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Agriculture and Pollinating Insects, No Longer a Choice but a Need: EU Agriculture's Dependence on Pollinators in the 2007–2019 Period

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Citation: Bugin, G.; Lenzi, L.; Ranzani, G.; Barisan, L.; Porrini, C.; Zanella, A.; Bolzonella, C. Agriculture and Pollinating Insects, No Longer a Choice but a Need: EU Agriculture's Dependence on Pollinators in the 2007–2019 Period. *Sustainability* **2022**, *14*, 3644. https://doi.org/10.3390/su14063644

Academic Editors: José Carlos Franco, Arturo Cocco, Stefano Speranza, António Onofre Costa Miranda Soares and Lucia Zappala

Received: 14 February 2022
Accepted: 17 March 2022
Published: 20 March 2022

Abstract: One of the new objectives laid out by the European Union's Common Agriculture Policy is increasing environmental sustainability. In this paper we compare the degree of average dependence index for each member state (ADIMS) in EU28 from 2007 to 2019 in order to verify the following: (1) whether there was a difference in this index when comparing two CAP periods—(a) from 2007 to 2013 and (b) from 2014 to 2019—and (2) which crops had a larger effect on the ADIMS. The study showed no significant variation in the average ADIMS at EU level between the first (2007–2013) and second (2014–2019) CAP periods. The AIDMS index highlighted three types of EU agriculture: (1) agriculture in Eastern Europe, including Bulgaria, Hungary, Romania and Slovakia, characterized by a high level of ADIMS (10.7–22) due to the widespread cultivation of oil crops as rapeseed and sunflower; (2) Mediterranean agriculture including Portugal, Spain, Italy, Croatia, Greece, Malta, Cyprus and France with lower AIDMS levels (5.3–10.3) given their heterogeneous crop portfolios with different degrees of dependence on animal pollination (almond, soy, rapeseed, sunflower and tomatoes) and (3) continental agriculture including Germany, Austria, Slovenia, Poland, the Czech Republic, Baltic countries, Benelux, Finland, Sweden and Ireland, which are characterized by the lowest ADIMS level (0.7–10.6) due to the widespread cultivation of cereals (anemophily and self-pollination) which increase the denominator of the index. The study suggests that a sustainable management of the agroecosystem will be possible in the future only if CAP considers pollinators' requirements by quantifying the timing and spatial food availability from cultivated and uncultivated areas.

Keywords: pollination; Common Agriculture Policy; crop dependence; harvested area; principal component analysis

1. Introduction

Approximately 70% of 1330 tropical crops [1] and 85% of 264 crops cultivated in Europe [2] benefit from animal pollination. Furthermore, pollinators can increase the production of ≈75% of the 115 most important crops worldwide, as measured by food production [3,4] and economic value [5]. In temperate regions, pollinators are generally insects, mainly hymenopterans (especially bees) but also dipterans (especially hoverflies) [6]. With 20,000 species all over the world, bees represent the most significant pollinators in terms of abundance and importance both for wild plants and crop species in most ecosystems, with honeybees and bumblebees playing an important role in Europe and North America [4,7].

According to Potts et al. [8], bees visit more than 90% of cultivated plants, while 30 percent of crops may be visited by flies. Bees are considered excellent pollinators because they are the only group that rely almost completely on floral resources both as adults and larvae, while syrphids only visit flowers in their adult stage [9,10]. The floral resources on which they forage are nectar and pollen, which represent their source of sugar and proteins, respectively. Moreover, pollen is an essential resource for offspring development and its nutritive value can vary between plant species; for this reason, it is fundamental for bees to have different pollen sources [7]. Food preferences vary between bee species, and this specialization is called lecty; oligolectic species forage on few plants, while polylectic species, such as honeybees and bumblebees, have a broader diet. In light of this, it becomes of primary importance to have a diversified landscape both inside and around cultivated fields, since many studies have highlighted the positive correlation between enhanced floral resources and a higher density and/or diversity of pollinators [11–13]. Managed pollinators, namely the western honeybee (*Apis mellifera*) and bumblebees (*Bombus* spp.), contribute to crop pollination but some studies have underlined the importance of wild bees for an improved seed set and fruit quality [14–16], especially for species that require cross pollination such as apples. There is clear evidence that both honeybees and wild bees are threatened by climate change and intensive agriculture, mainly based on monocultural plantings and the use of pesticides that impact both the landscape and pollinator communities, thus reducing the ecosystem services provided by this class of organisms. Some studies have underlined the relation between agricultural intensification, especially soybean, corn and wheat monoculture, and decrease in functional diversity, wild bee abundance and species richness [17,18] with special concern for ground nesting species and oligolectic species. Pesticides affect bees in different ways by shortening their life span but also through alterations of their immune system and development [19], thus contributing to the overall decline of bee populations. Moreover, honeybee colonies are facing a phenomenon called Colony Collapse Disorder (hereafter CCD), which has been occurring since 2006/2007 in North America and Europe and consists of a sudden decline in the number of worker bees that leads to depopulation of the entire colony. The CCD is attributable to different factors which include pesticides (especially neonicotinoids), microorganisms and mites such as *Varroa destructor* but also degradation of natural habitats due to anthropic activities [19]. The CCD phenomenon has highlighted that the reliance on a single pollinating species, *Apis mellifera*, puts our food supply at risk [4,8]. Therefore, it is necessary to restore and preserve an adequate environment for bees through new approaches to agricultural and landscape management. Less intensive farming, such as organic farming, but also the use of IPM have shown a positive effect on pollinator diversity and abundance, though with lower effects at the local scale. The use of more expensive and lower-impact pesticides is another solution proposed by Bolzonella et al. [20]. In fact, several studies [13,21–23] have demonstrated that landscape composition has a pivotal role in the support of bee populations, whereby a higher landscape heterogeneity provides more floral resources alongside nesting habitats, since around 70% of bees nest in the ground. The growing concern for the decline of pollinators has led to a legal protection represented by different strategies adopted by the European Union, such as the EU Pollinators Initiative adopted in June 2018 which outlines three main objectives: (1) improving the knowledge of pollinator decline, (2) tackling the causes of pollinator decline and (3) raising public awareness on pollinators. In addition, the new European Green Deal aims to significantly reduce the use of pesticides by 2030 ("From Farm to Fork") and to support the pollination process by inverting pollinator decline ("Biodiversity") [19]. Regarding pesticide exposure, Regulation (EC) No. 1107/2009 [24] which regulates the market placement of Plant Protection Products foresees that new products must not be harmful to bees and such claims must be supported by an adequate risk assessment. Other initiatives, such as the EU project Life4Pollinators, are implemented with the aim of sensitizing the public and policy makers to conservation actions for bees, such as urban gardens and landscape management. The EU28 utilized agricultural area (UAA) covers 38.16% (161,548,000 ha) of the total surface

(423,326,200 ha) [25]. Populations of pollinating insects are strongly affected by the type of agriculture (intensive degree) and by the type of crops. Certain agricultural practices are among the leading causes of the alarming decline of pollinators in Europe [26]. In the present paper, we analyze the dynamic of the crop surface in the European Member States (MS) during the 2007–2019 period with the aim of quantifying the dynamics of the average dependence index per member state (ADIMS) over time in the European agricultural sector. The paper is structured as follows. First, we describe the data used in the analysis and the methodology is introduced. The data used for the ADIMS calculation are 2007–2019 crops' harvested areas collected by the FAO database and the pollination dependency index (PDI) for each crop obtained from bibliographic sources [4]. Second, the major findings from data analysis are presented in Section 3. Different types of agriculture are classified according to the ADIMS degree and the crops per MS with a larger effect on the ADIMS. Finally, the concluding discussion of the study is reported in Section 4 (Figure 1).

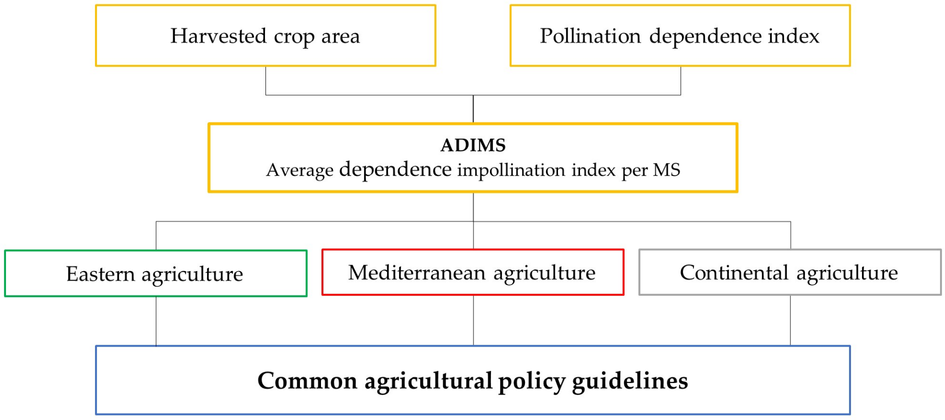

Figure 1. Research workflow diagram.

2. Materials and Methods

2.1. Data Collection

The analysis quantifies the evolution of the Average Dependence Index per MS (ADIMS) per hectare of crops in the EU. For this purpose, we considered the individual harvested crop area as reported in FAO dataset [27] from 2007 to 2019 for each EU28 Member State (MS). The Primary Crops Area harvested refers to the area from which a crop is gathered. Primary Crops are those which come directly from the land and without having undergone any real processing, apart from cleaning. They maintain all the biological qualities they had when they were still on the plants [27]. Primary Crops include fiber crops, cereals, coarse grain, fruits, jute and jute-like fibers, oilcakes and their equivalents, oil crops, pulses, roots and tubers, tree nuts and vegetables. The FAO dataset recorded 173 primary crops in the world and 119 in EU28. The usable agricultural area (UAA) describes the area used for farming. The term does not include unused agricultural land, woodland and land occupied by buildings, farmyards, tracks, ponds, etc. The UAA of each country for the period 2009–2019 was evaluated summing the harvested surface area of each crop per year. During this period, two programming periods of the Community Agricultural Policy (CAP) took place. These plans influenced the range of crops practiced in the EU through crop diversification obligations, establishment of ecological areas of interest (EFA), maintenance of permanent meadows and pastures and implementation of agri-environment-climate measures (AECM). The Common Agricultural Policy (CAP), in addition to pursuing the fundamental objectives for which it was established (Article 39 Treaty of Rome, 1957) [28], such as increasing agricultural productivity, ensuring a fair standard of living for the agricultural population, stabilizing markets, guaranteeing security of supply and ensuring reasonable prices for consumers, tries to respond to the growing demand for environmental sustainability by the EU population. The CAP guides farmers' choices and its role in the future will be decisive [29]. However, the needs of pollinators have rarely been explicitly considered in the CAP design and planning, so rural development programs of EU MS have not used the full range of possible CAP measures to support pollinator conservation [26]. In particular, it has been limited to advice on how to preserve biodiversity in general and in relation to honeybees, but without mention of wild pollinators, and it does not consider the abundance, diversity and continuity of floral resources at the landscape level [26]. In order to assess the degree of agriculture's dependence on pollinators, we considered only the cultivated areas of primary crops as reported in the FAO dataset. As can be seen from the crop pollination dependency index (PDI) [4], some crops only offer integration in the feeding of pollinators, as their blooming period is concentrated in specific time and area. The index of dependence on the pollination service (PDI) for each known crop was developed by the FAO [30]. It provides a measure of the decrease in the total volume of production that a crop undergoes in the event of a lack of pollination by pollinators. Following Klein et al. [4], we classified crops on the basis of their level of pollinator dependence, defined as the percentage of yield reduction resulting from an absence of pollinators. The dependence categories were: none (0% yield reduction), little (<10% yield reduction), modest (10 to 40% yield reduction), great (40 to 90% yield reduction) and essential (≥90% yield reduction). The levels of pollinator dependence contained between 5 ("essential") and 56 ("none") crops, representing respectively 253,815.23 ha and 71.2 million ha each year in EU.

Table 1 shows in column 5 the harvested crops' average areas (2007–2019) in EU28 and the incidence (column 6) on the total average cultivated area (UAA). The average annual area of the 119 crops in the FAO database is equal to 89,029,995 ha, where grass and pasture are not considered.

Table 1. List of the 119 crops grown in 28 MS (Member States) during the 2007–2019 period.

Crops	Pollination Dependency Index (PDI)	Dependence Categories	Number of MS Growing the Crop	Average Harvested Crop Surface (ha) during 2007–2019 Period	Percentage of Average Harvested Crop Surface on Total Average Cultivated Area
Almonds, with shell	0.65	Great	10	692,707.31	0.78
Anise, badian, fennel, coriander	0	None	9	46,508.77	0.05
Apples	0.65	Great	28	537,018.92	0.6
Apricots	0.65	Great	17	72,230.46	0.08
Artichokes	0	None	10	70,564.38	0.08
Asparagus	0	None	22	55,164.62	0.06
Avocados	0.65	Great	4	11,859.38	0.01
Bananas	0	None	6	11,714.31	0.01
Barley	0	None	28	12,683,738.31	14.25
Beans, dry	0.25	Modest	20	103,491.62	0.12
Beans, green	0.25	Modest	25	81,384.69	0.09
Berries nes	0.25	Modest	25	29,413.77	0.03
Blueberries	0.65	Great	20	13,881.54	0.02
Broad beans, horse beans, dry	0.25	Modest	28	356,149.92	0.4
Buckwheat	0.65	Great	10	135,112.31	0.15
Cabbages and other brassicas	0	None	28	170,425.46	0.19
Canary seed	0	None	3	4134.77	0.00
Carobs	0.25	Modest	6	23,166.92	0.03
Carrots and turnips	0	None	28	132,518.46	0.15
Cauliflowers and broccoli	0	None	28	134,352.31	0.15
Cereals nes	0	None	22	165,041.31	0.19
Cherries	0.65	Great	24	124,098.15	0.14
Cherries, sour	0.65	Great	20	57,584.23	0.06
Chestnut	0.25	Modest	11	106,673.77	0.12
Chickpeas	0.25	Modest	9	45,552.92	0.05
Chicory roots	0	None	7	11,905.85	0.01
Chilies and peppers, dry	0.05	Little	7	46,139.77	0.05
Chilies and peppers, green	0.05	Little	20	65,570.23	0.07
Coconuts	0.25	Modest	1	391.77	0.00
Cow peas, dry	0.05	Little	3	744.85	0.00
Cranberries	0.65	Great	3	407.85	0.00
Cucumbers and gherkins	0.65	Great	28	53,695.46	0.06
Currants	0.25	Modest	24	61,671.15	0.07
Dates	0.05	Little	1	579.15	0.00

Table 1. *Cont.*

Crops	Pollination Dependency Index (PDI)	Dependence Categories	Number of MS Growing the Crop	Average Harvested Crop Surface (ha) during 2007–2019 Period	Percentage of Average Harvested Crop Surface on Total Average Cultivated Area
Eggplants (aubergines)	0.25	Modest	16	27,057.38	0.03
Figs	0.25	Modest	10	25,690.00	0.03
Flax fiber and tow	0.05	Little	14	103,699.38	0.12
Fruit, citrus nes	0.25	Modest	5	3928.15	0.00
Fruit, fresh nes	0	None	17	58,991.00	0.07
Fruit, pome nes	0	None	9	1096.92	0.00
Fruit, stone nes	0	None	15	9056.38	0.01
Fruit, tropical fresh nes	0	None	5	11,909.46	0.01
Garlic	0	None	22	41,830.77	0.05
Gooseberries	0.25	Modest	14	14,491.62	0.02
Grain, mixed	0	None	18	1,274,740.54	1.43
Grapefruit (inc. pomelos)	0.05	Little	7	3194.85	0.00
Grapes	0	None	22	3,271,681.85	3.67
Groundnuts, with shell	0.05	Little	5	1297.00	0
Hazelnuts, with shell	0	None	14	97,647.38	0.11
Hemp tow waste	0	None	17	9036.54	0.01
Hempseed	0	None	5	11,167.46	0.01
Hops	0	None	16	28,971.00	0.03
Kiwi fruit	0.95	Essential	8	38,619.31	0.04
Leeks, other alliaceous vegetables	0	None	27	29,020.85	0.03
Lemons and limes	0.05	Little	8	77,678.69	0.09
Lentils	0.25	Modest	9	45,072.85	0.05
Lettuce and chicory	0	None	27	128,202.38	0.14
Linseed	0.05	Little	22	81,223.85	0.09
Lupins	0.25	Modest	15	129,540.00	0.15
Maize	0	None	21	8,950,883.38	10.05
Maize, green	0	None	9	87,724.77	0.1
Melons, other (inc. cantaloupes)	0.95	Essential	15	80,747.62	0.09
Melonseed	0.95	Essential	1	1934.38	0.00
Millet	0	None	11	38,041.69	0.04
Mushrooms and truffles	0	None	14	1770.62	0.00
Mustard seed	0	None	10	44,028.15	0.05
Nuts nes	0	None	8	19,515.46	0.02
Oats	0	None	27	2,707,016.23	3.04
Oilseeds nes	0	None	22	113,660.46	0.13
Okra	0.25	Modest	1	67.08	0.00
Olives	0	None	9	4,875,850.00	5.48
Onions, dry	0	None	28	184,529.54	0.21
Onions, shallots, green	0	None	10	10,893.00	0.01
Oranges	0.25	Modest	8	293,831.77	0.33
Peaches and nectarines	0.65	Great	17	233,352.15	0.26
Pears	0.65	Great	26	125,002.00	0.14
Peas, dry	0.05	Little	26	689,649.92	0.77
Peas, green	0.05	Little	28	170,534.77	0.19
Peppermint	0	None	2	86.69	0.00
Persimmons	0.05	Little	3	10,899.38	0.01
Pineapples	0	None	1	50.92	0.00
Pistachios	0.25	Modest	4	12,416.62	0.01
Plums and sloes	0.65	Great	25	166,822.00	0.19
Poppy seed	0.25	Modest	11	67,203.69	0.08
Potatoes	0	None	28	1,874,528.46	2.11
Pulses nes	0.05	Little	24	342,637.31	0.38
Pumpkins, squash and gourds	0.95	Essential	25	52,097.38	0.06
Quinces	0.65	Great	13	4184.62	0.00
Rapeseed	0.25	Modest	25	6,539,190.54	7.34
Raspberries	0.65	Great	24	37,560.31	0.04
Rice, paddy	0	None	8	441,226.77	0.5
Roots and tubers nes	0	None	4	7510.00	0.01
Rye	0	None	26	2,291,657.38	2.57
Safflower seed	0.65	Great	2	3383.69	0.00
Seed cotton	0.25	Modest	3	286,910.38	0.32
Sesame seed	0.25	Modest	3	370	0.00
Sorghum	0	None	11	130,301.15	0.15
Soybeans	0.25	Modest	16	607,399.92	0.68
Spices nes	0	None	3	4296.77	0.00
Spinach	0	None	23	33,733.46	0.04
Strawberries	0.25	Modest	28	106,316.15	0.12
String beans	0.25	Modest	2	30,162.23	0.03
Sugar beet	0	None	24	1,632,742.38	1.83
Sugar cane	0	None	3	11,626.08	0.01
Sunflower seed	0.65	Great	17	4,090,919.92	4.59
Sweet potatoes	0	None	4	2970.92	0.00
Tangerines, mandarins, clementines, satsumas	0.05	Little	8	170,650.46	0.19
Taro (cocoyam)	0	None	1	67.38	0.00
Tea	0	None	1	20.23	0.00
Tobacco, unmanufactured	0	None	15	98,268.15	0.11
Tomatoes	0.65	Great	28	277,620.15	0.31

Table 1. *Cont.*

Crops	Pollination Dependency Index (PDI)	Dependence Categories	Number of MS Growing the Crop	Average Harvested Crop Surface (ha) during 2007–2019 Period	Percentage of Average Harvested Crop Surface on Total Average Cultivated Area
Triticale	0	None	25	2,733,456.08	3.07
Vegetables, fresh nes	0	None	28	306,573.54	0.34
Vegetables, leguminous nes	0	None	17	30,451.46	0.03
Vetches	0.25	Modest	14	88,068.85	0.1
Walnuts, with shell	0	None	18	78,468.85	0.09
Watermelons	0.95	Essential	14	80,416.54	0.09
Wheat	0	None	28	26,117,138.00	29.34
Yams	0	None	1	117.15	0.00

The average annual area of the 119 crops in the FAO database is equal to 89,029,995 ha, where grass and pasture are not considered. Pollinated crops have limited impact in terms of surface area at EU level. The most cultivated is rapeseed, with more than 6.5 million hectares equal to 7.34% of the EU cultivated area, thus being the fourth largest crop after wheat (29.34%), barley (14.25%) and corn (10.05%) in terms of surface. It is followed by sunflower with 4 million hectares (4.59%). Other crops have an incidence lower than 1% as almonds (0.78%), soybeans (0.68%), apples (0.60%), tomatoes (0.31%), peaches (0.26%) and plums (0.19%).

In order to quantify the average dependence index for each member state (ADIMS) on entomophilic pollination, the crop areas were multiplied by their respective dependency indices (PDI). The indicator thus obtained for each crop was added up for each state in each year and then divided by the total crop area of the MS (UAA). The index was multiplied by 100 in order to obtain a whole number (1).

$$\text{ADIMS} = \sum \frac{(\text{crop area } * \text{ pollination dependency index })}{\text{UAA}} \cdot 100 \quad (1)$$

Our study does not consider semi-natural and natural areas for which data relating to the phytosociological composition at country level are not available (grassland, meadows, etc.) nor the surface of the marginal areas of these elements within or near the cultivated areas.

2.2. Statistical Analysis

First, based on the average ADIMS calculated in the period 2007–2019, a one-way ANOVA was carried out to determine whether there are any significant differences in ADIMS when comparing three main types of agriculture in the EU (Eastern European, Mediterranean and continental). Second, a principal component analysis (PCA) was carried out to identify which crops dependent on entomophilic pollination affect the indices of the various MS. The PCA is a statistical procedure that allows an inspection of data structure by transforming a set of possibly correlated measures into a series of uncorrelated linear combinations of the variables, the principal components which represent most of the variance. The first component contains the greatest variance, whereas each subsequent component explains the remaining part of the variance.

3. Results

3.1. Trend of ADIMS for EU28 MS

At the EU level, the dependence indicator ADIMS increased by 1.97% from 7.86 (average index 2012–2014) to 8.01 (average index 2017–2019) but it was not statistically significant. The range varied from 1.1 in Finland 2014 to 22.00 in Bulgaria 2017 (Figure 2). We considered for the first period and second period the middle triennial 2012–2014 and 2017–2019 where the CAP was completely in place.

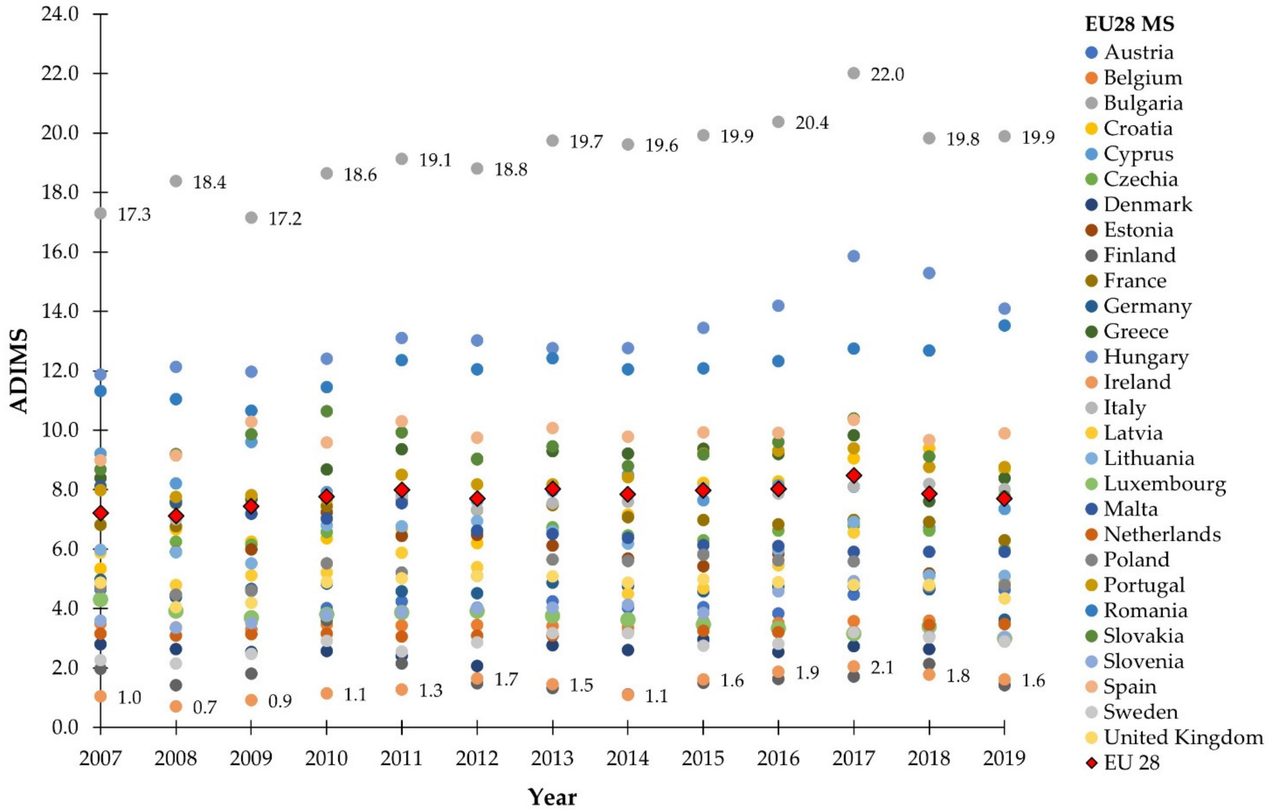

Figure 2. ADIMS distribution by MS per year (2007–2019).

The dependency of agriculture on animal pollination varies among MS according to different climate conditions and crops cultivated. Figure 3 shows the average ADIMS, with darker colors representing higher ADIMS levels.

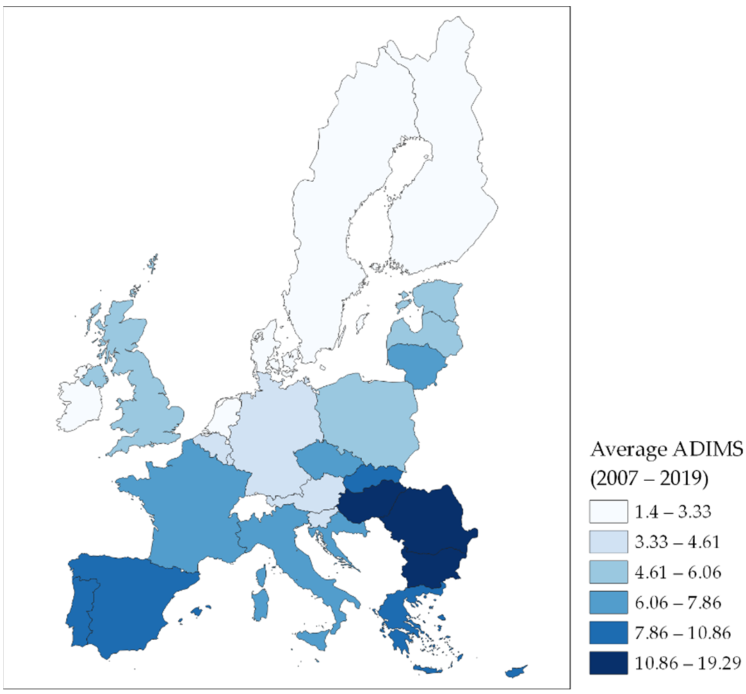

Figure 3. Average ADIMS (2007–2019) distribution by EU28 MS.

Figure 4 classified MS by average ADIMS level obtained by ANOVA one-way analysis with the Tukey test ($p < 0.005$).

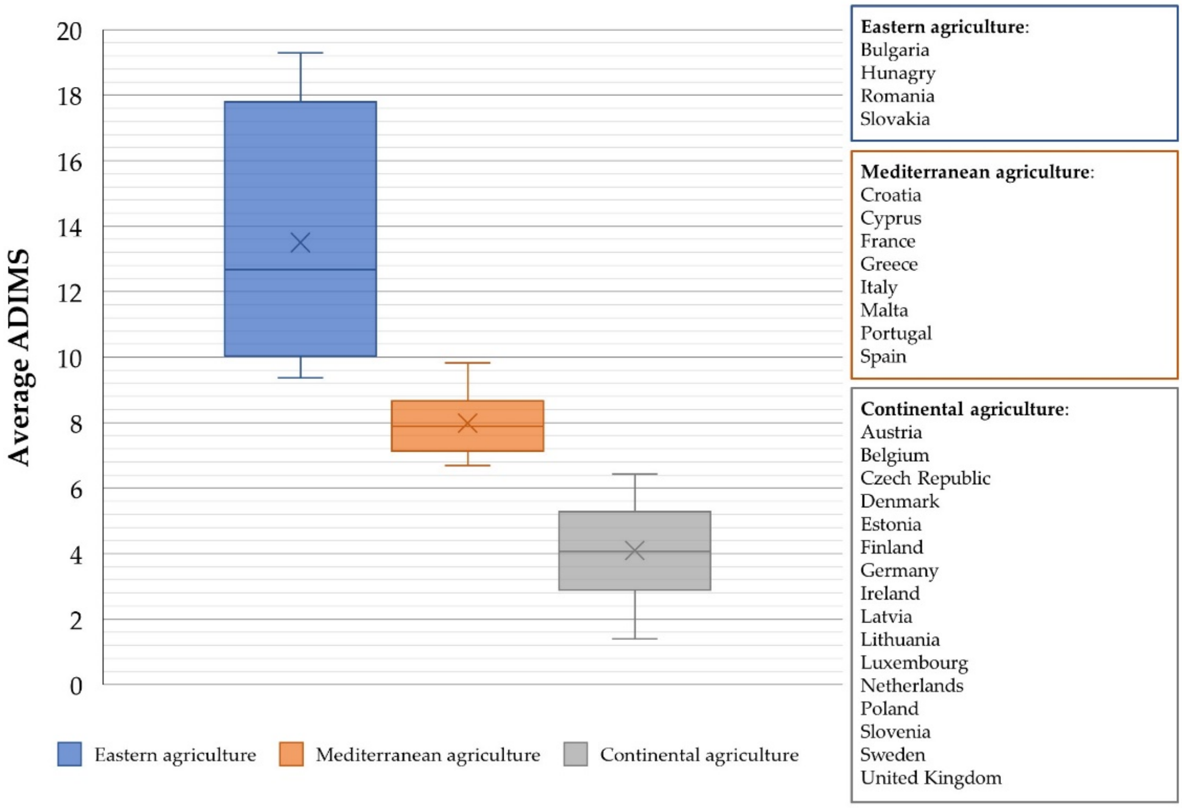

Figure 4. Comparison of average ADIMS (2007–2019) for the three main agriculture groups in the EU ($p < 0.005$).

The first group is composed of Eastern European countries: Bulgaria, Hungary, Romania and Slovakia. These states had the highest indices, ranging from 9.36 in Slovakia to 19.29 in Bulgaria. All these states grow rapeseed, which is an important contribution to their ADIMS values. In Group 2, there are Mediterranean countries including Spain, Portugal, Greece, Italy, Cyprus, Malta, Croatia and France. The ADIMS ranged from 6.69 in Malta to 9.82 in Spain, and the crop portfolio of these countries is more heterogeneous. Group 3 contains continental countries characterized by lower ADIMS, ranging from 1.4 in Ireland to 6.42 in Czech Republic. In this category, the main crops dependent on pollination are soy, as in the case of Slovenia, pears and apples in the case of Benelux and broad beans and horse beans in Northern European countries such as Ireland, Finland, Sweden and Denmark.

3.2. Crop Surface by Pollination Dependence Index (PDI)

Table 2 drives crop surface into categories by pollinator dependence index level (PDI) per year. It appears that there was a reduction in crops that are not dependent on animal pollination (category "none"). In particular, barley had an average variation of −1,459,967 ha, mixed grains an average variation of −542,465 ha and potatoes an average variation of −492,523 ha. Increases in surface area were seen in crops classified as either great (sunflower seeds with + 1,039,784 ha, almonds with shell with + 100,528 ha and raspberry + 9146 ha) or little (peas, dry + 234,929 ha, flax fiber and tow + 34,468 ha and green peas + 27,643 ha).

Table 2. Total crop surface (ha) classified by pollinator dependence index level (PDI) from 2007 to 2019.

Year	None (PDI = 0.0)	Little (PDI ∈]0; 0.10])	Modest (PDI ∈]0.10; 0.40])	Great (PDI ∈]0.40; 0.90])	Essential (PDI ∈]0.90; 1.00])
2007	72,322,852	1,522,140	8,823,634	5,970,830	259,972
2008	75,442,274	1,336,588	8,129,447	6,420,167	255,727
2009	73,704,270	1,513,517	8,622,838	6,557,592	259,852
2010	70,444,215	1,738,031	9,511,739	6,381,924	263,184
2011	70,864,039	1,658,320	9,142,330	6,904,868	254,806
2012	71,578,065	1,506,194	8,528,481	6,793,795	253,858
2013	71,375,722	1,397,555	9,033,752	7,087,081	252,704
2014	71,557,958	1,541,823	9,345,461	6,708,432	241,882
2015	70,728,359	1,908,645	9,728,680	6,665,563	24,886
2016	70,388,748	2,036,658	9,664,397	6,694,428	256,089
2017	69,165,866	2,231,957	10,172,091	6,944,051	244,304
2018	68,882,055	2,353,198	9,388,462	6,417,551	253,760
2019	70,297,718	2,193,869	8,021,667	6,740,444	254,600
Variation (2019–2007)	−2,025,134	671,729	−801,967	769,614	−5372
Var. %	−2.80	+44.13	−9.08	+12.88	−2.06

Figure 5 shows the surface area of cultivated crops classified by their dependence index levels (PDIs) in EU28.

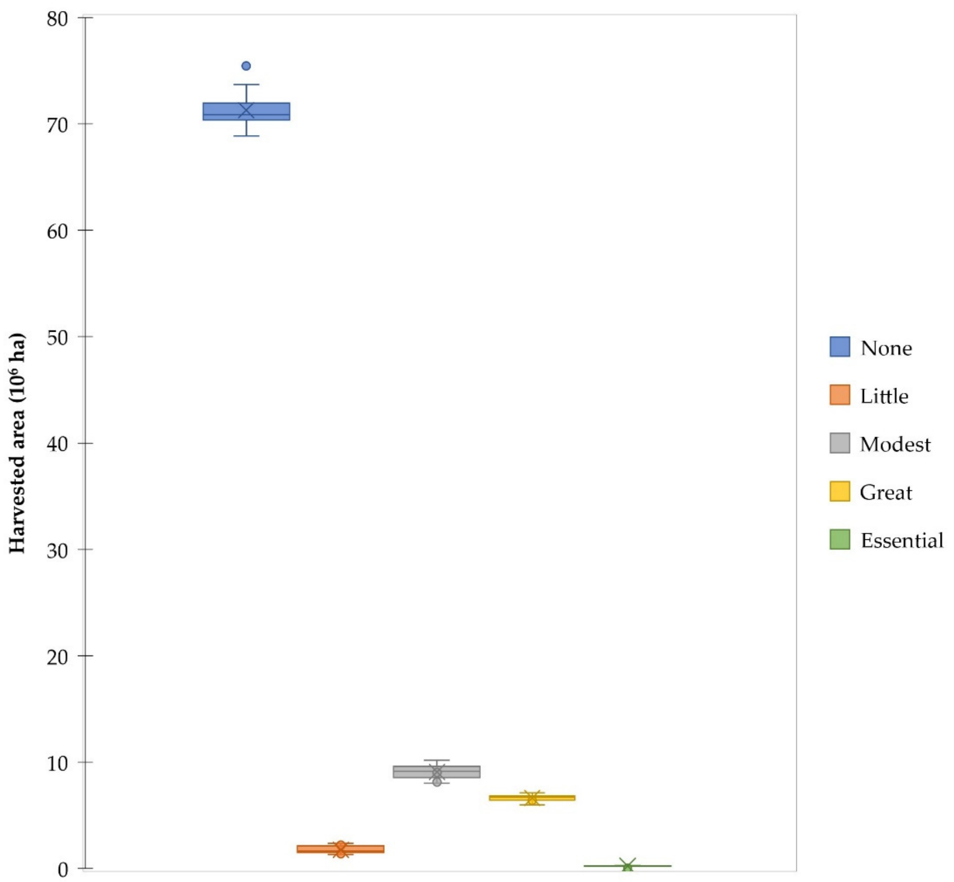

Figure 5. Differences in crop surface (ha) when grouped by pollinator dependence index level (PDI) (2007–2019) in EU28.

European agriculture is characterized by crops that are not dependent on animal pollination such as wheat, corn, barley, grapes, olives, sugar beet, potatoes, rye, etc. Crops classified as none decreased by 3% during the period analyzed (−2,025,134 hectares). Other crops that depend to various degrees on animal pollination are classified into little, modest, great and essential. These crops cover in total a surface of 20% equal to 17,741,369 hectares at the EU28 level.

3.3. Which Crops Influenced ADIMS Variation by MS?

Table 3 shows the ADIMS change between the first and second CAP periods by MS (columns 1 to 4). Column 5 indicates the two crops with the higher surface values multiplied by the PDI for each MS as reported in columns 6 and 7. Column 8 shows the difference between columns 7 and 6.

Table 3. ADIMS variation and surface variation of the first and second most important pollinated crops by MS.

MS	ADIMS (2012–2014)	ADIMS (2017–2019)	Difference	Most Important Pollinated Crops by MS	Crop Surface (ha) × PDI (2012–2014)	Crop Surface (ha) × PDI (2017–2019)	Difference
Austria	4.1	4.6	0.5	Soybeans Rapeseed	10,248.75 13,932.83	16,774.75 9747.67	6526.00 −4185.17
Belgium	3.41	3.55	0.14	Pears Apples	5763.33 4615.00	6613.32 3892.20	849.98 −722.80
Bulgaria	19.39	20.58	1.18	Rapeseed Apples	38,280.50 2900.08	41,203.33 2620.15	2922.83 −279.93
Croatia	6.66	9.04	2.38	Rapeseed Apples	4248.92 3748.55	12,083.83 3145.57	7834.92 −602.98
Cyprus	8.03	7.39	−0.64	Tomatoes Carobs	134.77 373.75	180.05 81.83	45.28 −291.92
Czech Republic	6.59	6.46	−0.12	Soybeans Poppy seed	1624.25 5469.42	3567.83 2715.50	1943.58 −2753.92
Denmark	2.48	2.75	0.27	Broad beans, horse beans, dry Cherries, sour	0.00 728.43	3533.33 283.40	3533.33 −445.03
Estonia	6.09	5.65	−0.44	Broad beans, horse beans, dry Rapeseed	0.00 21,107.08	2345.00 18,239.67	2345.00 −2867.42
Finland	1.31	1.76	0.45	Broad beans, horse beans, dry Rapeseed	0.00 12,758.33	2608.33 11,666.67	2608.33 −1091.67
France	7.29	6.73	−0.56	Soybeans Sunflower seed	13,012.92 456,758.03	38,289.92 377,479.92	25,277.00 −79,278.12
Germany	4.72	4.35	−0.37	Broad beans, horse beans, dry Rapeseed	4400.00 347,166.67	12,575.00 282,500.00	8175.00 −64,666.67
Greece	9.18	8.61	−0.57	Sunflower seed Seed cotton	45,514.30 70,346.50	55,948.97 21,681.83	10,434.67 −48,664.67
Hungary	12.85	15.08	2.23	Rapeseed Poppy seed	48,024.17 1601.67	77,847.08 430.67	29,822.92 −1171.00
Ireland	1.4	1.81	0.41	Broad beans, horse beans, dry Rapeseed	0.00 3383.33	1272.50 2495.83	1272.50 −887.50
Italy	7.49	8.11	0.61	Soybeans Peaches and nectarines	47,500.50 47,951.37	76,861.42 40,854.45	29,360.92 −7096.92
Latvia	5.18	5.5	0.32	Broad beans, horse beans, dry Buckwheat	0.00 5893.33	5416.67 3965.00	5416.67 −1928.33
Lithuania	6.58	5.71	−0.86	Broad beans, horse beans, dry Buckwheat	300.00 22,056.67	10,417.50 10,508.12	10,117.50 −11,548.55
Luxembourg	3.76	3.19	−0.58	Apples Rapeseed	157.30 1103.50	174.85 794.75	17.55 −308.75
Malta	6.5	5.9	−0.6	Tomatoes	204.32	61.10	−143.22

Table 3. *Cont.*

MS	ADIMS (2012–2014)	ADIMS (2017–2019)	Difference	Most Important Pollinated Crops by MS	Crop Surface (ha) × PDI (2012–2014)	Crop Surface (ha) × PDI (2017–2019)	Difference
Netherlands	3.12	3.38	0.26	Pears Apples	5477.55 5135.65	6463.38 4327.48	985.83 −808.17
Poland	5.45	5.04	−0.41	Lupines Buckwheat	16,125.67 44,223.83	26,362.17 16,905.85	10,236.50 −27,317.98
Portugal	8.26	8.97	0.71	Almonds, with shell Sunflower seed	18,317.43 11,195.60	24,544.43 6749.17	6227.00 −4446.43
Romania	12.18	12.98	0.81	Rapeseed Tomatoes	64,815.92 30,725.93	131,904.83 18,804.28	67,088.92 −11,921.65
Slovakia	9.09	9.1	0.01	Rapeseed Sunflower seed	30,747.58 54,349.32	37,606.83 44,351.23	6859.25 −9998.08
Slovenia	4.06	3.67	−0.39	Soybeans Rapeseed	68.50 1402.92	508.17 840.42	439.67 −562.50
Spain	9.87	9.97	0.1	Almonds, with shell Sunflower seed	344,642.57 516,867.00	428,688.43 458,830.45	84,045.87 −58,036.55
Sweden	3.07	3.04	−0.03	Broad beans, horse beans, dry Rapeseed	4401.67 29,340.83	6247.50 26,422.50	1845.83 −2918.33
United Kingdom	5.02	4.64	−0.38	Broad beans, horse beans, dry Rapeseed	20,207.33 178,792.92	40,354.17 139,583.33	20,146.83 −39,209.58
EU28	7.86	8.01	0.16	Soybeans Sunflower seed	123,014.67 2,841,879.30	235,328.33 2,743,078.22	112,313.67 −98,801.08

The ADIMS difference by MS shows an equal distribution between states with high ADIMS (15) and states with reduced ADIMS (13). Croatia (+2.38), Hungary (+2.23), Bulgaria (+1.18) and Romania (+0.81) registered the main ADIMS increase in absolute terms driven by rapeseed. Although at EU level the rapeseed area in the period 2007–2019 decreased by −899,255 ha (−13.73%), it was replaced with barley, corn and sunflower. Rapeseed reduction is linked to climate change and pest pressure—in particular, unfavorable climatic conditions characterized by drier summers and autumns accompanied by insufficient winter and spring rainfall. Flea beetle (*Phyllotreta cruciferae*) attacks in countries most intensely cultivated such as France, Germany and Bulgaria and simultaneous bans of neonicotinoid products discourages the cultivation. ADIMS decreased in Lithuania (−0.86), Cyprus (−0.64) and Malta (−0.60) because of surface reduction in buckwheat, carob and tomatoes.

In order to identify the crop effect on ADIMS by MS in the Figures 6–8, we report the PCA analysis results. The PCA was conducted using as variables the annual harvested crop surface multiplied by per dependence index (PDI) in the period 2007–2019 and MS. The titles of the graphs' axes show the first two crops with the highest eigenvalue for each component. The PCA explained 77% of the cumulative variance.

Spain recorded an increase in the pollination dependence index driven by almonds (component 2). At EU28 level, almonds' surface expanded by 100,528 ha (+14.38%). Among the perennial fruit trees, almond is the only one that increased during the period due to rising demand and genetic improvement. Among nuts, almond is the most used ingredient in Europe in new food products of confectionery, snacks, bakery, bars, dairy and cereal categories [31]. The increasing demand is driven by consumer awareness of the beneficial effects on health. The almond traditional Mediterranean cultivation area is expanding towards areas with a less mild climate thanks to genetic improvement. New self-fertile and late flowering varieties suitable for intensive cultivation are being introduced on the market.

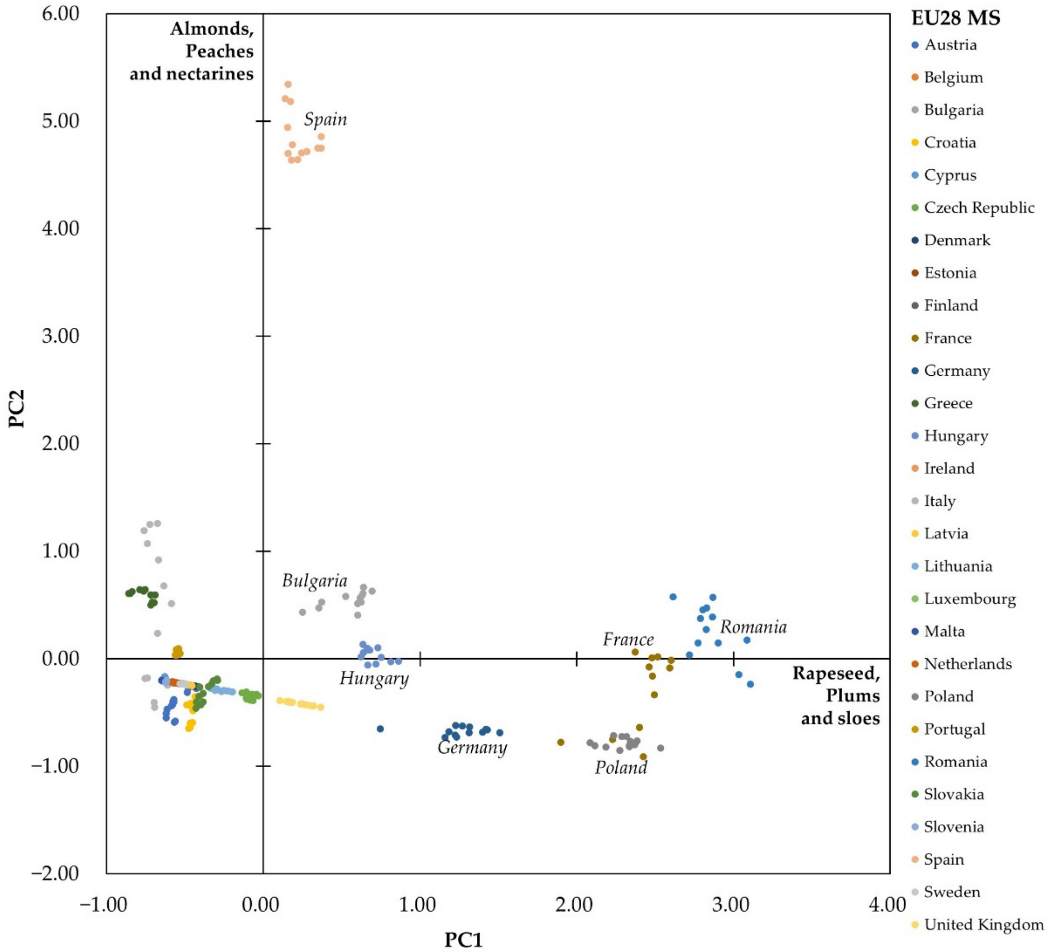

Figure 6. PCA analysis component 1 (Rapeseed, Plums and sloes) vs. component 2 (Almonds, Peaches and nectarines). The PCA was conducted using the annual crop harvested surface from the FAOSTAT database multiplied by the respective dependence index (DPI) in the period 2007–2019 and MS.

Italy is the first EU soybean producer (43% of total EU production) followed by France and Romania. The cultivated area is growing due to the protein demand from the feed industry. Soy cultivation is favored by low production costs and high sales prices, interrupts the single-succession cereal and enriches the land. France, Germany, Poland and Romania stand out for rapeseed cultivation since rapeseed cropping is suitable for colder continental climates [32]. Rapeseed is mainly used in the non-food sectors (biodiesel, tire compound, lubricant, hydraulic oil, etc.) [33].

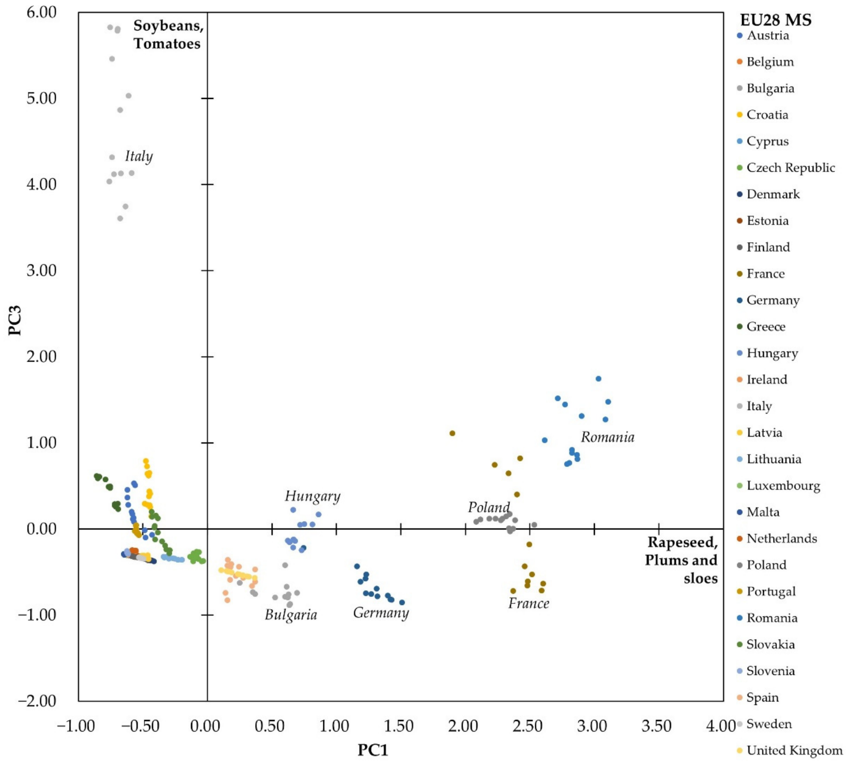

Figure 7. PCA analysis component 1 (Rapeseed, Plums and sloes) vs. component 3 (Soybeans, Tomatoes). The PCA was conducted using the annual crop harvested surface from the FAOSTAT database multiplied by the respective dependence index (DPI) in the period 2007–2019 and MS.

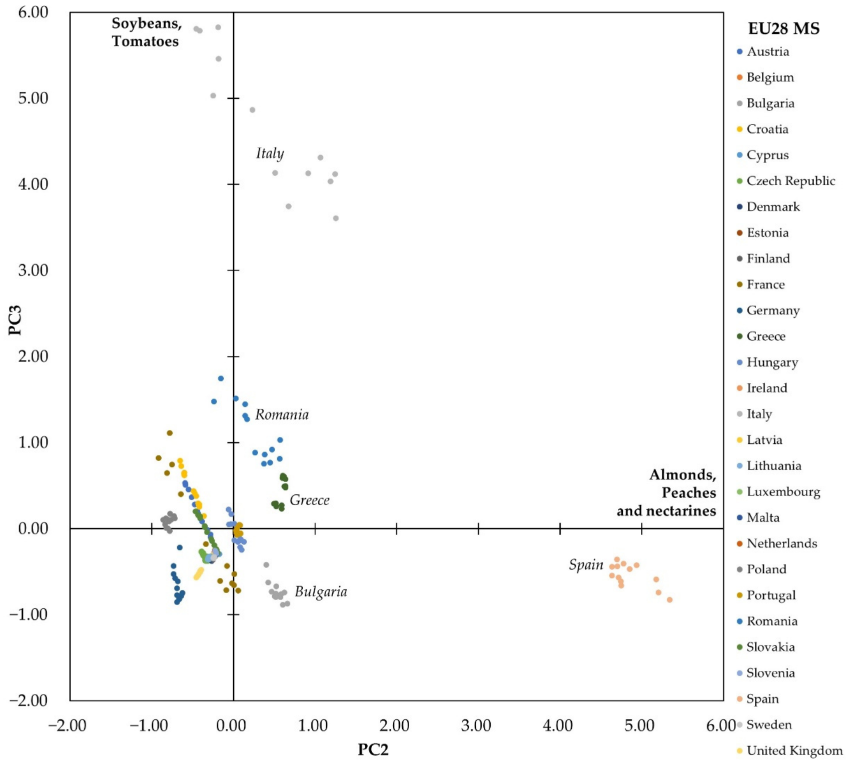

Figure 8. PCA analysis component 2 (Almonds, Peaches and nectarines) vs. component 3 (Soybeans, Tomatoes). The PCA was conducted using the annual crop harvested surface from the FAOSTAT database multiplied by the respective dependence index (DPI) in the period 2007–2019 and MS.

In Belgium, Bulgaria and the Netherlands, the ADIMS decrease is driven by apple tree reduction. Apple tree decreasing trends involved the EU with a loss of 40,705 hectares (−7.28%) but with a stable production due to the intensification process [34].

4. Discussion and Conclusions

The study showed no significant variation between the first (2007–2013) and second (2014–2019) CAP periods in the average ADIMS at the EU level. EU agriculture is dominated by crops not dependent on entomophilic pollination. However, this does not affect the importance of natural pollinators which play a fundamental role in the agroecosystems [35]. The AIDMS index highlighted three types of EU agriculture: agriculture in Eastern Europe (Bulgaria, Hungary, Romania and Slovakia) characterized by a high level of ADIMS (7.8–22) due to the widespread cultivation of oil crops such as rapeseed and sunflower; Mediterranean agriculture (Portugal, Spain, Italy, Croatia, Greece, Malta, Cyprus and France) with lower AIDMS level (5.3–10.3) and more heterogeneous crop portfolios with different degrees of dependence on animal pollination (almond, soy, rapeseed, sunflower and tomatoes); continental agriculture (Germany, Austria, Slovenia, Poland, Czech Republic, Baltic countries, Benelux, Finland, Sweden and Ireland) characterized by the lowest ADIMS level (0.7–4.9) due to the widespread cultivation of cereals (self-pollinating in wheat, rice, barley and oats and anemophilous in rye, corn) which increases the denominator of the index.

Intensification of agricultural systems is leading to a landscape homogenization with a growing gap between agriculture and natural ecosystems—a new landscape characterized by disappearance of ruderal, riparian and semi-natural vegetation [36].

Agriculture, forestry and other land use (AFOLU) activities represent 23% of total net anthropogenic emissions of GHGs during 2007–2016 period. Sustainable land management, including agricultural practices, contributes to climate change adaptation and reduction in land degradation. For instance, cover crops, crop residue retention and reduced or no tillage have important effects in reducing soil erosion, nutrient loss, water surface runoff and biodiversity decline [37].

A need is emerging to rebalance cultivated and non-cultivated areas, increasing natural or semi-natural habitats, in order to allow the conservation of biodiversity, the diversification of landscape and the biological crop pest control [38,39] and to improve the carbon balance in agroecosystems. Such agriculture must certainly be revised through integrated, organic and biodynamic pest management techniques. Managed honeybees are a useful agricultural tool [40] for improving the yield of many mass-flowering crops. However, managed honeybees are not sufficient to replace wild pollinators' ecosystem service and biodiversity [41].

Additionally, many factors that negatively affect managed honeybees (such as pesticides, parasites and diseases) are also harming other native pollinators; honeybees may simply be the "canary in a coalmine" [42]. *Apis mellifera* is the most widely managed species, while more than 20,000 known species are considered wild [43], so a holistic approach is suggested in managing pollinators. Farmers should consider different bee taxa in relation to blooms, flight ranges and seasonal activities in order to integrate managed bees with the availability and abundance of wild pollinators. Farmers' activities should be supported by sustainable agriculture policies, including ecological principles in farming systems and agroecological or organic farming practices providing ecological infrastructures and semi-natural areas [8,44,45].

The CAP has proposed tools for crop diversification (see EFA, crop rotations, etc.) with the purpose of improving sustainable land management and reducing habitat fragmentation and biodiversity-loss-related farming, by obligation under the green direct payment scheme [46] but without proven effects. The result was the favoring of intensification processes that contrast with the needs of wild pollinators that live in a limited area. For these reasons, conservation of natural and semi-natural areas is fundamental for offering continuous food and nesting points. A sustainable management of the agroecosystem will be possible in the future only if CAP considers pollinators' requirements by quantifying the timing and spatial food availability from cultivated and uncultivated areas. However, above all, the pollination ecosystem service should be an integral part of biodiversity conservation, land use and natural resource management and environmental and agricultural policies [47]. The ADIMS fosters this aim, but it is not enough because it does not take into account the natural elements, as it considers only agricultural crops and their dependence on entomophilic pollination. To become a useful CAP programming tool, ADIMS must be integrated with other indexes in order to quantify the crops' intensification degree with special concern for pesticide use and food resources and supplies for pollinators (nectar and pollen) by extra agricultural crops [48]. In addition, calculating ADIMS at the regional scale supports policy maker's decisions about the local scale, integrating indexes to Corine Land Cover data or remote sensing imaging, both for programming and assessing policies tools. Once the integrated ADIMS has been developed, a range of values can be quantified to guarantee the pollinators' wellbeing in a given agroecosystem.

Author Contributions: Conceiving research and designing research framework, C.B., C.P. and A.Z.; analyzing and processing data, G.B., G.R., L.B. and L.L. All authors wrote and reviewed the paper. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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