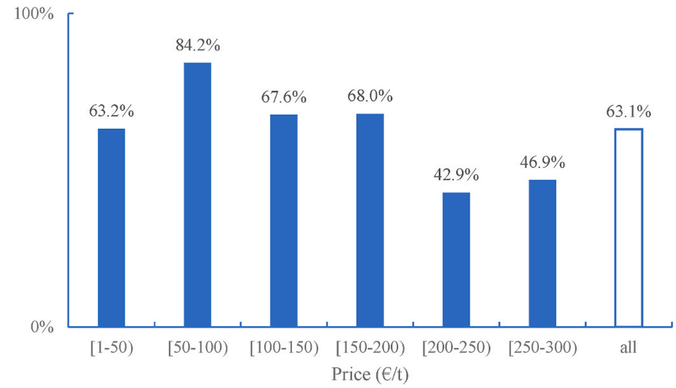


**Fig. 1.** Farmers' WTP distribution for the BCmix for different price ranges, € per tonne (n = 176).

greater than 0.5 (details are included in the Supplementary Material, Tables S1–S2). Components PC1, PC2 and PC3 related to the advantages were interpreted as following: statements 1–4 describe the property of being fit for purpose, statements 5–8 include conditions that link affordability to accessibility and work cycle integration, while statements 9–11 indicate properties that make organic fertilisers trustworthy; for these reasons, they were labelled, respectively, as *Suitability*, *Feasibility*, and *Reliability*. Analogously, the barrier component PC4 was labelled as *Costs*, while the barrier component PC5 was labelled as *Dysfunctions*, as it is related to undesired effects and unsuitable conditions undermining the desirability of organic fertilisers.

### 3.3. Hierarchical clustering

Both the components retained (PC1-5) and the variables discarded from PCA (*adv*12, *barr*7-16) were used as input to cluster farmers into homogeneous groups. As graphically shown in Fig. 2, five clusters were identified, each consisting of several sub-groups (G1-G10), whose sizes ranging from 3 to 21 observations (Fig. 2). Although cluster selection is usually based on the sensibility of the researcher, in this case, the choice of five clusters was corroborated by the $\omega_k$ criterion, a useful reformulation of the variance ratio criterion (Caliński and Harabasz, 1974). The $\omega_k$ criterion displayed its minimum value (−0.092) at the fifth cluster, indicating a clear demarcation among the groups. Significant differences (at 1 % level) were found for all variables considered except for PC2 (*Feasibility*), at 5 % level (statistical details are available in Supplementary Material). The same analysis was conducted for the socio-demographic variables; in this case, too, the clusters showed significant differences for almost all variables (Table 4), except for "Organic production", for which no significant difference was found between the clusters. This finding suggests that there is no strict separation between organic and conventional producers, a fact recently confirmed in a sample of Swedish farmers (Höglind et al., 2021). Overall, the five clusters show different socio-demographics and attitudes towards organic fertilisers, which were interpreted according to the significant factors contributing to each group.

Cluster 1: *The Neutral* (n = 42; 23.86 %). Farmers of this cluster mostly run small single-product farms and favour adopting sustainable practices. Even though they do not acknowledge relevant barriers towards organic fertilisers, they use them in small quantities (Table 4). Possible additional costs related to the use of organic fertilisers do not hamper their use (negative value for *Costs*). Compared to other profiles, most of the barriers show lower values. Apparently, these farmers are characterised by a moderate level of interest or ambivalence towards organic fertilisers, which may originate from scale economies and/or diversification issues. In fact, small farms may not rely on sufficient resources and infrastructure to invest in organic farming practices such as organic fertilisers, or they may find it hard to use organic fertilisers on

**Table 3**
The component structure of advantages and barriers.

| | # | Statements | Principal component |
|---|---|---|---|
| **Advantages** | 1 | Yield increase | PC1 *Suitability* |
| | 2 | Soil structure improvement | |
| | 3 | Crop quality increase | |
| | 4 | Suitable N, P, K content | |
| | 5 | Inexpensive machinery | PC2 *Feasibility* |
| | 6 | Easy to apply and manage | |
| | 7 | Inexpensive product | |
| | 8 | High/good availability | |
| | 9 | Reliable fertilising power | PC3 *Reliability* |
| | 10 | Quality certification | |
| | 11 | Available expert advice | |
| | 12 | No harm, no pollution | |
| **Barriers** | 1 | Additional labour costs | PC4 *Costs* |
| | 2 | Expensive machinery | |
| | 3 | Expensive products | |
| | 4 | Crop quality decrease | PC5 *Dysfunctions* |
| | 5 | Unsuitability for specific conditions | |
| | 6 | Yield decrease | |
| | 7 | Nitrogen regulation limitations | |
| | 8 | Lack of public subsidies | |
| | 9 | Odours | |
| | 10 | Risk of environmental pollution | |
| | 11 | Delayed effects and benefits | |
| | 12 | Difficult to manage | |
| | 13 | Unreliable N, P, K content | |
| | 14 | Unsuitable N, P, K content | |
| | 15 | No quality certification | |
| | 16 | No expert advice | |

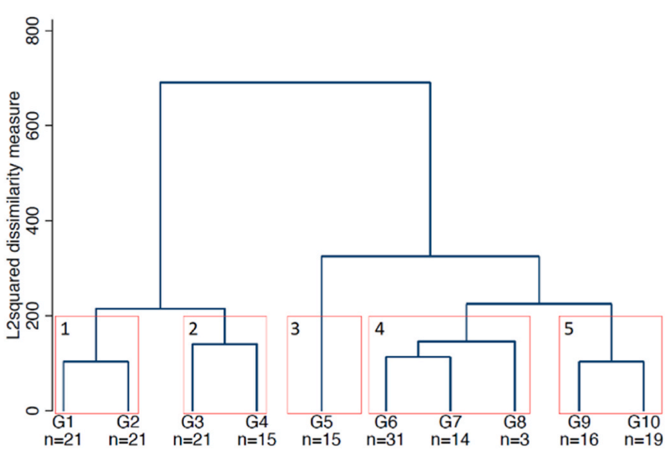


**Fig. 2.** Dendrogram resulting from exploratory PCA.

a portion of their land. This group shows affinity with the cluster "forward-looking hesitators" found by Mohrmann and Otter (2023) who adopted a similar approach to categorise agricultural biogas plant operators according to their intention to use straw pellets as biogas substrate.

Cluster 2: *The Unready* (n = 36; 20.45 %). Members of this group are relatively young farmers who appreciate organic fertilisers' intrinsic characteristics (high values for Suitability). However, low values for *Feasibility* can be explained by the scarcity of equipment for the use of fertilisers, which are generally applied in limited quantities. They seem to be sceptical towards some external product attribute (low values for *Reliability*), which can be due to structural problems, lack of confidence in selling and support services, or even lack of awareness (low values for Barr15-16). Anyhow, The Unready is characterised by uncertainty or a lack of readiness to change their current farming methods and hesitates to adopt innovative technologies or practices. This profile has been linked to scarce openness to new experiences and reluctant to change their status quo to not incur a loss (Dessart et al., 2019) and may be associated with non-adopters for neither financial reasons nor difficulties in implementing novel practices (see, e.g., Defrancesco et al., 2008; Nainggolan et al., 2023). Similarly, Skevas and Kalaitzandonakes

**Table 4**
Cluster characteristics with respect to farm characteristics.

| Cluster | Farmer age | Agricultural area | No. cropping systems | Fertiliser quantity (t/ha) | No. sustainable practices | Organic production |
|---|---|---|---|---|---|---|
| 1. *The Neutral* | 54.452 | 0.858 | 1.476 | 13.786 | 3.167 | 0.251 |
| 2. *The Unready* | 48.417 | 1.160 | 1.972 | 13.778 | 2.944 | 0.306 |
| 3. *The Opposed* | 58.133 | 1.043 | 2.200 | 16.733 | 2.200 | 0.201 |
| 4. *The Sceptic* | 56.271 | 1.153 | 1.854 | 15.667 | 3.063 | 0.185 |
| 5. *The Engaged* | 46.829 | 1.412 | 2.057 | 26.914 | 3.286 | 0.383 |
| ANOVA | 17.663*** | 14.337*** | 10.367** | 8.813* | 14.545*** | 5.006 |

Significance levels: *** <0.01; ** <0.05; * <0.10. Note: *Agricultural area* is expressed in terms of natural logarithm.

(2020), in the context of drone adoption in agriculture, defined "complexity worried" those farmers aware of innovative applications but perceiving associated operations as challenging. The resulting inertia is probably one of the most relevant reasons innovations are not adopted (Dessart et al., 2019). Among others, resistance to change has been observed in the past to slow down the switch to organic farming (Hermann et al., 2016) and the adoption of conservation tillage (Heller et al., 2024).

Cluster 3: *The Opposed* (n = 15; 8.52 %). This cluster is characterised by elder farmers running small but diversified farms that are not inclined to adopt sustainable practices (Table 6). Although they appreciate some organic fertiliser attributes (high values for *Reliability*) and are equipped for their management (high values for *Feasibility*) also thanks to their extensive experience, they believe that the intrinsic characteristics of organic fertilisers make them unsuitable for their context (low values for *Suitability* and high values for *Dysfunctions*). They differ significantly from the other clusters, with members scoring higher in nearly every barrier towards organic fertilisers. This group refers to farmers who actively resist the adoption of innovations in agriculture, perceiving the use of organic fertilisers as incompatible with their farming practices and beliefs. This opposition may stem from numerous factors, including concerns about modern technologies' environmental or social impacts, cultural or social norms, and economic considerations (Rieple and Snijders, 2018). Adoption barriers might be mitigated by providing full information regarding the various aspects of organic fertilisers.

Cluster 4: *The Sceptic* (n = 48; 27.27 %). The lowest values in *Suitability* and confidence in safety of the product and risk of pollution (*Adv*12) make this profile the most sceptical about organic fertilisers' intrinsic characteristics and environmental footprint. Even this cluster, like the previous, represents mostly elderly farmers, and it highlights a farmer profile along the same line as *The Opposed* but somehow less marked, depicting personality traits closer to a late adopter profile (Vlachos, 2011). More in detail, *The Sceptic*, who does not consider early adoption as an option, but not even refuse it a priori, resembles the "reluctant majority" described by Mohrmann and Otter (2023). Since the main barriers to adoption are related to the intrinsic characteristics of organic fertilisers, their aversion towards them may be mitigated with the benefit of field trials and demonstrations.

Cluster 5: *The Engaged* (n = 35; 19.89 %). Members of this cluster are young farmers running large farms, highly inclined to adopt sustainable practices while using considerable quantities of organic fertilisers (Table 4). They find them useful and suitable for their context (low values for *Dysfunctions* and high values for *Suitability*). Economic constraints represent the main barrier to their use (highest values for *Costs*), with the lack of subsidies for using them playing a significant role (high values for *Barr*8). They are convinced that organic fertilisers do not harm the environment or at least that they cause little pollution (high values for *Adv12*), and take a stand on existing nitrogen usage limits, finding them too stringent (high values for *Barr7*). This profile refers to farmers inclined towards adopting sustainable agricultural practices, including a higher use of organic fertilisers than mineral fertilisers, showing affinity with the *conservation-oriented* farmer typology (Ofosu-Ampong et al., 2025). They are aware of the environmental benefits associated with sustainable agriculture, such as improved soil health and reduced environmental pollution. Engaged farmers can serve as models within their communities, inspiring and influencing other farmers to adopt sustainable practices.

**Table 5**
Stepwise interval regression results of WTP the BCmix.

| Variable | Value | Std error | z-value | p-value |
|---|---|---|---|---|
| (intercept) | 2.164 | 0.246 | 8.18 | <2.8e-16 |
| 1. *The Neutral* | 0.451 | 0.202 | 2.24 | 0.025** |
| Agricultural area | −0.294 | 0.172 | −1.71 | 0.087* |
| No. cropping systems | −0.344 | 0.103 | −3.35 | 0.001*** |
| Precision fertilisation | −0.497 | 0.200 | −2.49 | 0.013** |

Significance levels: *** <0.01; ** <0.05; * <0.10.

**Table 6**
BCmix potential quantity across clusters (t/ha).

| Variable | Min | Max | Mean | Median | Sd |
|---|---|---|---|---|---|
| 1. *The Neutral* | 0 | 46 | 11.24 | 8.50 | 10.99 |
| 2. *The Unready* | 1 | 41 | 14.19 | 10.50 | 10.35 |
| 3. *The Opposed* | 4 | 50 | 14.40 | 10.00 | 12.43 |
| 4. *The Sceptic* | 0 | 50 | 11.60 | 10.00 | 10.53 |
| 5. *The Engaged* | 0 | 50 | 19.40 | 15.00 | 14.85 |

Kruskal-Wallis ANOVA = 10.742, p-value = 0.030.

The two counterparts that are favourable (*The Engaged*) and not favourable (*The Opposed* and *The Sceptic*), find correspondence with other farmer profiles identified in the literature, and proves that the "regular farmer" profile, mostly elder and not much engaged in environmental issues, may indeed be more elaborated and discerned in sub-profiles. Furthermore, two profiles in the middle were identified (*The Unready* and *The Neutral*). *The Unready* may lack either physical assets or confidence in the external features linked to the innovation (or both) while *The Neutral* mostly reflect small farmers who, in principle, are favourable to adopting sustainable practices but are constrained by economies of scale. Nevertheless, this profile, not characterised by prejudices nor positive judgements towards BCmix characteristics, showed a significantly higher WTP for an innovative organic fertiliser such as the BCmix, a circumstance not verified for the other groups of farmers (Section 3.4). It was found that the farmer profile most committed to sustainability (*The Engaged*) and using relevant amounts of organic fertilisers, acknowledged economic challenges associated with their use, particularly due to high management costs and the lack of subsidies.

### *3.4. Effects of clusters and farm characteristics on willingness-to-pay*

A significant relationship was found between farm characteristics and the WTP (Table 5). Concerning clusters, findings reveal that all groups are not significant, with a reference WTP statistically similar to that of the reference Cluster 5 (*The Engaged*), used as a baseline for the regression.

Only Cluster 1 (*The Neutral*) shows a WTP that significantly differentiate from the WTP of Cluster 5. This suggests that neutral profiles add higher reservation prices than those farmers more inclined to adopt sustainable practices who already use high amounts of organic fertilisers. Although *The Engaged* has been associated to openness in experimenting with innovations, premium prices for sustainable products and cost benefits in the long term, its financial interest towards the BCmix remain undefined and this may call into question the acceptance of some agricultural innovations by similar profiles. Being experienced adopter, this profile is probably going to take into consideration perceived risks, long-term economic viability, and other possible financial obstacles related to adoption. *The Neutral*, on the other hand, may evaluate BCmix with more optimism and less critical financial scrutiny due to their less direct involvement in sustainable practices or innovations, which explains his higher reservation price. These farmers may be willing to adopt innovations if they are perceived as beneficial or if certain barriers to adoption are addressed, even though they may not actively seek out or readily embrace new ideas without sufficient evidence. The higher reservation prices in *The Neutral* cluster imply that specific incentive programs or risk-reduction techniques might promote adoption among farmers who are less proactive. Nevertheless, *The Engaged* showed a remarkable agronomic interest in the BCmix, indicating the highest quantity potential foreseen for the fertilisation campaign (Table 6). *The Engaged*'s vague financial interest highlights the need for more precise economic value propositions and customised communication tactics. For this profile, risk-reduction strategies and more lucid economic value propositions may be essential to raising their WTP. This distinction between this type of farmers and more neutral profiles suggests that adoption strategies should address perceived risks and financial uncertainties in addition to agronomic benefits.

Regarding farm characteristics showed in Tables 6 and it can be observed that differences concerning agricultural area, number of cropping systems, and precision fertilisation (as a part of the set including sustainable practices) were found to be significant. The latter three variables resulted to negatively affect WTP, which means that farmers managing small areas with a limited number of cropping systems and not adopting precision fertilisation perceive a higher value for the BCmix. This finding suggests that the management of BCmix could be an issue, especially in case of multi-cropping systems, thereby not economically convenient for large farms due to its impact on fixed costs (e.g., machines) and variable costs like the fertiliser itself. Also, the practice of variable-rate fertilisation does not necessarily match the management of fertiliser such as the BCmix, which is associated with uniform application rates. Other surveyed characteristics, including age, organic fertiliser quantity, number of sustainable practices adopted, and organic production, showed no significance. BCmix quantity was found to be significant across clusters (Table 6). Every cluster showed a moderate interest in the BCmix, willing to apply it in quantities higher than 11 t/ha on average, whereas the technical suggestion that accompanied the product description felt between 15 and 25 t/ha.

According to these results, the perceived value and viability of adopting the BCmix are significantly influenced by farm size and complexity, with smaller and less diversified farms finding it to be a more appealing choice. Large farms with multiple cropping systems might encounter challenges when trying to adopt the BCmix fertiliser due to logistical and economic barriers: in facts, managing different crops with varying nutrient requirements could make it complex to coordinate fertilisation schedules and adapting machinery for different fields; at the same time, the cost-effectiveness of BCmix might be lower for large farms due to higher fixed costs (such as specialised machinery).

Concerning limitations, the online nature of the survey may have introduced a bias toward farmers with higher IT literacy and internet access, which should be considered when interpreting the findings.

### 3.5. Policy implications

Cost-related barriers were found to be particularly significant for farmers more committed to sustainability (i.e., *The Engaged*). Additionally, large and diversified farms face considerable complexity in implementing sustainable practices. These observations indicate that future regulations and extension services ought to concentrate on offering focused support and demonstrate the economic viability of BCmix across diverse management circumstances.

To address economic constraints and promote the development of circular business models linked to organic fertiliser production, policies should incorporate subsidies or financial rewards. The need of policy incentives in stimulating circular solutions has been emphasized in recent literature (Lima et al., 2024). Incentive mechanisms like feed-in tariffs can provide predictable revenue streams (Teleshkan et al., 2024). In general, broader policy frameworks could focus on enhancing the recycling of organic household waste, food waste, and green waste into organic fertilisers (Case et al., 2017). Such measures, which require overcoming barriers to organic fertiliser adoption and the creation of adaptive policies developed through citizen engagement (Bahers and Giacchè, 2019; Moinard et al., 2021), would not only facilitate the use of organic fertilisers but also support their efficient application and the closure of nutrient loops.

In addition, communication and consulting initiatives should be implemented to raise awareness of the BCmix value proposition. Extension services and farmer training programs -particularly those incorporating demonstrations and field trials-can play a key role in addressing concerns about the reliability and feasibility of organic fertilisers among sceptical farmer profiles (Garmendia-Lemus et al., 2024) and in providing guidance on the effective use of BCmix across various management contexts.

## 4. Conclusions

Farmers' attitudes towards using organic fertilisers were investigated in this study, aiming to verify suitability, complexity, and relative advantage issues with respect to agronomic innovations. Judgements towards a total of 28 statements were surveyed, and through a PCA they were reduced to 16 variables, of which 5 principal components (*Suitability, Feasibility, Reliability, Costs*, and *Dysfunctions*). Then, these 16 variables were used to group farmers into homogeneous clusters, which in turn were matched up against the WTP for an original organic fertiliser, the BCmix. The five components retained in the PCA concurred to explain most of the variance inter-cluster and represent a comprehensive key for understanding farmers' attitudes towards other agricultural innovations, even in other agricultural sectors. Five farmer profiles were identified, representing varying degrees of appreciation towards organic fertilisers. The interval regression analysis of the WTP highlighted that a decrease in agricultural area and the number of cropping systems increases the WTP for an extensive organic fertiliser such as the BCmix, confirming that complexity can serve as a barrier to innovation entry. Study findings offer interesting points to address farmer issues and their relations with other food system actors. Involving stakeholders would contribute to increasing organic fertiliser acceptance. Technology providers and market representatives may provide dedicated training regarding the various aspects of organic fertilisers and in-field demonstrations, which would be helpful to convince farmer profiles that are more resistant and sceptical. Providing economic subsidies can help reduce farm direct costs, making organic fertilisers more affordable for farmers. This can encourage adoption among farmers who may be hesitant due to the cost of organic inputs perceived as excessive. In general, broader policy programs are expected to explore strategies aimed at increasing the recycling of organic waste for use as organic fertiliser, while also facilitating the necessary conditions for the operation of sustainable business models.

## CRediT authorship contribution statement

**Marco Medici:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Data curation, Conceptualization. **Massimiliano Calvia:** Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Nicolas Greggio:** Writing – review & editing, Resources, Conceptualization. **Alessandro Buscaroli:** Writing – review & editing, Validation, Resources. **Diego Marazza:** Writing – review & editing, Visualization, Supervision, Resources, Funding acquisition. **Maurizio Canavari:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

## Data availability statements

The dataset generated by the survey research is available in the Open Science Framework repository at https://doi.org/10.17605/OSF.IO/567CE.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.farsys.2025.100156.

## Appendix A

**Table A.1**
Summary of the survey design

| Question | Possible responses |
|---|---|
| **1. Farm/farmer characteristics** | |
| Please indicate the main cultivated crops on your farm | Cereals, vegetables, fruit trees, industrial crops, leguminous crops, and other |
| What is the size of the agricultural land of your farm? | 0.1–999 ha |
| Is organic farming part of your current activity? | yes/no |
| What is the share of the organic farming surface compared to the total cultivated land? | % of total area |
| Please indicate the types of organic fertilisers you use on your farm | Cattle manure, compost, poultry manure, other (*specify*), I don't use them, I don't know |
| How much cattle manure/compost/poultry manure/*other* do you think is needed on average in your farm every year? | 0-100 t/ha |
| Is soil conservation/precision fertilisation/minimum soil tillage/integrated pest management/absence of chemical weeding in place on your farm? | yes/no |
| How old are you? | 0–99 years |
| **2. Advantages and barriers** | |
| Please indicate how relevant each of these items is for the use of organic fertilisers on your farm (statements are reported in Supplementary Material) | 0 = not relevant, 1 = little relevant, 2 = quite relevant, 3 = very relevant |
| **3. Quantity and WTP for a biochar-compost mixture** | |
| Approximately how much biochar-compost would you use during an entire fertilisation campaign? | t/ha |
| … and on how many hectares? | ha |
| Would you buy the biochar-compost mixture at a price of € x per quintal? | 0-30 €/q |

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