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Estimating Supply and Demand of Organic Seeds in Europe Using Survey Data and MI Techniques

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Abstract: The lack of sufficient information about organic seed production and use is among the key factors affecting the development of the organic seed market in the EU. Currently, only very basic organic seed market data are being reported at the country level. Those available from each member state are seldom comparable over time between countries and sometimes even within one country. This study provides the first overall statistics on European organic seed supply and demand. Estimates of the organic seed demand and supply of twelve important crops in EU organic agriculture are provided by developing and testing innovative approaches to improve data collection and analysis, such as multiple imputation (MI) techniques to estimate missing values. The estimates are based on data extracted from official EU datasets from 2014 to 2018 and collected by an online survey of 756 farmers, as well as various expert assessments across the EU. The results were provided by four EU geographical regions, with a specific focus on wheat, lucerne, carrot, and apple. Although strong sector and regional differences currently characterise the organic seed market, organic seed demand considerably exceeds supply for most crops. Generally, farms in the central and northern regions revealed a higher organic seed supply than those in the southern and eastern regions, and organic seed supply is higher for wheat than other crops. A significant output of this study is the development of recommendations to improve methodologies to increase the transparency and availability of organic seed market data.

Keywords: organic farming; seeds; supply and demand; certification; missing data

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1. Introduction

According to the current European Organic Regulation 2018/848 [1], the use of organic seeds is mandatory for all organic farmers. This reflects the principle of organic farming that whenever external inputs are required on the farm, only organic inputs should be used. Nevertheless, there is a lack of organic seeds for many crops, resulting in the frequent use of non-organic untreated seeds granted through derogation requests [2]. Therefore, the EU's actual demand for certified organic seeds—which can be defined as the quantity of organic seeds that organic farmers are willing to pay for and purchase—may represent only a portion of the total potential seed requirement [3]. Although authorisation for the use of non-organic seeds is considered an exceptional production rule, according to Solfanelli [4], data on derogation requests in the EU showed a general increase in the total volume of non-organic seeds and vegetative propagating material over the last few years. The demand for organic seeds could also be affected by the rate of farm-saved seeds used by organic producers [5]. According to the available literature, organic farm-saved seeds represent a high proportion of the total seed used on farms, particularly for cereal crops in southern EU countries such as Greece [6] and Italy [7].

In addition, in many EU member states, there is an emerging informal seed sector that aims to address the on-farm biodiversity conservation aspects, and aspects related to the lack of suitable varieties for organic agriculture, through participatory models. These initiatives still represent a small part of the entire seed market, and accurate data on production and use are missing in most EU countries [8].

The lack of information about organic seed production and use is among the key factors affecting the current development of the organic seed market in the EU. In this changing environment, the organic seed sector has now developed, increasing the need for statistical data in sufficient quantity and of appropriate quality. The demand for good statistics on EU organic seed production and use can no longer be ignored. Seed suppliers and breeders need the information to make appropriate investment decisions, including whether to enter the organic sector. Farmers need data to support their purchasing decisions. Finally, policymakers need information on seed production and use to monitor when the target of 100% organic seed could be reached and to determine the appropriate level of regulation and support measures for the sector. These aspects become increasingly important with the new European organic regulation [1], according to which the derogations for the use of untreated conventional seeds should be phased out, and only organic seeds should be used by January 2036.

According to our knowledge, currently, no official statistics and reports on the production and sales of organic seeds exist, neither at the national nor the EU level. Some authors (see, among others, [9]) have tried to explore the gap between potential demand and actual demand for organic seeds. However, these estimates are mainly based on case study countries and only refer to a few crops. Previous scattered and dated reports at the national level also exist, showing increasing areas devoted to organic seed production [3]. In France, organic land for seed production is growing: organic land dedicated to seed multiplication increased from 2691 ha in 2003 to nearly 5.000 ha in 2012 [10]. In Italy, the organic seed area is also growing; currently, the share of organic land dedicated to seed production is approximately 3% [11].

This work provides original statistics on organic seed supply and demand in Europe. As described more deeply under "material and methods", the data presented in this report are all derived from the land area devoted to organic seed per crop and on a set of survey data on organic farm seed use collected under the EU-funded H2020 project LIVESEED. Innovative approaches were developed and tested to improve data collection and analysis, with specific reference to organic crop area estimates and the organic seed use rate in EU member states. This work can provide a basis for the public and private institutes in the EU member states to improve the collection and quality of organic seed market data and to increase the availability of these data.

The paper is structured as follows. The next section describes the data collection and methodological approach. The results and discussion section provides potential organic seed demand and supply for the selected crops and discusses the results considering the factors influencing the organic seed market. Conclusions follow.

2. Materials and Methods

The analysis of organic seed supply and demand requires prioritising crop species based on their importance in the EU. The selection of focus crops has considered several criteria, such as the relevance of derogation, relevance of crop production area, geographical coverage, and data availability. Based on these criteria, a strategic crop list was defined, including 12 crops covering combinable arable crops (barley, grain maize, lucerne, lupine, oats, soybean, wheat), vegetables (carrot, onion, tomato), and fruits (apples, strawberries).

For each crop, from 2014 to 2018, supply and demand of organic seeds in the EU (referring to 27 EU member states, the UK and Switzerland in this study) were estimated following two main steps (Figure 1). First, potential organic seed demand was estimated based on information from 2014 to 2018 on the organic land area in the EU countries and on average estimations of seed rates. Second, organic seed use was estimated and applied to the known 2018 organic seed potential demand to give an overall estimate for both organic and untreated conventional seed supply used in organic farming.

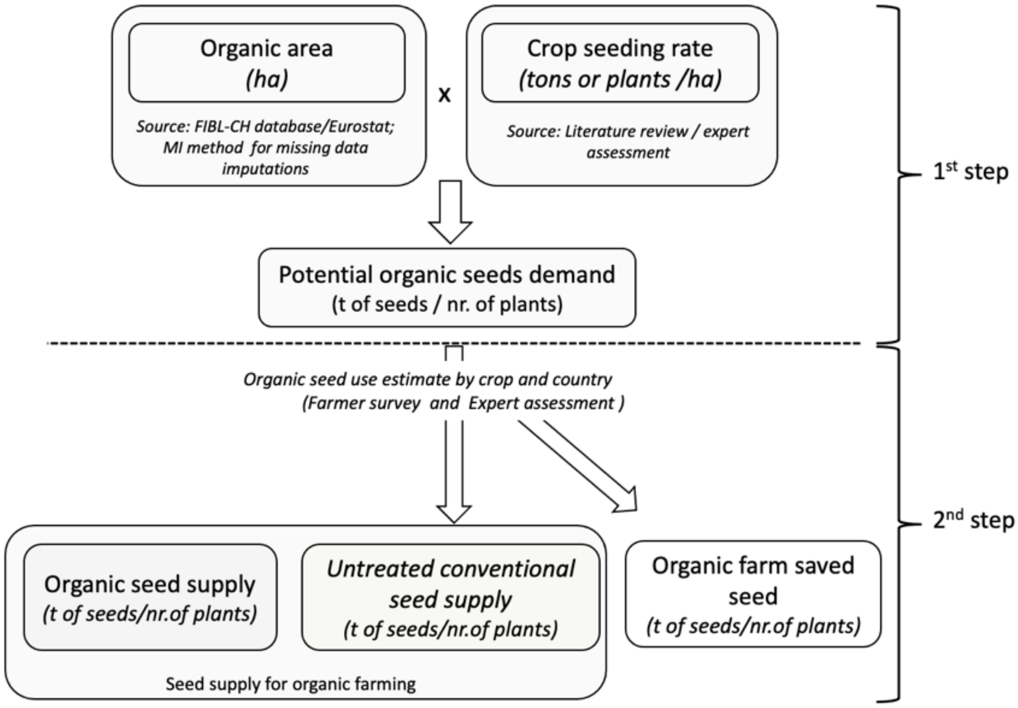


Figure 1. Procedure for data collection and estimation of organic seed demand and supply.

2.1. Step 1—Estimates of the Potential Organic Seed Demand

The likely organic seed demand, which is the amount of seed and propagation materials needed for each crop if all organic farmers in the EU buys organic seeds for their crops, was estimated by combining the data on the organic land area with the average crop seeding rates.

As for the organic area (i.e., fully converted and in conversion areas), data for each crop were extracted from the Research Institute of Organic Agriculture (FiBL) dataset on a country basis covering the years from 2014 to 2018 [12]. The collected information was cross-checked and complemented by the data from Eurostat [13]. All countries included in the analysis had data on the area under organic agricultural management, though with different levels of breakdown by crop. As a result, for some strategic crops, there was scattered coverage of data for organic land, with a large proportion of missing data at the national level.

Apart from fruits, for which the dataset does not show any missing values, the vegetable crop category is the one with the highest number of missing values (151 missing values out of 509 observations: 30%), followed by arable crops (101 missing values out of 967 observations: 10%).

In this research, missing data were estimated using the multiple imputation (MI) method. MI, first proposed by Rubin [14], has proven to be a very flexible approach for estimating missing data. Compared to other imputation methods, such as the mean imputation approach, MI is more accurate, as it combines all available information from the observed data with proper statistical assumptions to estimate the population parameters statistically [15–17]. The MI method is based on creating a set of multiple estimates (imputations) for each missing value based on observed data (i.e., non-missing values). According to some authors (see, among others, [15–17]), the performance of the MI method may vary from different datasets depending on the mechanism causing the missingness, the missingness rate, and the nature and number of explanatory variables included in the MI models. Therefore, before an MI can be implemented, some assumptions about missing data mechanisms and patterns must be carefully considered.

According to [16,17], the nature of the missing data could be divided into three categories: data missing completely at random (MCAR), data missing at random (MAR), and data missing not at random (MNAR). In the case of MCAR, the missing data generation process was completely independent of any other potential variables so that the observed (non-missing) data are considered a random sample. In the case of MAR, the missing data generation process was somehow dependent on observed variables. MNAR refers to cases where missing values depend on unobserved variables.

Under the MAR or MCAR conditions, the MI methodology can be effectively applied to obtain unbiased estimates based on imputed values (for more details, see [14,18]). In our dataset, the available data on organic crop areas are assumed to be a random sample of the complete dataset, and the missing data mechanism can be considered as MCAR. Another type of data missingness particularly relevant in our research refers to filtered values [19]. Filtered values cannot be considered missing values, as these refer to cases where information about a specific aspect is not pertinent (e.g., due to adverse environmental conditions, some crops may not be cultivated in certain EU countries). To avoid the issue of filtered values, we have previously deleted from the dataset all observations for which total agriculture area for the specific crop and country accounts for zero.

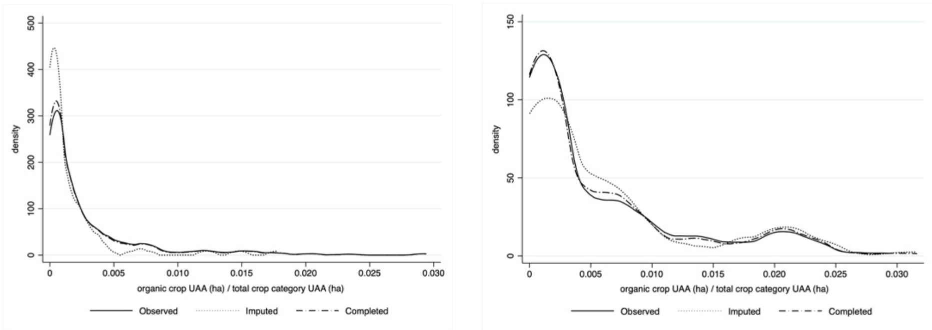
To estimate the missing values for the variable organic crop area, we developed two MI models (one each for arable crops and vegetable crops). Given the univariate missing data pattern of our datasets (i.e., only one variable is missing and the rest are observed), the MI method based on a predictive mean matching (PMM) algorithm has proven to be a valid approach for missing data imputation [20].

A linear regression imputation model, as described in (1), was developed to specify the variable to impute and the set of regressors. More specifically, $Y_{i\,j} = (Y_{i\,j;\,obs},\ Y_{i\,j;\,mis})$ is the partially observed share of total organic crop area out of total crop category area, where $Y_{i\,j;\,obs}$ is the observed value, and $Y_{i\,j;\,mis}$ is the missing value. $X_{1\,j}$ is the share of organic crop category area out of total crop category area and β_1 the relative coefficient. $X_{2\,i\,j}$ is the share of total crop area out of total crop category area and β_2 the relative coefficient. In our dataset, both $X_{1\,j}$ and $X_{2\,i\,j}$ are fully observed values.

$$Y_{i\,j} = \beta_0 + \beta_1 X_{1j} + \beta_2 X_{2\,i\,j} + \varepsilon_{i\,j} \tag{1}$$

where $i = 1, \ldots, n$ refers to the crops; $j = 1, \ldots, m$ refers to the 29 countries. The estimates were performed using Stata software, version 15.0. Following [21], a graphical comparison of the observed and imputed data was performed; the complete dataset was used to make a first diagnosis of the two imputation models. Figure 2a (kernel density for vegetable crop category) and Figure 2b (kernel density for arable crop category) demonstrate that for both categories, the distributions of the imputed and completed datasets closely match the distribution of the observed dataset. Two-sample Kolmogorov–Smirnov tests (see [22]) were also used to compare the distributions of the observed and imputed data. The tests were performed on all imputations, showing no significant differences.

The goodness-of-fit of the imputation models used in this research was further explored by performing standard regression diagnostics to both the observed data before performing MI, and after imputation [21,23]. These diagnostics were primarily a check of the fit of the proposed linear regression models. Still, they were also used to check for differences in the model fit between the observed and the completed datasets. Appendix A shows the standard regression diagnostics before and after imputation for both arable and vegetable crop models.



(**a**) Dataset for arable crops (**b**) Dataset for vegetables crops

Figure 2. Distributions of $Y_{i\,j}$ in the observed, imputed (imputation m = 100), and completed datasets.

As for the crop seeding rate and plant density used for the estimate of the potential demand (see Figure 1), data were collected from the available literature and through consultation with various farm management handbooks (see, among others, [24,25]). An online process of crop seeding rate assessment was followed, where experts from the different EU member states could fine-tune their judgments based on the available information for the 12 strategic crops selected for this study. The survey was administered mainly by LIVESEED partners in their respective countries from November 2018 to January 2019. Based on their knowledge and experience, experts were asked to confirm or modify the seeding rate data collected through literature research. As a result of the survey, average, minimum, and maximum seeding/planting rates per hectare were obtained for each strategic crop and geographic region. Details of the seeding/planting rates are presented in Appendix B.

2.2. Step 2—Estimates of Seed Supply for Organic Farming

To estimate the seed supply used in organic farming, we broke down the potential demand using the information on organic seed use collected at the farm level. Therefore, for each crop, we could estimate the following three components: the organic seed supply, the untreated conventional seed supply, and the organic farm-saved seed (see Figure 1). Data on organic seed use were collected as part of a survey conducted from November 2018 to February 2019 within the LIVESEED H2020 project. Originally written in English, the survey was translated into 14 languages and administered online using the Qualtrics platform. The data were collected from a sample of 756 farmers distributed among 16 EU member states and Switzerland. Table 1 describes the main characteristics of the sample.

Table 1. Structural farm characteristics of the sample.

Variables			Eastern EU *	Central EU	Northern EU	Southern EU
Farm size	Ha	Mean	121	66	185	166
Production orientation	Arable	%	45	39	54	27
	Vegetables		20	43	20	31
	Fruit		21	13	7	35
	Forage/livestock		14	5	19	7
Main seed source	Seed company	%	58	78	72	52
	Farm-saved seed		37	15	21	37
	Public seed agency		1	0	4	3
	Other		4	7	3	8
Marketing channel	*Long-SC* (*Supermarket/processors/traders*)	%	40	29	48	33
	Short-SC (*organic shop/consumers*)		35	27	14	34
	Long and short-SC		25	44	38	33
Total completed survey			134	305	126	191

* European geographical areas: central Europe: AT, BE, DE, FR, LU, NL, CH; eastern Europe: BG, CZ, HU, PL, RO, SK; northern Europe: DK, EE, FI, IE, LT, LV, SE, UK; southern Europe: CY, EL, ES, HR, IT, MT, PT, SI.

In the survey, farmers were asked to indicate the average percentage of organic seed used in the past year (i.e., 2018 was the reference year) for each organic crop they sow.

Additionally, they were asked to state the primary source of organic seed used: whether predominantly purchased from external suppliers or produced within their farms (farm-saved). This qualitative information may be treated as fuzzy since predominantly could refer to any range from 51% to 100%. Therefore, in attributing the declared organic seed use percentage to either the purchased or saved amount, the fuzziness of the concept was considered by using three discrete thresholds: the minimum level for the concept to be true (51%), the median (75%), and the maximum (100%, corresponding to complete truth). Through this approach, we could estimate a minimum, median, and maximum value of purchased organic seeds from an external supplier, providing the range within the true actual organic seed used by the EU organic farmers. The organic seed use estimates for each strategic crop and geographical area were further validated by an online expert survey from September 2019 to October 2019. This was necessary, as the farmer survey results could not be generalised to the whole population of organic farmers in Europe. It is important to note that the survey was based on a convenience sample and the available pool of respondents that provided feedback generally use short-chain marketing schemes to sell their products. Therefore, the estimated percentage of seed sources (purchased certified organic seed; farm-saved seed; purchased untreated conventional seed) for each crop and country could be biased towards different organic seed rates compared to what could generally occur among average organic farms in the respective EU member states and Switzerland.

Participants in the expert survey were selected among established experts in their respective crop sectors and country. A total of 37 interviews were performed in this study, covering 18 EU countries. The expert group includes seed suppliers, advisors, and researchers. We asked the expert to confirm or amend the data, based on their knowledge and experience, for 2018, the reference year. To facilitate the data collection process, we provided the experts with the average values derived from the farmer survey for each crop and EU geographical area. According to [26], the intraclass correlation coefficient (ICC) was used to measure experts' inter-rater reliability and check the relative values' consistency and homogeneity.

3. Results and Discussion

The results of the study are presented and discussed in four main sections. The first shows the estimated potential organic seed demand for the selected strategic crops by EU geographical region, with a specific focus on wheat, lucerne, carrot, and apple. The second section provides estimates of the seed supply for the organic market, distinguishing between organic and untreated conventional seed. Factors influencing the development of the organic seed market are discussed in the third section. Finally, the limitations of the study were discussed in the last section.

3.1. Potential Organic Seeds Demand in the EU

This session provides the potential demand for organic seeds between 2014 and 2018. The graphs presented are only part of the estimates conducted in this study, which are fully available in Appendix C.

Cereals and green fodder occupy the most significant proportion of organic arable land in the EU. With 2.4 million ha in 2019, cereals represent approximately 36% of all EU organic agricultural land, with an increase of approximately 70.7% between 2015 and 2019 and 11.9% between 2018 and 2019 [27]. Italy, France, and Germany have the largest cereal areas. Wheat is the most crucial organic cereal with a 1.1 million ha production area [27]. Figure 3 shows the estimated organic wheat seed demand in the EU between 2014 and 2018. In parallel to the increase in the production area, potential seed demand increased between 2014 and 2018. In 2018, the total demand in terms of seed volume required by organic farmers in the EU member states and Switzerland was estimated to be approximately 167,270 t, with a minimum of approximately 128,197 t and a maximum of approximately 198,776 t.

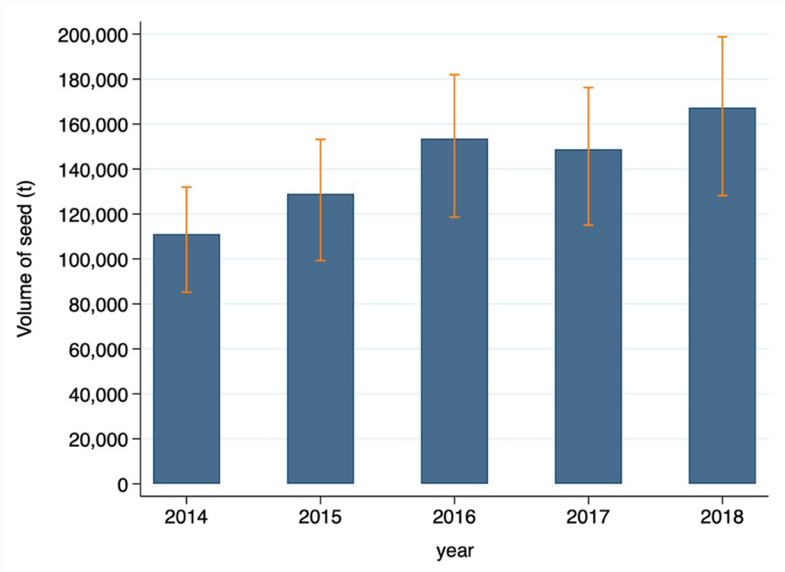


Figure 3. Estimated demand for wheat seed used in organic farming in the EU member states and Switzerland in the years from 2014 to 2018 (t).

As for cereals, forage crops also showed significant growth in organic land in the last years, resulting in higher demand for organic seeds. Organic green fodder, which consists of the main crops of the forage sector such as lucerne (alfalfa), clover, fescue, timothy, and other grasses, accounted for 2.5 million ha in 2019, with an increase of 73.8% in 2015–2019 [27]. Figure 4 shows the estimate of organic lucerne seed demand in the EU between 2014 and 2018. In 2018, the potential seed demand required by organic farmers in the EU member states and Switzerland was estimated to be approximately 2580 t, with a minimum of approximately 1881 t and a maximum of approximately 3061 t.

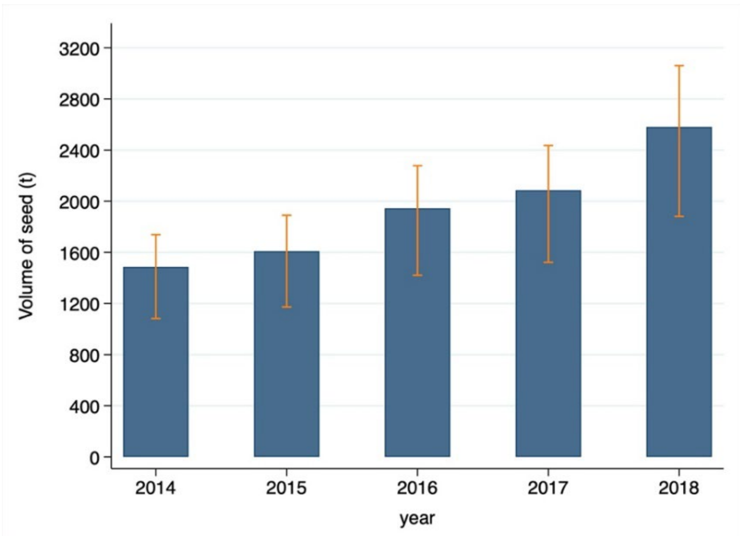


Figure 4. Estimated demand for lucerne seed used in organic farming in the EU member states and Switzerland in the years from 2014 to 2018 (t).

The organic vegetable production area in the EU increased by 90% between 2015 and 2019 and 8.6% between 2018 and 2019. In 2019, more than 180,000 hectares in the EU were used for organic vegetables (covering 8.7% of the total vegetable area). While Italy, France, and Spain exhibited the largest areas, high organic shares of all vegetables were reported in Luxembourg (50%), Iceland (44.8%), and Denmark (33.5%) [27]. Various vegetable crops (e.g., carrots, onion, tomato, brassicas) are grown organically from seeds or transplants.

According to our results, among all organic vegetable crops cultivated in the EU, carrots represent a share of the land area of approximately 4.6% in 2018. Approximately 50% of the total organic carrot land area is cultivated in central EU regions. Figure 5 illustrates the estimate of organic carrot seed demand in the EU between 2014 and 2018. In 2018, the total organic seed demand in volume was estimated to be approximately 14.9 t, with a minimum of 11.2 t and a maximum of 18.7 t, across the EU member states and Switzerland.

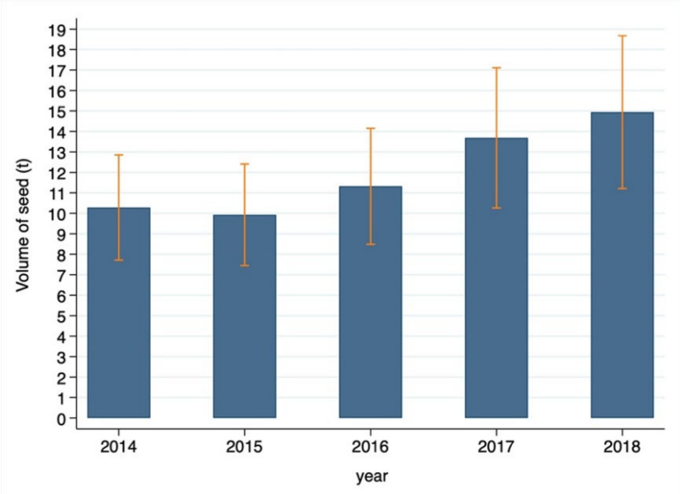


Figure 5. Estimated demand for carrot seed used in organic farming in the EU member states and Switzerland in the years from 2014 to 2018 (t).

Permanent cropland in the EU increased by 29% between 2015 and 2019 and 7.5% between 2018 and 2019 [27]. Olives, grapes, nuts, and temperate fruits represent the largest share of permanent-crops land area. The largest producers are Italy and France, while Latvia has the highest percentage of organic area (33%) [28]. The estimated demand for plants needed for an organic apple, which is among the most important temperate fruits, is shown in Figure 6. In 2018, the total demand in terms of the number of plants required by organic farmers in the EU member states and Switzerland was estimated to be approximately 5.1 million plants, with a minimum of 3.3 million plants and a maximum of 6.9 million plants.

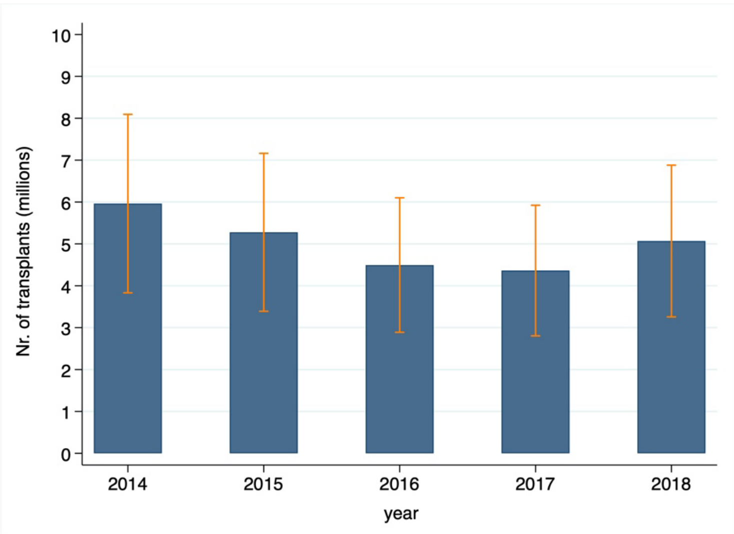


Figure 6. Estimated demand for apple plants used in organic farming in the EU member states and Switzerland in the years from 2014 to 2018 (million plants).

3.2. Organic Seed Supply Estimates

Our research has shown apparent differences concerning the use of purchased seeds in organic farming between the different regions of Europe and crops. The Kruskal–Wallis rank test was performed to test whether the untreated conventional seed and the certified organic seed purchased by the surveyed farmers differ based on EU geographical regions and production orientation. The test showed statistically significant differences in untreated conventional seed use among the four EU geographical regions (p = 0.000) and production orientation (p = 0.001). On average, farms located in southern and eastern EU regions showed the highest use of untreated seed granted through derogation, with the top value in eastern EU regions (48.5%), followed by southern (38.1%), northern (33.0%) and, lastly, the central region (18.6%) (Figure 7). Sector differences were also observed, with the highest use of untreated seed associated with the farms grouped into the fruit PO (41.9%), followed by forages (35.6%), arable (29.8), and vegetables (24.6%) (Figure 7).

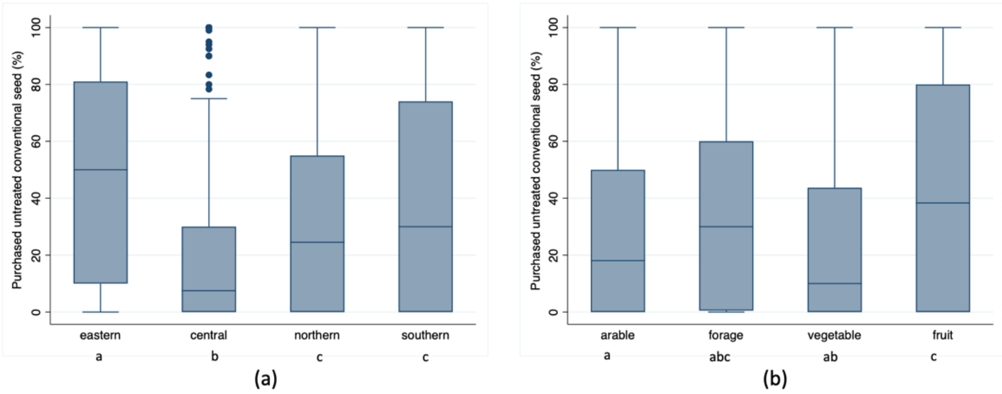


Figure 7. Percentage of untreated conventional seed purchased for organic farming by EU region (**a**) and farm production orientation—PO (**b**). According to the Kruskal–Wallis test with a 95% confidence level, groups with the same letter are not significantly different.

As for the purchased certified organic seed, the parametric test confirms the statistically significant differences among the four EU geographical regions (p = 0.000) and production orientation (p = 0.001). On average, farms located in southern and eastern EU regions demonstrated the lowest use of purchased certified organic seed (42.7% and 34.7%, respectively), followed by northern (55.4%) and central EU (71.1%) (Figure 8). Sector differences were also observed, with the highest use of purchased certified organic seed associated with the farms grouped into the vegetable PO (62.4%), followed by forages (56.6%), arable (53.1), and fruit (45.7%) (Figure 8).

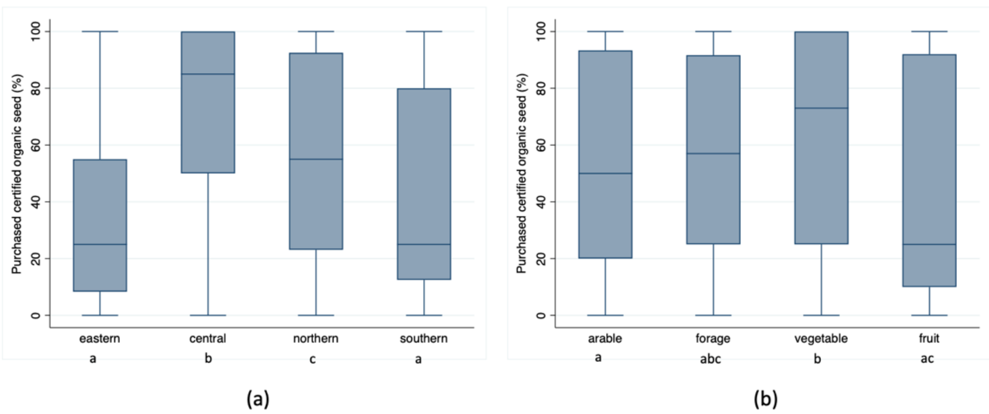


Figure 8. Percentage of purchased certified organic seed by EU region (**a**) and farm production orientation—PO (**b**). According to the Kruskal–Wallis test with a 95% confidence level, groups with the same letter are not significantly different.

The overall picture of the current use of seed in organic farming presented in Figures 7 and 8 clearly shows that the demand for organic seed vastly exceeds the supply, particularly in the southern and eastern European regions. Furthermore, the expert interviews performed to validate the data for the 12 strategic crops included in this research indicate even stronger sector and regional differences (Appendix D). When analysing these data, it is essential to note that each crop differs from the others in terms of technical challenges concerning organic seed use, national rules for granting derogations, availability of organic seed in the market for locally adapted varieties, and local policy measures. Combining the data on the current use of seed with the estimated demand for organic seed for selected crops and countries (see Section 3.1), it was possible to gain a first seed supply estimate in organic farming by crop and geographical area. The figures below show the estimated supply of seeds used in organic agriculture between 2014 and 2018 for the selected crops by EU regions. These figures are only part of the estimates conducted in this study, which are fully available in Appendix E.

Figure 9 illustrates the estimates of organic wheat seed use in the EU organic farming by region. Central Europe is in first place with around 67% organic seed supply; northern Europe follows right after with 55%. Southern and eastern Europe represent lower organic wheat seed supply with 31% and 13%, respectively. In addition to the certified seed market, our results showed that the use of farm-saved seed has an essential role in organic cereal production (especially in eastern and southern Europe). In the example of wheat, seed production and exchange among the farmers and cooperatives is quite common, especially for local and traditional varieties [29]. In Europe, small–medium-sized organic seed producers are mainly active in the arable sector. Organic seeds can be sold either through retailers or directly to farmers. Vertical solid supply chain integration is established with breeders and seed traders. It was reported that the supply of organic arable crop seed is concentrated mainly in central Europe, particularly France, Germany, Austria, and the Netherlands, and Italy in southern Europe [29].

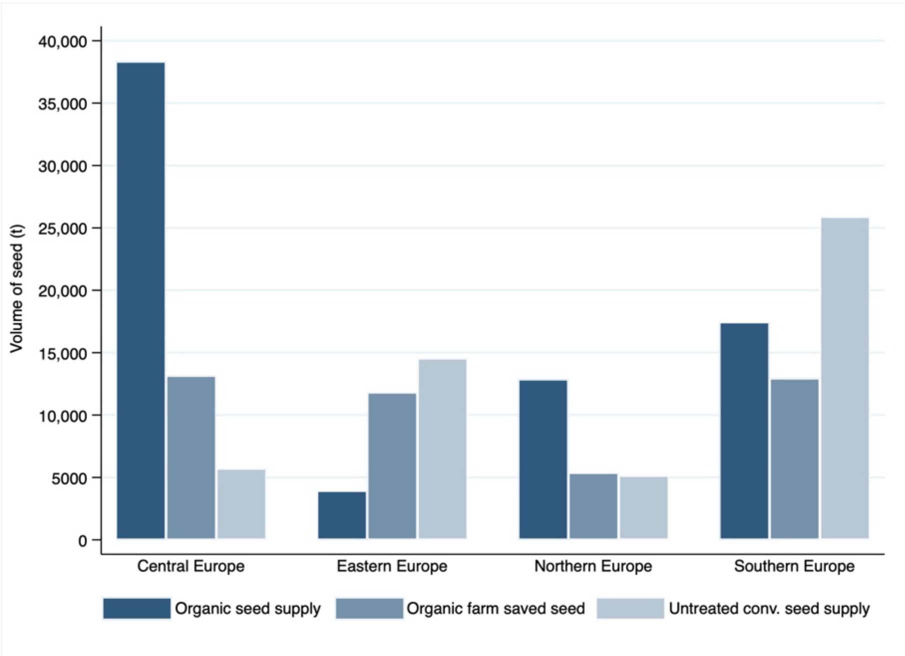


Figure 9. The estimated amount of wheat seed used in organic farming in the EU member states and Switzerland in 2018 by EU regions (t).

The organic forage market is relatively new and small compared to the organic cereal and vegetable markets, resulting in the limited availability of organic forage seeds for a broader range of varieties. In contrast to other sectors, supply chain interaction mainly occurs between seed companies and farmers. Breeding and seed multiplication are mainly carried out by separate companies. Organic forage seed production is concentrated in a few central northern European countries. Exceptionally, lucerne is largely multiplied as organic in Italy and France [29]. Figure 10 illustrates the estimates of lucerne seed use in the EU organic farming by region. Central and southern Europe have higher organic seed supply shares (74% and 55%, respectively) than eastern and northern Europe, where non-organic untreated seed supply is higher (93% and 91%, respectively).

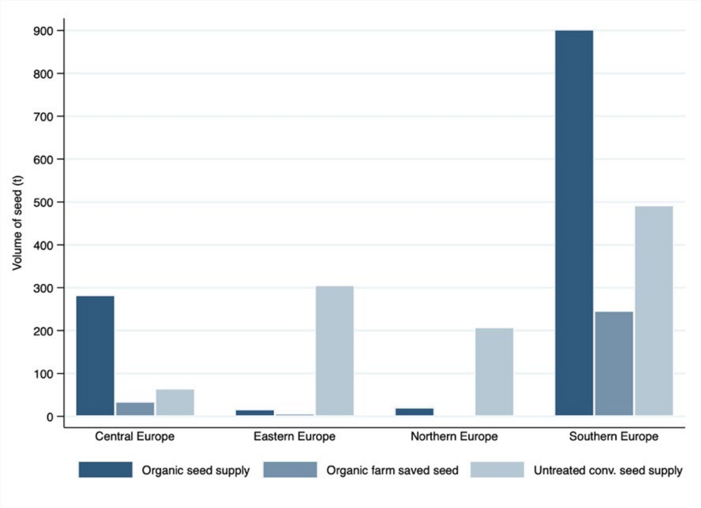


Figure 10. The estimated amount of lucerne seed used in organic farming in the EU member states and Switzerland in 2018 by EU regions (t).

Like arable crops, vertical integration among breeding and seed multiplication characterises the organic vegetable seed sector. In addition, horizontal integration has also developed in the last years due to mergers of vegetable seed companies [30]. Organic seed supply for vegetables is concentrated mainly in central Europe, and initiatives in southern and eastern Europe are scarce. Regarding organic carrot seed production, several medium or large-sized companies produce seeds from their breeding activities. Most organic vegetable seed production takes place in western and northern Europe and is exported from here to other EU countries [29,31]. Figure 11 shows the estimated amount of carrot seed used in organic farming in the EU by region. Accordingly, non-organic untreated seed use is relatively high in all EU regions. The highest shares are in eastern (91%) and southern Europe (88%), followed by central (74%) and northern Europe (68%).

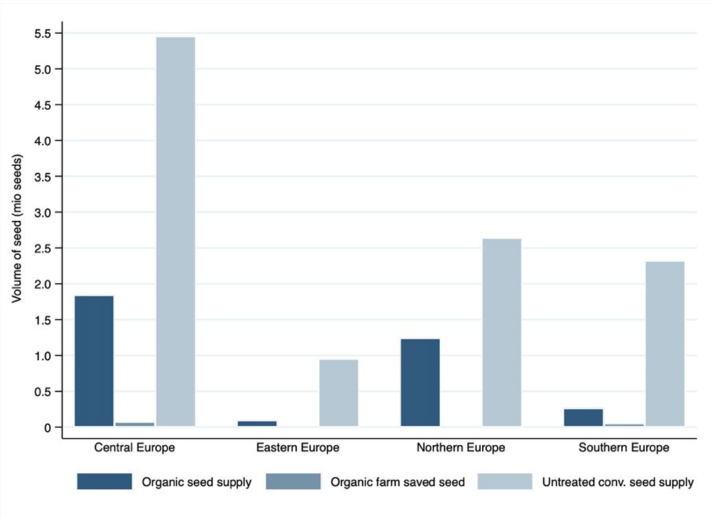


Figure 11. The estimated amount of carrot seed used in organic farming in the EU member states and Switzerland in 2018 by EU regions (t).

Figure 12 shows the estimated amount of apple plants used in organic farming in the EU by region. The highest share of organic plants supply is in central Europe with approximately 59%, followed by northern and eastern Europe with 46%. Lower organic seed supplies were found in eastern (23%) and southern Europe (19%).

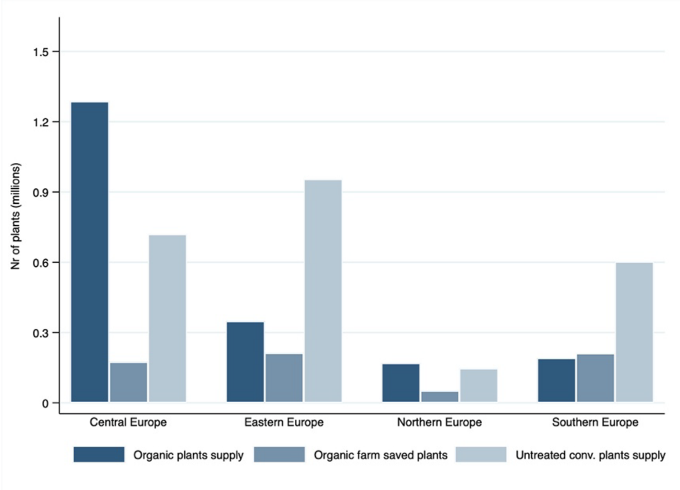


Figure 12. The estimated amount of apple plants used in organic farming in the EU member states and Switzerland in 2018 by EU regions (millions of plants).

3.3. Policy Recommendations

Our findings indicate that the organic seed demand and supply are inconsistent across EU geographical regions and crops. Generally, farms in the central and northern regions revealed a higher organic seed supply than those in the southern and eastern regions. At the same time, substantial differences were found in the availability of organic seeds between arable, vegetable, and fruit crops.

The high use of derogations for untreated conventional seeds indicates that the current European organic seed sector is not ready yet to deliver 100% organic seed to all EU organic farmers. However, the current European Organic Regulation 2018/848 has already established the phasing out of the derogations for using untreated conventional seeds by 2036. Furthermore, the Farm to Fork and Biodiversity strategies have set ambitious objectives for transitioning to more sustainable farming and food systems, with the specific target of 25% of European agricultural land farmed organically by 2030.

In terms of policy actions, to help the transition towards 100% organic seed use, specific measures should be taken to support both the demand and the supply side. Specific factors that could influence the EU organic seed market are discussed below.

Cultivars for organic farming. The use of varieties that are adapted to organic production is crucial to achieving success in organic agriculture. Pest, disease, and weed tolerance, and efficient use of nutrients, are among the critical requirements for the traits to be cultivated under organic production [32]. However, organic breeding programmes are minimal and almost 95% of all organic produce comes from conventionally bred varieties [33]. Organic farmers confirmed that the lack of a wide range of organic varieties limits the use of organic seeds [2]. In addition, how the available cultivars perform under organic conditions is crucial for the farmer's choice [8]. Official cultivar testing is carried out mainly under conventional conditions, and information from on-farm trials under organic conditions is missing. Therefore, in addition to more developments in organic breeding initiatives, variety testing under organic conditions needs to be increased to collect better information and share it with farmers [34]. Lastly, more investments should be enhanced by the EU member states in capacity building that allows organic farmers and their associations to increase the production and quality of their farm-saved seed, as well as the participatory/collaborative on-farm breeding initiatives for the production of populations and cultivars arising from heritage varieties. These initiatives are of great importance for the organic sector at two levels. First, according to the results of our analysis, they can significantly contribute to reducing the shortage of supply. Secondly, they can enhance the farmers' role in conserving agro-biodiversity and developing new genetic diversity and varieties, contributing to agro-eco resilience and local food security [35].

Investments for organic seed breeding and multiplication. Insufficient organic breeding programmes due to the low return on investment and high costs in organic seed production caused by technical difficulties are among the main challenges of the organic seed sector. Insufficient investment in these fields was underlined in previous studies as one of the critical causes of the low availability of organic seeds [3,36]. Organic plant breeding activities are mainly carried out in central Europe, followed by southern Europe. Only a few activities are reported in northern and eastern Europe [36]. Research projects and donations are described as principal funding for organic breeding activities. Despite their importance, it was emphasised that they do not guarantee long-term funds. Royalties and seed sales are used less, and revenues obtained through them seem insufficient to work on more varieties and crop species [37]. Indeed, most seed companies consider the return on investments in dedicated organic breeding programmes relatively low, mainly because the organic market size is minimal compared to the conventional market [29]. Therefore, more efforts in organic plant breeding are needed via public funding and public–private partnerships, including a contribution of supply chain actors. In addition, research to reduce the costs of organic seed production and overcome technical difficulties in organic seed multiplication should be supported. Private labelling of the foods produced from organically bred varieties can also help differentiate them and set a premium price that can allow sharing of the additional costs along the whole chain [34].

Current derogation regimes. According to the existing organic regulations, derogations for the use of non-organic seeds are allowed only if the variety that the farmer has planned to grow is not available in the database or existent alternatives of the same species on the database are proven to be not appropriate for his production. The high use of derogations is perceived as a limiting factor for the growth of the organic seed sector in Europe. In many cases, derogations can create a competitive disadvantage for the seed companies investing in organic seed breeding and multiplication [29,38]. The situation could be even worse in the countries where general derogations are implemented. Organic regulations allow competent authorities to give a general derogation if no organic seed is available on the database for a particular crop. Although the administrative burden and costs are reduced by this rule when no organic seeds are available, the drawback is that providing a broad exemption does not encourage the production of organic seeds for that crop [39]. Furthermore, data from derogation requests on specific varieties are considered a valuable input for breeders and multipliers to make appropriate investment decisions. However, a previous study by the LIVESEED project revealed that no data are available for the use of non-organic seeds in case general derogation is granted by the competent authority of the EU member state [4].

Organic seed databases. The results from the functionality of the organic seed database analysis [40] and a recent survey conducted among organic farmers in the EU and Switzerland [41] confirm the general expectation that organic seed use is higher in the countries where there is a well-functioning organic seed database with a well-developed seed sector. Derogations for the use of conventional seed need to be granted considering organic seed availability in the organic seed database and provide the basis to seed companies on which crops they will invest. Currently, the actual situation of available organic seeds in the European market is not reflected in the organic seed databases, since many of them are not listed in the national databases. To provide a substantiated basis for derogations and to improve the use of organic seeds, databases should be available online and kept updated [40]. In addition, easy access to all 27 EU member state's databases by seed suppliers can support market transparency. To this end, the new EU-wide Router database (www.seeds4organic.eu/rdb accessed on 29 June 2022), developed within the LIVESEED project, gives seed suppliers one login access to all national EU member state databases [42].

3.4. Limitations of the Study

In the current study, different advanced statistical methodologies were used to overcome the insufficient availability of official statistics on organic seed data, and to incorporate information deriving from different sources (existing secondary data such as Eurostat and the FiBL organic database; primary data collected through various surveys and expert assessments). However, as with any estimation method, it is affected by some limitations. First, the performance of any estimation method is conditioned by the availability and quality of the data used in the models. The high share of missing organic land area data used to estimate the potential demand for organic seeds required the use of multiple imputation (MI) techniques to fill data gaps. Despite the statistical robustness of the method, it should be clearly stated that MI, like any other imputation method, is not a substitute for good data. Improving the quantity and quality of data on the organic land area in the EU is of paramount importance for estimating the demand and supply of organic seeds and improving market transparency.

The second limitation refers to the data sources used for the study. Though the sample size (n = 700) of the organic farmers' survey was significant, exploring official data from other important players such as organic seed certification bodies operating at the country level could provide more reliable data on organic seed use. Additionally, the amount of certified organic seed could be obtained more reliably if the European Seed Certification Agencies Association (ESCAA), collecting data on certified seeds at the member state level, would differentiate between certified organic and certified non-organic seeds. Currently, organic seed production data are available only for Germany and Austria. However, changing long-established data collection procedures is not easy or quick to implement, especially if the organic seed market is still considered a niche. Concerning the amount of seed granted through derogation, the derogation reports have proven to be not fully reliable in many cases. A better way to collect information on the quantity of organic seeds used by farmers is by the organic inspection system. If possible, the information should include both purchased and farm-saved organic seeds. However, this is not very likely to happen in the short run; establishing new data requirements will cause a relatively high additional burden to the organic inspection bodies.

4. Conclusions

In this study, we have provided overall statistics on organic seed supply and demand in the EU. To the best of our knowledge, this is the first study that has considered different strategic crops from all crop sectors in the entire EU. General findings revealed a considerable lack of organic seed supply in the European market, with significant availability differences among crop groups and EU regions. Farms in the central and northern areas revealed a higher organic seed supply than those in the southern and eastern regions. The organic seed supply is higher for wheat than the other investigated crops. The new European organic regulation [1], which came into force in 2022, brings several challenges to the EU seed sector and organic farmers. Apart from the decision to phase out the derogation by 2036, it strongly recognises the need to develop specific breeding programmes to overcome the lack of suitable varieties for organic farming. Additionally, the European Commission's Farm to Fork Strategy aims that 25% of the total EU's farmland should be managed organically by 2030. Therefore, a considerable increase in the use of untreated non-organic seeds is expected in the following years if the organic seed supply will not meet the demand. A set of actions should be implemented to help the transition towards 100% organic seed use, which cannot be discussed here. However, any policy or supply-chain strategy needs to hinge upon improved information on organic seed demand and supply. Good-quality data availability is key to overcoming the current situation of the organic seed market, where supply is significantly less than demand. This study is the first attempt in this direction. It suggests that dialogue among stakeholders is critical in initiating new methodologies and approaches to obtain accurate, complete, and reliable data on the organic seed market. The establishment of a permanent forum or network between associations such as the European Consortium of Organic Plant Breeding (ECO-PB), the European Seed Association (ESA), the European Seed Certification Agencies Association (ESCAA), and the member states' national competent authorities entitled to collecting and publishing data on organic farming, could support further development of organic seed market data estimates and publication.

Lastly, our methodology and results may serve as a starting point to predict seeds' potential supply and demand from now until 2036, when derogations are supposed to end. This goes beyond the scope of the current paper.

Author Contributions: This study was based on the collective effort of the authors. Conceptualisation, R.Z. and F.S. (Francesco Solfanelli). methodology, F.S. (Francesco Solfanelli), R.Z. and S.O.; validation, M.M., E.C.D., S.M. and F.S. (Freya Schaefer); formal analysis, F.S. (Freya Schaefer) and S.O.; investigation, F.S. (Francesco Solfanelli), S.O. and E.O.; data curation, E.O., F.S. (Francesco Solfanelli) and E.W.; writing—original draft preparation, F.S. (Francesco Solfanelli), S.O. and E.O.; writing—review and editing, R.Z., E.C.D. and S.N.; supervision, R.Z. and M.M.; funding acquisition, R.Z. and M.M. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: Ethical review and approval were waived for this study givent at the time of the study our University had not established an IRB. However, the informed consent and privacy form were approved by the university legal department and Data Protection Manager.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data are available upon request from Authors.

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Appendix A

Table A1. Standard regression diagnostics of the MI models for arable crops, prior to and after imputation.

Prior Imputation					
				Number of obs =	358
				F(2, 355) =	121.49
				Prob > F =	0.0000
				R-squared =	0.4063
				Adj R-Squared	0.4030
				Root MSE =	0.01923
UAA_ORG_C	Coef.	Std. Err.	P > |t|	95% Conf. Interval	
UAA_ORG_P	0.1950395	0.0159052	0.000	0.1637592	0.2263198
UAA_TOT_P	0.0607453	0.0081214	0.000	0.0447732	0.0767174
_Cons	−0.0116558	0.001734	0.000	−0.0150661	−0.0082456
After imputation					
				Number of obs =	509
				F(2, 355) =	170.97
				Prob > F =	0.0000
				R-squared =	0.4033
				Adj R-Squared	0.4009
				Root MSE =	0.01635
UAA_ORG_C	Coef.	Std. Err.	P > |t|	95% Conf. Interval	
UAA_ORG_P	0.1907407	0.0127517	0.000	0.165688	0.2157935
UAA_TOT_P	0.496524	0.005633	0.000	0.0385854	0.0607193
_Cons	−0.0100614	0.00126	0.000	−0.0125368	−0.007586

Table A2. Standard regression diagnostics of the MI models for vegetable crops, prior to and after imputation.

Prior Imputation					
				Number of obs =	883
				F(2, 355) =	356.23
				Prob > F =	0.0000
				R-squared =	0.4474
				Adj R-Squared	0.4461
				Root MSE =	0.00383
UAA_ORG_C	Coef.	Std. Err.	P > ∣t∣	95% Conf. Interval	
UAA_ORG_P	0.0599712	0.0029138	0.000	0.0542523	0.0656901
UAA_TOT_P	0.0213542	0.0012333	0.000	0.0189337	0.0237747
_Cons	−0.0021253	0.0002351	0.000	−0.0016638	−0.0016638
After imputation					
				Number of obs =	967
				F(2, 355) =	405.24
				Prob > F =	0.0000
				R-squared =	0.4567
				Adj R-Squared	0.4556
				Root MSE =	0.00367
UAA_ORG_C	Coef.	Std. Err.	P > ∣t∣	95% Conf. Interval	
UAA_ORG_P	0.0589114	0.0027234	0.000	0.0535669	0.0642558
UAA_TOT_P	0.0213145	0.001156	0.000	0.0190459	0.0235832
_Cons	−0.0020385	0.0002127	0.000	−0.0024558	−0.0016211

Appendix B

Table A3. Crop seeding/planting rate by crop: average, minimum, and maximum values by EU geographical region.

Crop	EU Geographical Area	Crop Seeding Rate (Average)	Crop Seeding Rate (min)	Crop Seeding Rate (max)
		Arable crops		
Barley (metric tons)	central	140.00	140.00	175.00
	eastern	239.00	210.00	27200
	northern	166.88	135.00	210.00
	southern	166.88	135.00	210.00
Grain maize (kg/ha)	central	25.00	14.50	35.00
	eastern	25.00	14.50	35.00
	northern	41.25	30.00	60.00
	southern	41.25	30.00	60.00
Lucerne (kg/ha)	central	14.33	11.33	17.00
	eastern	20.00	15.00	25.00
	northern	28.50	20.00	40.00
	southern	35.00	25.00	40.00
Lupine (kg/ha)	central	150.00	95.00	210.00
	eastern	150.00	95.00	210.00
	northern	150.00	95.00	210.00
	southern	150.00	95.00	210.00

Table A3. *Cont.*

Crop	EU Geographical Area	Crop Seeding Rate (Average)	Crop Seeding Rate (min)	Crop Seeding Rate (max)
Oats (kg/ha)	central	143.00	110.00	174.00
	eastern	196.00	110.00	259.00
	northern	170.00	110.00	247.00
	southern	170.00	110.00	247.00
Soybean (kg/ha)	central	135.00	120.00	150.00
	eastern	135.00	120.00	150.00
	northern	135.00	120.00	150.00
	southern	135.00	120.00	150.00
Wheat (kg/ha)	central	203.32	150.00	250.00
	eastern	225.00	145.00	275.00
	northern	203.32	173.33	238.33
	southern	210.00	173.33	238.33
Fruits and berries				
Apples (nr. of plants/ha)	central	1965.00	750.00	3550.00
	eastern	1965.00	750.00	3550.00
	northern	1965.00	750.00	3550.00
	southern	1965.00	750.00	3550.00
Strawberries (nr. of plants/ha)	central	30,000.00	28,000.00	40,000.00
	eastern	62,500.00	50,000.00	75,000.00
	northern	62,500.00	50,000.00	75,000.00
	southern	62,500.00	50,000.00	75,000.00
Vegetables				
Carrots (kg/ha)	central	1.60	1.20	2.00
	eastern	1.60	1.20	2.00
	northern	1.60	1.20	2.00
	southern	1.60	1.20	2.00
Onions (nr. of plants/ha)	central	0.95	0.80	1.15
	eastern	0.95	0.80	1.15
	northern	0.95	0.80	1.15
	southern	0.95	0.80	1.15
Tomatoes (nr. of plants/ha)	central	26,400.00	12,000.00	36,250.00
	eastern	33,000.00	23,000.00	43,000.00
	northern	20,000.00	12,500.00	35,000.00
	southern	33,000.00	23,000.00	43,000.00

Appendix C

Table A4. The estimated demand of seed and reproductive material used in organic farming in EU member states and Switzerland in the years from 2014 to 2018.

Crop	Year	Potential Demand (Average)	Potential Demand (min)	Potential Demand (max)
Arable crops				
Barley (metric tons)	2014	39,887	34,178	49,408
	2015	43,493	37,378	54,005
	2016	45,179	38,801	56,173
	2017	47,608	40,804	59,204
	2018	55,116	47,437	68,558
Grain maize (metric tons)	2014	2572	1587	3637
	2015	2675	1652	3782
	2016	2686	1682	3806
	2017	3379	2122	4791
	2018	4405	2741	6236
Lucerne (metric tons)	2014	1486	1082	1738
	2015	1609	1173	1889
	2016	1945	1421	2278
	2017	2086	1522	2435
	2018	2580	1881	3061
Lupine (metric tons)	2014	3021	1913	4230
	2015	3757	2379	5260
	2016	3101	1964	4342
	2017	3960	2508	5544
	2018	4263	2700	5968
Peas (metric tons)	2014	43,647	28,644	61,562
	2015	47,075	30,948	66,430
	2016	55,950	36,562	79,115
	2017	61,936	40,585	87,383
	2018	65,989	43,194	93,148
Soybean (metric tons)	2014	6247	5553	6941
	2015	9097	8086	10,107
	2016	9867	8770	10,963
	2017	10,716	9525	11,907
	2018	12,761	11,343	14,179
Wheat (metric tons)	2014	111,025	85,187	131,952
	2015	128,907	99,224	153,155
	2016	153,511	118,584	181,947
	2017	148,737	115,042	176,212
	2018	167,270	128,197	198,776
Fruits and berries				
Apples (nr. of transplants)	2014	5,962,793	2,275,875	10,772,475
	2015	5,276,811	2,014,050	9,533,170
	2016	4,494,643	1,715,513	8,120,093
	2017	4.363.577	1.665.488	7.883.308
	2018	5,067,833	1,934,288	9,155,628

Table A4. *Cont.*

Crop	Year	Potential Demand (Average)	Potential Demand (min)	Potential Demand (max)
Strawberries (nr. of transplants)	2014	158,790,000	130,204,000	193,720,000
	2015	161,850,004	132,360,000	197,100,000
	2016	178,552,500	146,774,000	218,195,000
	2017	182,947,500	149,526,000	222,705,001
	2018	190,237,504	155,930,000	232,025,000
		Vegetables		
Carrots (metric tons)	2014	10,284	7713	12,855
	2015	9929	7446	12,411
	2016	11,321	8491	14,152
	2017	13,688	10,266	17,110
	2018	14,943	11,207	18,679
Onions (mio of seeds)	2014	3245	2733	3929
	2015	3612	3041	4372
	2016	4272	3598	5172
	2017	5010	4219	6065
	2018	5497	4629	6654
Tomatoes (nr. of transplants)	2014	153,519,902	105,391,314	200,932,014
	2015	167,705,870	115,091,796	219,452,993
	2016	226,028,070	155,053,590	295,806,588
	2017	370,763,919	255,608,035	484,485,994
	2018	410,774,645	283,025,243	536,735,700

Appendix D

Table A5. Percentage of seed used in organic farming by type of seeds and crop (data validated through expert interviews).

Crop	EU Geographical Area	Organic Seed (%)	Organic Farm Saved Seed (%)	Untreated Conv. Seed (%)
		Arable crops		
Barley	central	67	19	14
	eastern	12	69	19
	northern	62	20	18
	southern	37	26	37
Grain maize	central	71	10	19
	eastern	45	0	55
	northern	33	0	67
	southern	30	5	65
Lucerne	central	74	9	17
	eastern	5	2	93
	northern	9	0	91
	southern	55	15	30
Lupine	central	39	38	23
	eastern	5	40	55
	northern	100	0	0
	southern	5	5	90

Table A5. *Cont.*

Crop	EU Geographical Area	Organic Seed (%)	Organic Farm Saved Seed (%)	Untreated Conv. Seed (%)
Oats	central	65	23	12
	eastern	14	38	48
	northern	46	38	16
	southern	41	32	27
Soybean	central	64	24	12
	eastern	19	12	69
	northern	19	12	69
	southern	21	21	58
Wheat	central	67	23	10
	eastern	13	39	48
	northern	55	23	22
	southern	31	23	46
		Fruits and berries		
Apples	central	59	8	33
	eastern	23	14	63
	northern	46	14	40
	southern	19	21	60
Strawberries	central	83	7	10
	eastern	5	1	94
	northern	14	0	86
	southern	32	13	55
		Vegetables		
Carrots	central	25	1	74
	eastern	9	0	91
	northern	32	0	68
	southern	10	2	88
Onions	central	76	5	19
	eastern	15	9	76
	northern	52	4	44
	southern	23	7	70
Tomatoes	central	49	2	49
	eastern	26	9	65
	northern	59	12	29
	southern	20	10	70

Appendix E

Table A6. Estimated demand and supply of seed and reproductive material used in organic farming in 2018 by EU regions.

Crop	EU Geographical Area	Organic Seed Supply	Organic Farm Saved Seed	Untreated Conventional Seed Supply
		Arable crops		
Barley (metric tons)	central	8,586,264.43	2,434,910.85	1,794,144.84
	eastern	691,044.59	3,973,506.38	1,094,153.92
	northern	10,066,381.86	3,247,219.84	2,922,497.90
	southern	7,513,164.63	5,279,521.24	7,513,164.63

Table A6. *Cont.*

Crop	EU Geographical Area	Organic Seed Supply	Organic Farm Saved Seed	Untreated Conventional Seed Supply
Grain maize (metric tons)	central	1,526,517.69	215,002.48	408,504.72
	eastern	443,925.00	-	542,575.00
	northern	4192.65	-	8512.35
	southern	376,608.37	62,768.06	815,984.80
Lucerne (metric tons)	central	282,733.73	34,386.54	64,952.34
	eastern	16,462.53	6585.01	306,203.01
	northern	20,560.08	-	207,885.22
	southern	902,389.94	246,106.34	492,212.69
Lupine (metric tons)	central	621,954.45	606,006.90	366,793.65
	eastern	82,635.83	661,086.61	908,994.12
	northern	277,080.36	-	-
	southern	36,897.89	36,897.89	664,162.00
Oats (metric tons)	central	5,765,223.73	2,040,002.29	1,064,348.97
	eastern	1,241,385.58	3,369,475.01	4,256,179.10
	northern	15,283,526.10	12,625,521.70	5,316,009.07
	southern	6,161,050.19	4,808,624.53	4,057,277.03
Soybean (metric tons)	central	5,042,736.03	1,891,026.08	945,513.04
	eastern	521,849.25	329,589.00	1,895,136.75
	northern	49,248.00	31,104.00	178,847.98
	southern	394,036.64	394,036.64	1,088,291.72
Wheat (metric tons)	central	38,340,967.56	13,161,824.92	5,722,532.46
	eastern	3,941,876.28	11,825,628.88	14,554,620.13
	northern	12,877,311.84	5,385,057.58	5,150,924.55
	southern	17,455,718.43	12,951,016.37	25,902,032.74
Fruits and berries				
Apples (nr. of transplants)	central	1,286,704.58	174,468.42	719,682.24
	eastern	348,453.46	212,102.11	954,459.45
	northern	169,074.49	51,457.46	147,021.30
	southern	190,837.85	210,926.05	602,645.85
Strawberries (nr. of transplants)	central	23,281,500.00	1,963,500.00	2,805,000.00
	eastern	4,853,125.25	970,625.06	91,238,756.03
	northern	4,068,749.97	-	24,993,749.75
	southern	11,540,000.02	4,688,125.01	19,834,375.03
Vegetables				
Carrots (mio of seeds)	central	1843.13	73.73	5455.65
	eastern	94.30	-	953.46
	northern	1242.39	-	2640.08
	southern	264.02	52.80	2323.34
Onions (mio of seeds)	central	2113.67	139.06	528.42
	eastern	104.28	62.57	528.33
	northern	381.19	29.32	322.55
	southern	296.08	90.11	901.12
Tomatoes (nr. of transplants)	central	6,430,350.63	262,463.29	6,430,350.63
	eastern	18,451,070.68	6,386,909.05	46,127,675.74
	northern	744,868.39	151,498.65	366,121.75
	southern	65,084,666.83	32,542,333.42	227,796,326.66

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