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Review

A Systematic Review of Field Trials to Synthesize Existing Knowledge and Agronomic Practices on Protein Crops in Europe

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Abstract: Protein crops can represent a sustainable answer to growing demand for high quality, protein-rich food in Europe. To better understand the state of scientific studies on protein crops, a systematic review of field trials results to collect existing knowledge and agronomic practices on protein crops in European countries was conducted using published data from the literature (1985–2017). A total of 42 publications was identified. The following seven protein crops were considered: quinoa, amaranth, pea, faba bean, lupin, chickpea, and lentil. Observations within the studies were related to one or more of eight wide categories of agronomic managements: deficit irrigation (n = 130), salinity (n = 6), tillage (n = 211), fertilizers (n = 146), sowing density (n = 32), sowing date (n = 92), weed control (n = 71), and multiple interventions (n = 129). In 86% of the studies, measures of variability for yield mean values are missing. Through a multiple correspondence analysis (MCA) based on protein crops, European environments, and agronomic management factors, we provide a state of art of studies carried out in Europe on protein crops over the 32-year period; this study will allow us to understand the aspects that can still be developed in the topic. Most investigated studies refer to southern Europe and showed some trends: (i) faba bean, pea, and lupin provide highest seed yields; (ii) sowing date, sowing density, fertilization, and deficit irrigation are the agronomic practices that most influence crop yield; (iii) studies conducted in Central Europe show highest seed yields. The output from this study can be used to guide policies for sustainable crop management.

Keywords: protein crops; systematic review; Europe; multiple correspondence analysis (MCA)

1. Introduction

Meeting the globally growing demand for high quality, protein-rich food, that can satisfy the need of a growing world population while considering environmental sustainability, adapted land-use practices, and food security are special challenges [1]. Europe has a large consumption of animal-based proteins for food, i.e., meat and dairy products whereas most plant protein in the European market is used as feed (for instance more than 95% in the Netherlands; [2]).

The European Union has a 70% deficit in protein-rich grains that is met primarily by imports of GMO soya for feed from USA and South America [3–5]. The deficiency in locally grown protein sources also creates price volatility and trade distortions [6].

Increasing the proportion of vegetable proteins and decreasing those of animal origin in the human diet is a win-win situation from both environmental and nutritional standpoints [6], but also for bio-diversity and sustainability in crop production. However, there are currently few options to encourage this. Vegetable protein sources should have high protein content, high digestibility, low anti-nutritional factor levels, high amount of essential amino acids, and be comparable in price to animal protein sources [7].

Arable land for dry pulses in the Europe, from 2007 to 2017, ranged between 1.7 and 4.2 million hectares. In recent years, this area increased considerably. In that period, an increase of 53.15% of the area harvested at Europe-level was recorded [8]. In 2017, the total harvest of dry pulses in Europe was 9.47 million tons (Figure 1). The production in 2016 was 7.43 million tons with an increase of 17.62% in comparison to 2015. The dry pulse harvested in 2017 was 101.1% higher than the average production of 4.7 million tons registered in 2007–2016. Other high-quality protein crops like quinoa were recently introduced in Europe; the area under quinoa cultivation in Europe increased from 0 in 2008 to 5000 ha in 2015, mainly in France, Spain, and the UK [9].

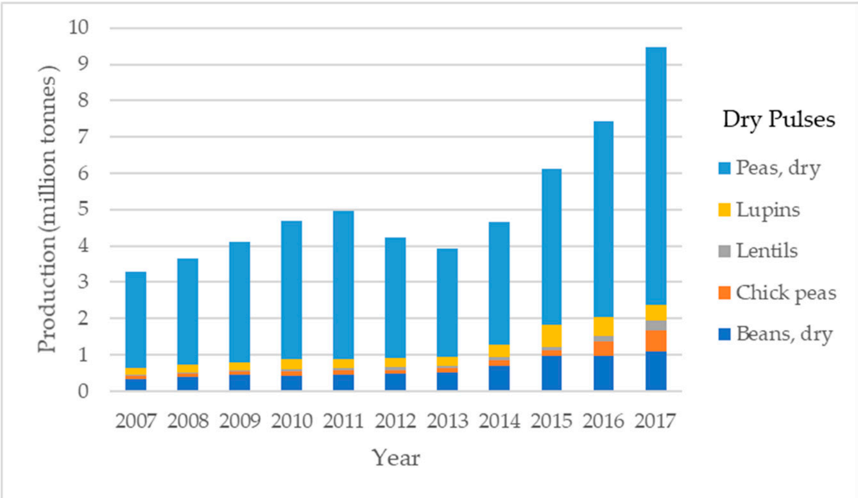

Figure 1. Evolution of harvest production (million tons) of dry pulses by species on Europe.

Producing protein crops as grain legumes is often viewed as risky by European farmers, who tend to prefer cultivating non-legume species such as cereals, oilseeds, and tubers [10,11]. Several authors have in fact hypothesized that a large adoption of legume crops by European farmers is hampered by frequent losses due to high inter-annual yield variability [3,10,12].

The objective of this study was to evaluate, using a systematic review, the agronomic management practices in different European environments on the basis of the literature on protein crops, in order to establish the weight and the significance of the three factors (agronomic management, European environment, and protein crop) for the improvement of production and diffusion of these crops.

A systematic review (SR) of the literature provides a replicable, transparent, and reliable method of identifying, assessing, and summarizing available evidence on a research question, with reduced bias [13,14].

This work is part of a European project called "Development of high-quality food protein from multi-purpose crops through optimized, sustainable production and processing methods" (PROTEIN2FOOD, AMD-635727). This project aims to provide a platform for a diverse production of protein crops throughout various EU-climate zones, supporting reduction of soybean import, and generating novel protein food products by combination of nutritious protein sources, i.e., the quality and quantity of protein from selected high protein quality seed crops (quinoa, amaranth) and legumes with high protein content (lupin, faba beans, pea, chickpea, lentil), to support the reduction of meat consumption. The positive trend will be strengthened by the development of new plant-based protein-rich products of high consumer acceptance, environmental sustainability, and income generation for farmers in European countries.

2. Methods

2.1. Literature Research

A systematic review (SR), across two bibliographic databases (ISI Web of Science™ and Scopus™) and one website search (Google Scholar), was used to identify studies exploring the agronomic practices on protein crops in European countries (we are including Turkey as European country, because it is a (founding) member of the Council of Europe, and a member of the EU Customs Union) and that were written in English, French, Spanish, and Italian (languages the authors felt competent to review) between 1985 and 2017 in peer-reviewed journals. Searches of academic databases were performed on 21 December 2017. In bibliographic databases the following search strings were used to search on 'topic words' combined with Boolean operators: (field OR cultivar* OR genotyp* OR ecotype* OR crop* OR farm* OR cultivar* OR accessions) AND (yield OR grain OR product* OR protein OR seed*OR ((water OR nitrogen) AND use AND efficiency)) AND (europ* OR Mediterranean NOT (Tunisia OR Algeria OR Morocco OR Egypt OR Lebanon OR Libya OR Syria OR Israel OR Palestine)) AND (legum* OR amaranth* OR (peas OR (Pisum AND sativum)) OR (bean OR (Vicia AND faba)) OR (lentil OR (Lens AND culinaris)) OR (lupin* OR (Lupinus AND (albus OR mutabilis))) OR (Chickpea OR (Cicer AND arietinum)) OR (quinoa* OR (Chenopodium and quinoa)). The wildcards * represent any number of characters. Because of the large number of treatments, genotypes, and investigation areas, we used abbreviations for each variable. The complete abbreviations list can be found in the Supplementary Materials (SM) 1.

2.2. Inclusion and Exclusion Criteria

We used a highly robust and rational systematic review methodology to synthesize the evidence from a wide range of sources. In this study, we constrained the SR by defining boundaries to include: (I) only studies that considered food crop production in specific locations in Europe; (II) studies conducted only under field conditions, but not under glasshouse conditions and pots; and (III) studies that focused on crop productivity, omitting forestry, fisheries, livestock, and other non-food crop agricultural sectors. Following SR convention, the search terms were based on the three PIO components (population, interventions, and outcome) (Table 1) and a list of references included in the SR meta-database is provided in SM2.

Table 1. Defining the PIO terms for the research 'question' used in this study

PIO	Description
Population	Agriculture—food crops under field conditions Crops included quinoa, amaranth, pea, faba bean, lupin, chickpea and lentil Europe: Study included all the countries in the continent
Intervention	Management included sowing date, sowing density, fertilizer, tillage, salinity, deficit irrigation, and weed control
Outcomes	Yield, yield gap, potential yield, farmer yield, and attainable yield

2.3. Screening

Following removal of duplicates, to extract yield information, data from accepted papers were entered into Endnote (online bibliographic management software) (version basic; Clarivate Analytics, https://access.clarivate.com/#/login?app=endnote), all the references retrieved and screened for relevance using the following inclusion criteria: every study identified was screened through three stages: title, abstract, and full text. At each level, records containing or likely to contain relevant information were retained and taken to the next stage.

2.4. Coding and Data Extraction

Meta-data (descriptive categorical information regarding citations, study setting, design, and methods) were extracted from included studies following full text assessment.

The treatments investigated (agronomic management) were recorded for each study as categorical variables where possible; in this case, a complete disjunctive coding of our variables (treatments investigated) was carried out. This means that variables are dichotomous, assuming value "1" if should the keyword be associated to the paper, and "0" if not. This coding was conducted according to methods described by Cuccurullo et al. [15].

Since meta-analysis considers each observation to be independent [16], data for different years or experimental conditions (i.e., cultivars or other experimental factors) within each publication were treated as independent observations. Data were obtained directly from tables and if data were provided in graphical form, means were extracted using WebPlotDigitizer [17].

2.5. Statistical Analysis

Multiple correspondence analysis (MCA) was performed on observations selected from literature sources analysis. The MCA is an exploratory multivariate technique used to simplify data visualization when individuals are described by categorical variables [18]. MCA allows the investigation of several qualitative parameters and permits a geometrical representation of all the information [19]. A MCA was performed to identify the overall correlation of the protein crops in the different agronomic management with environmental conditions (geographical and climatic region). To improve the quality (the total inertia) of the description provided by the MCA, an adjusted formula given by Benzécri [20] was used. This analysis was carried out using the software package FactoMineR [21] in R studio software [22].

3. Results

3.1. Screening Process

Schematic representation of the screening process is given in Figure 2. We ultimately identified and screened 2020 sources of literature (after removal of 1409 duplicates or non-journal papers), of which 42 were subsequently selected and analyzed, to provide 818 'observations'.

Our screening process reveals that accessible, published protein crop cropping systems research in European countries, of a high reporting standard suitable for this systematic review, is concentrated in the southern Europe (87% of observations) (Table 2 and Figure 3).

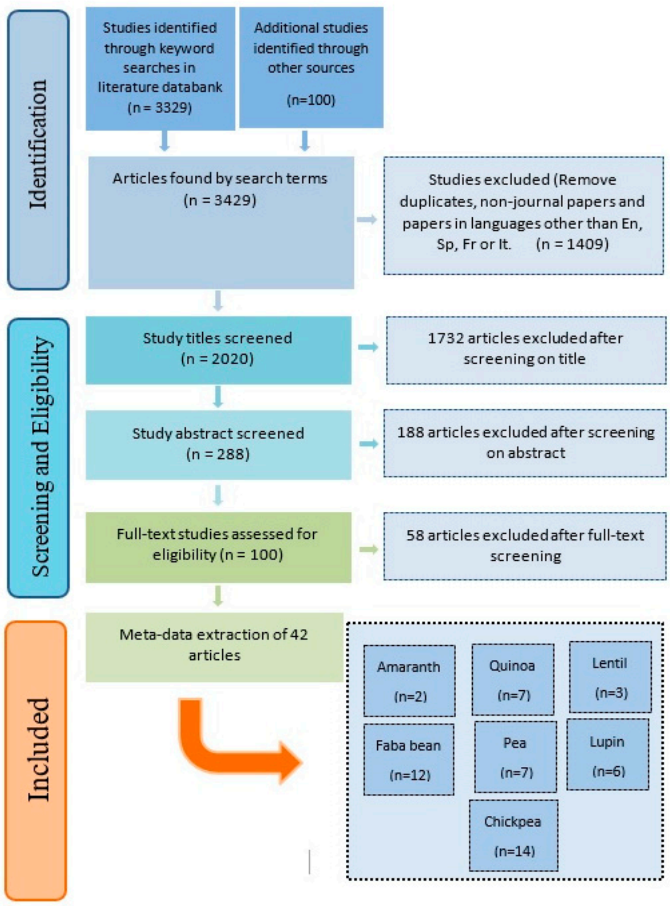

Figure 2. Selection of studies for inclusion in the systematic review (n represent the number of studies).

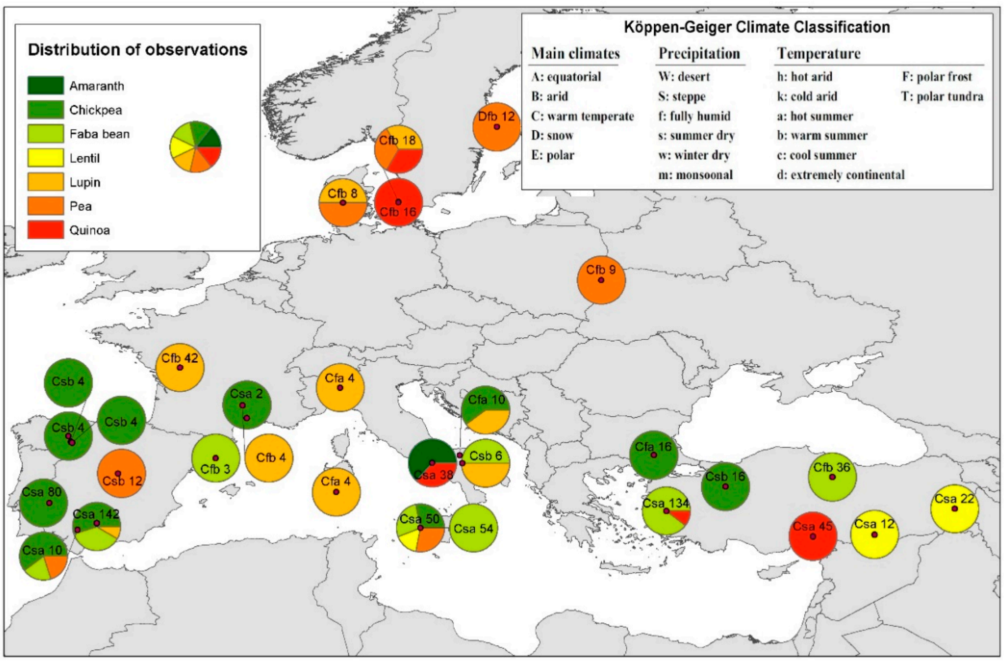

Figure 3. Distribution of doughnut chart of all observations (n = 818) by crops (amaranth, chickpea, faba bean, lentil, lupin, pea, and quinoa), by Köppen-Geiger climate classification zones (warm temperate climate zone (fully humid and summer dry, i.e., Cfa, Cfb, Csa, Csb, Csc); the snow climate zone (fully humid, i.e., Dfb)) and study sites on the map of Europe. The writing in each doughnut chart represents the climate classification and the total number of observations for each study area.

Table 2. Descriptive statistical parameters (minimum, maximum, mean, median, SD and CV) relative to yield (t ha^{-1}) for all crops and split into northern (NE), central (CE), and southern (SE) Europe.

European Region	No. of Countries	List of Countries	No. of Cases	No. of Observations	Crops	No. of Observations	Yield (t ha^{-1})				S.D.[1]	C.V.[2]
							Minimum	Maximum	Mean	Median		
Northern Europe (NE)	2	Sweden, Denmark	4	54	Lupin	10	0.98	3.95	2.83	2.96	1.03	36.18
					Peas	22	2.36	6.64	3.87	3.72	1.18	30.39
					Quinoa	22	1.54	2.27	1.82	1.76	0.21	11.42
Central Europe (CE)	2	France, Poland	4	57	Chickpea	2	2.86	3.18	3.02	3.02	0.23	7.49
					Lupin	46	2.15	4.67	3.51	3.44	0.58	16.47
					Peas	9	2.08	5.03	3.55	3.89	0.94	26.51
Southern Europe (SE)	5	Portugal, Spain, Italy, Greece, Turkey	34	707	Amaranth	24	1.3	2.65	1.94	1.93	0.41	21.39
					Chickpea	228	0.26	3.65	1.63	1.59	0.72	44.33
					Faba bean	284	0.01	8.29	3.36	2.98	1.77	52.63
					Lentil	42	0.01	2.18	0.78	0.73	0.60	77.32
					Lupin	28	0.64	3.99	2.20	1.78	1.18	53.45
					Peas	28	0.08	4.94	2.32	2.50	1.28	54.92
					Quinoa	73	0.87	3.31	2.11	1.95	0.56	26.54

[1] Standard deviation. [2] Coefficient of variation.

3.2. Geographical Distribution of Observations

Studies were reported from nine countries (Figure 3). In the following text, numbers in brackets indicate the number of individual observations in the categories described. Southern Europe (n = 706) was the most frequently studied region, with Italy (n = 166), Portugal (n = 80), Spain (n = 179), and Turkey (n = 265) being the most frequently studied countries.

The most commonly studied climate zones were Cfb (n = 136) with a marine mild climate with no dry season and warm summer and Csa (n = 589) with a warm temperate climate with dry and hot summer (Table 3).

Table 3. Number of observations included in the meta-dataset per Köppen-Geiger climate zone

Köppen-Geiger Climate Zone	Name of the Climate Zone	No. of Observations
Cfa	Cfa—Humid subtropical	34
Cfb	Cfb—Marin–mild winter	136
Csa	Csa—Interior mediterranean	589
Csb	Csb—Coastal mediterranean	46
Dfb	Dfb—Humid continental mild summer, wet all year	12

The most commonly studied crops were Faba bean (n = 284) and Chickpea (n = 230) (Table 2).

3.3. Management, Date, and Duration of Trials

Eight main groups of treatments were identified during the screening: deficit irrigation (Treatment A; n = 130), salinity (Treatment B; n = 6), tillage (Treatment C; n = 211), fertilization (Treatment D; n = 146), sowing density (Treatment E; n = 32), sowing date (Treatment F; n = 92), weed control (Treatment G; n = 71) and multiple interventions (Treatment AB/AD/CD/EF; n = 129). The number of studies reporting investigations of each group of treatments is shown in Figure 4.

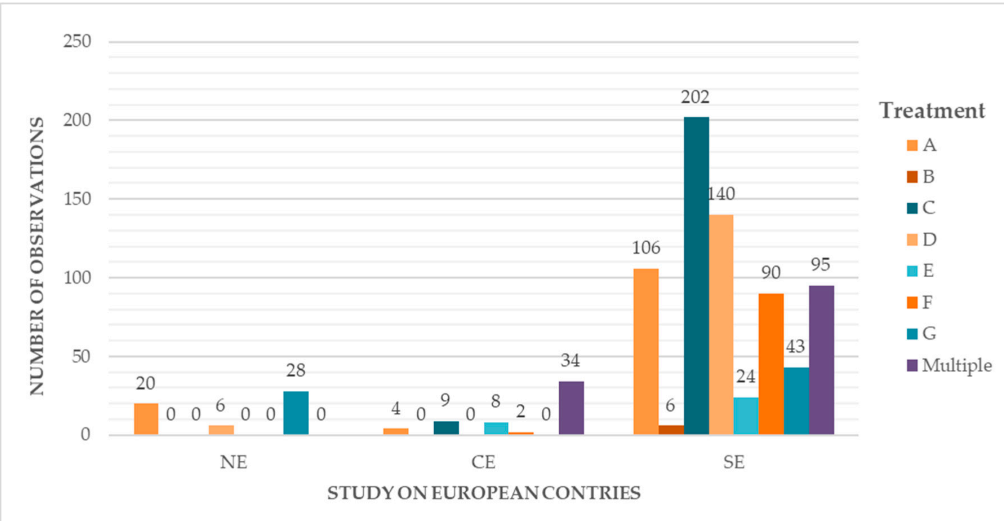

Figure 4. Number of studies undertaken across European countries. Numbers are separated by intervention group (treatment) investigated within each study. Studies may be present in more than one intervention category.

Treatment C (n = 202), Treatment D (n = 140), Treatment A (n = 106), and Treatment F (n = 90) were the most frequently studied treatments on southern Europe (SE). On northern Europe (NE) both Treatment A (n = 20) and G (n = 28) were the most frequently studied treatments and on central Europe (CE) we found only multiple interventions (e.g., Treatment EF) with 34 observations (data not shown).

A large number of studies was carried out over a 2-year period (n = 438), 136 for 1 year, 45 for 3 years, and 198 for more than 3 years (data not shown).

Forty-two papers were identified through cross-referencing dating from 1984 to 2014. An evident increase in the number of observations started after 1998. The peaks occurred in 2005 and 2010, while after 2010 there was a high drop in observations (data not shown). The longest-term studies occurred in southern Europe (18 years) in Italy [23] and in Spain (11–12 years; [24,25]).

Out of the 42 studies, 36 failed to report some critical information of measures of variability for yield mean values (e.g., standard deviation, standard error, and confidence intervals) and 18 observations failed to report the start year of treatment.

3.4. Distribution Frequencies of Yield

The descriptive statistical parameters, relative to yield (t ha^{-1}) for all crops and European regions, are shown in Table 2.

For northern Europe, most data were related to quinoa and pea (n = 22) with observations available from studies conducted in two countries in the region (Sweden, Denmark). In contrast, there was very limited published data on lupin (n = 10) and none for amaranth, chickpea, faba bean, and lentil. The average yields for pea and lupin were 3.87 and 2.83 t ha^{-1}, respectively.

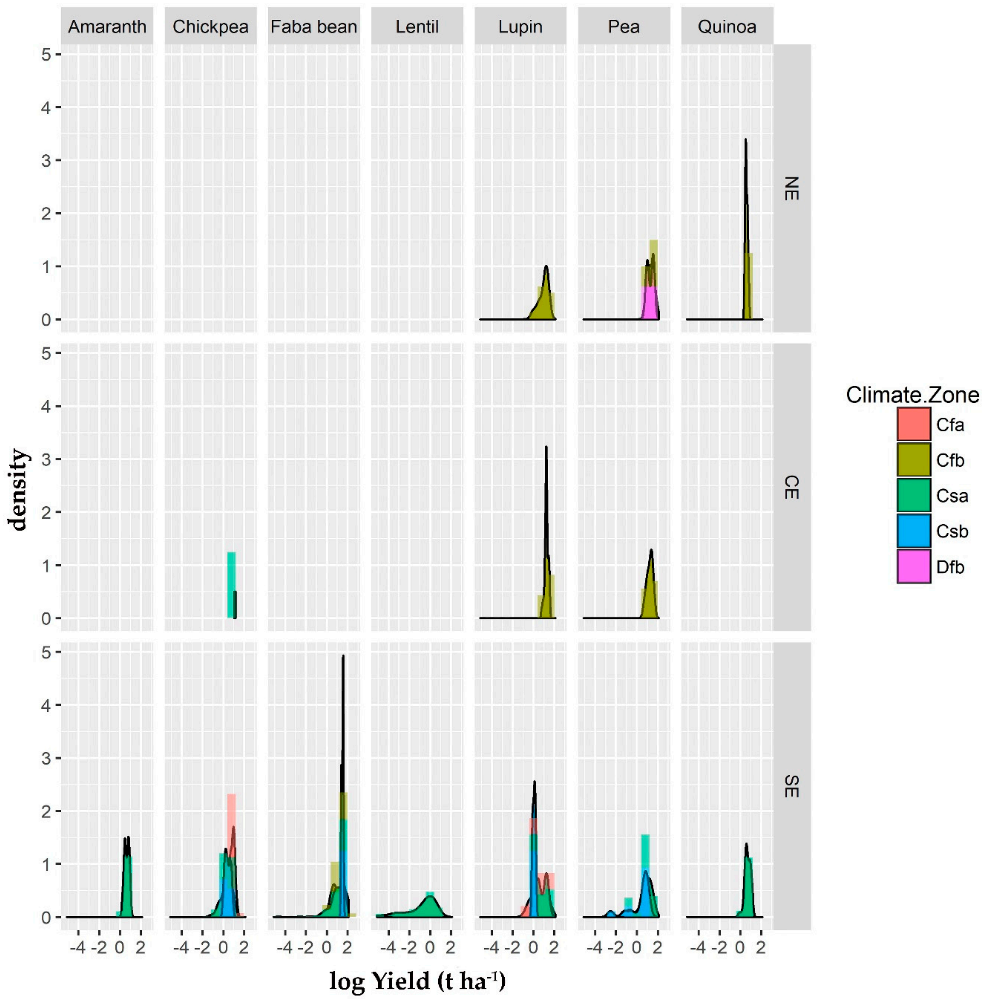

Figure 5. Distribution frequencies of log yield (t ha^{-1}) for all observations (n = 817) by crops (amaranth, chickpea, faba bean, lentil, lupin, pea, and quinoa) and European regions (northern (NE), central (CE), and southern (SE)) grouped by climate zone (Cfa: Humid subtropical; Cfb: Marin–mild winter; Csa: interior Mediterranean; Csb coastal Mediterranean; Dfb: humid continental mild summer, wet all year).

For central Europe, the average yield was relatively constant for different crops (chickpea, lupin, and pea). Lupin accounted for the largest number of observations (n = 46). Average yield in central

Europe for lupin and pea was similar to yields found in northern Europe, and higher than that observed in Southern Europe.

In Southern Europe, there were many different crops of our study (n = 706) with observations available from studies conducted in five countries of the region. Average yields varied from 0.78 t ha^{-1} for lentil to 3.36 t ha^{-1} for faba bean.

The Figure 5 shows that most of the yield observations was found in the south of Europe where all species were present. The plots convey the left skewness in the major part of the yield distributions for all crops, disaggregated into European regions.

3.5. Overall Yield across Factors of Variation

Figure 6 shows that the variation of yield due to environment, agronomic management, and crop factors was quite large.

Response yield varied across the five climatic zones classes with yield values for Dfb and Cfb ranging from 2.47 to 4.90 t ha^{-1} and 0.98 to 8.29 t ha^{-1}, respectively, with a higher percentage of values being below 4.9 and 3.9 t ha^{-1}, respectively (Figure 6a). In contrast, values of yield ranged from 0.64 to 3.99 t ha^{-1}, from 0.01 to 6.86 t ha^{-1} and from 0.08 to 4.87 t ha^{-1} for Cfa, Csa, and Csb, respectively. These results provide strong evidence to suggest that among the five climatic zones categories, Dfb and Cfb were the most productive climatic zones for all protein-crops.

Furthermore, this study found that the whisker values (the maximum and minimum values are displayed with vertical lines connecting the points to the center box) in the boxplot of the three-geographic zone categories can evaluate how yield variation is apportioned. Studies conducted in Northern Europe (NE) and Southern Europe (SE) showed the lowest yields which ranged from 0.98 to 6.64 t ha^{-1}, and 0.01 to 8.29 t ha^{-1}, respectively (Figure 6d). In contrast, values of yield ranged from 2.08 to 5.03 t ha^{-1} for central Europe (CE).

On the other hand, the variation of yield between protein-crops showed that faba bean, pea, and lupin were the most productive crops, with a higher percentage of values being below 4.9, 4.1 and 3.7 t ha^{-1}, respectively, and lentil the least one, with a higher percentage of values being below 1.2 t ha^{-1} (Figure 6b).

Figure 6c shows the yield variation between different agronomic management. Treatments AD, D, E, EF, and F were the agronomic interventions most affecting productive response and Treatment CD was the least one, with yield values ranging from 1.04 to 1.8 t ha^{-1} and with a higher percentage of values being below 1.2 t ha^{-1}.

3.6. Multiple Correspondence Analysis

To obtain a comprehensive view on the protein crop yield variation that occurred in the 44 cultivars, 8 ecotypes, 1 accession, and 14 genotypes as affected by climatic zone, geographic region, and agronomic management, the whole data set (categorical variables (column labels): protein crops, climatic zone, geographic region, and agronomic management); observations (row labels)) was subjected to multiple correspondence analysis (MCA). The first three dimensions components (dim.) explained 56.24% of the cumulative variance for our dataset, with Dim1 accounting for 27.91%, Dim2 for 16.30%, and Dim3 for 12.03% (Table 4). The loading plots (Figure 7) show the graphic display of the contribution and the cluster of variables on the plane defined by the two first axes of the analysis.

Table 4. Eigenvalues, relative and cumulative percentage of total variance for systematic review meta-database with respect to the three-dimension components (Dim1, Dim2, and Dim3)

Dimension Components	Dim1	Dim2	Dim3
Eigenvalue	0.741	0.566	0.486
Relative variance (%) *	27.91	16.30	12.03
Cumulative variance (%)	27.91	44.21	56.24

* Benzécri correction (1973).

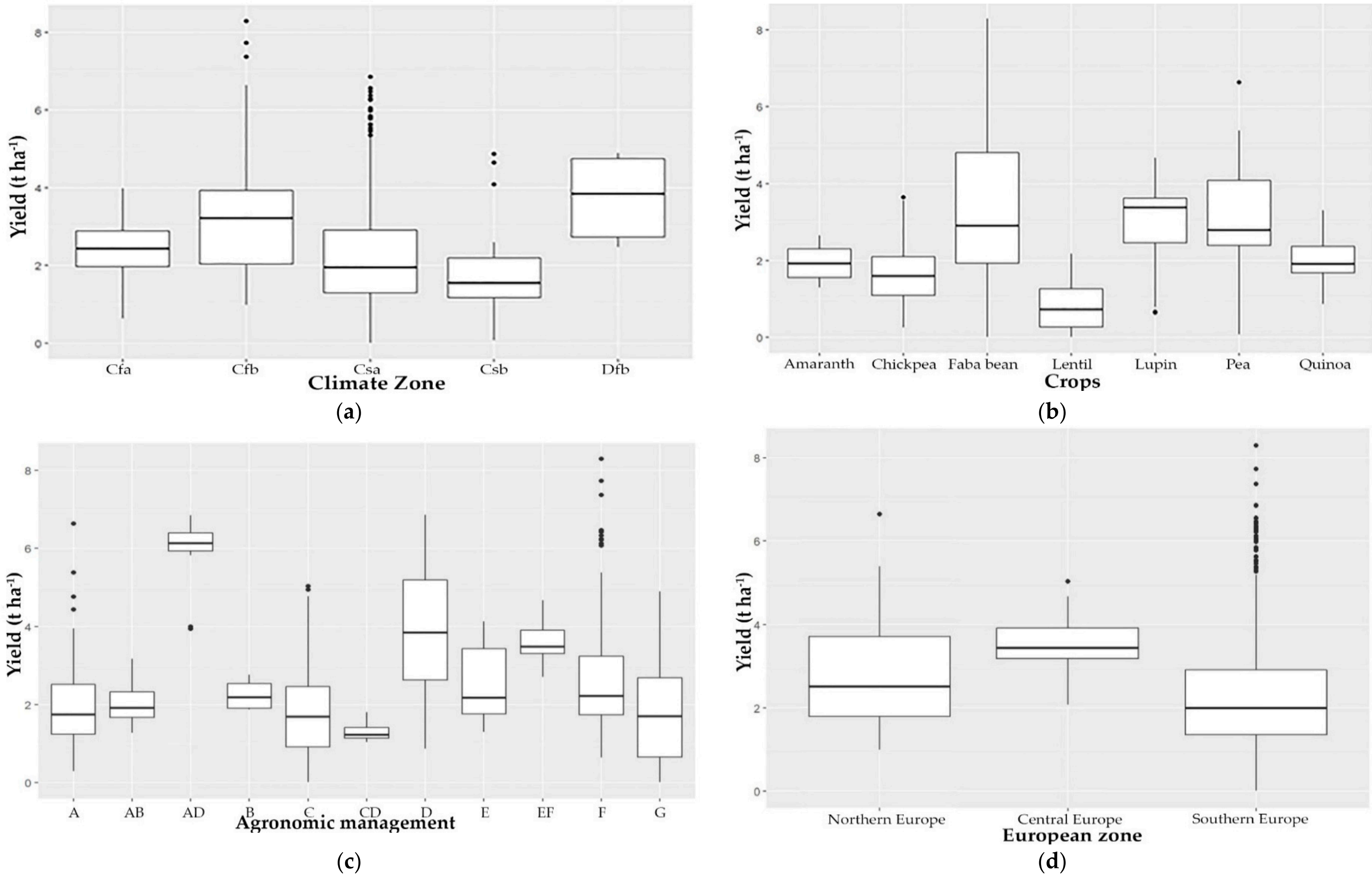

Figure 6. Box-plots of patterns of yield (t ha^{-1}) for all observations (n = 818) across: (**a**) different groups of climatic zones, Cfa: humid subtropical; Cfb: Marin–mild winter; Csa: interior Mediterranean; Csb: coastal Mediterranean:; Dfb: humid continental mild summer, wet all year (**b**) different group of Crops, (**c**) different groups of agronomic management A: deficit irrigation; AB: deficit irrigation and salinity; AD: deficit irrigation and fertilizer; B: salinity; C: tillage; CD: tillage and fertilizer; D: fertilizer; E: sowing density; EF: sowing density and sowing date; F: sowing date; G: weed control; and (**d**) different groups of European zone. Box edges represent the upper and lower quantile with median value shown in the middle of the box. The small circles on the boxplot relate to outliers.

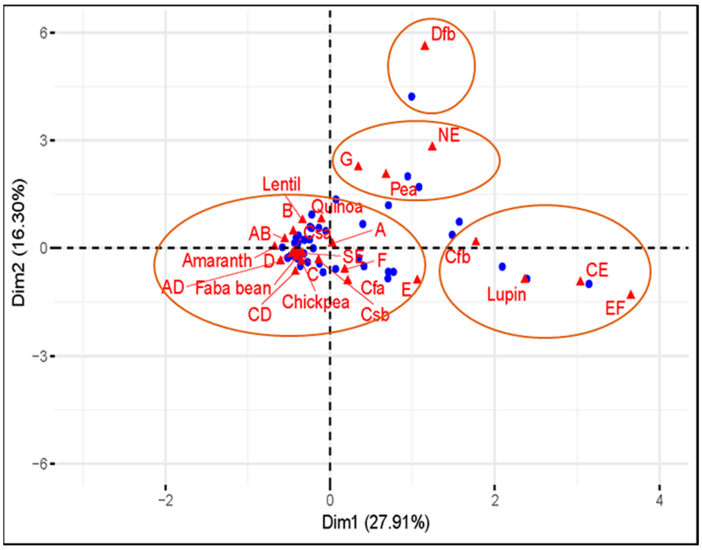

Figure 7. Multiple correspondence analysis plot of protein crops, European environments, and agronomic management factors induced by the first two dimensions components. Protein crops (quinoa, amaranth, pea, faba bean, lupin, chickpea, and lentil), European environments (geographic and climatic zones), and agronomic management (different agronomic practices) are plotted on the two first axes. Rows (observations) are represented by blue points and columns (categorical variables) by red triangles. Orange ellipses indicate different clusters analyzed.

Interpretation of correspondence analysis graphs is based on the distance between such proximate categorical variables (column labels: protein crops, climatic zone, geographic region, and agronomic management) or observations (row labels) to the origin of axes (the larger, the more significant). However, if we want to compare a row label to a column label, we need to:

1. Look at the length of the line connecting the row label to the origin. Longer lines indicate that the row label is highly associated with some of the column labels (i.e., it has at least one high residual).
2. Look at the length of the label connecting the column label to the origin. Longer lines again indicate a high association between the column label and one or more row labels.
3. Look at the angle formed between these two lines. Really small angles indicate association. 90° angles indicate no relationship. Angles near 180° indicate negative associations.

To interpret each axis (factor), it is necessary to consider different indicators, as absolute and relative contributions of each variable category. The former measures the extent to which one modality variable contributes to the determination of a specific factor. The latter is instead a quality indicator as it measures how much each factor contributes to the reproduction of the variable dispersion (Table 5). Particularly, we interpreted each factor considering categorical variables with a high absolute and relative contribution [15].

This path is mostly accounted for by the first (horizontal) axis and is strongly related to climatic zone (cfb) and positively correlated to agronomic management interaction (EF), geographic region (CE), and protein crops (Lupin). The second (vertical) axis was positively correlated to climatic zone (dfb), agronomic management (G), geographic region (NE), and protein crops (Pea) (Figure 7, Table 5).

The proximity between observations corresponds to shared-substance: observations are close to each other because a large proportion of articles treat the same search terms together; they are distant from each other when only a small fraction of articles discusses these search terms together. For example, the variables 'CE' and 'G' are far from each other, because no articles of central Europe discuss the G treatment.

Figure 7 shows that the most of observations has a large number of articles associated to agriculture management (A, AB, AD, B, C, CD, D, E, and F) and climatic zone (Csa, Csb, and Cfa) related to the southern Europe region. This information tells us that studies from southern Europe region represent the center of the research field and tend to resemble each other.

The partitioning in four clusters is represented on the map produced by the first two principal components (Figure 7). The graph shows that the four clusters are well-separated on the first two principal components.

Table 5. Contribution and value test of different sub categorical variables for systematic review meta-database with respect to the three-dimension components (Dim1 and Dim2 and Dim3).

Principal Components		**Dim1**		**Dim2**		**Dim3**	
Categorical variables	***Variables attributes***	**Abs. Contr.** [a]	**V-Test** [b]	**Abs. Contr.** [a]	**V-Test**	**Abs. Contr.** [a]	**V-Test**
Protein crops	Amaranth	0.45	−3.35	0.001	0.15	**7.66**	−11.19
	Chickpea	1.15	−6.22	1.66	−6.54	**2.74**	16.78
	Faba bean	**1.95**	−8.51	0.98	−5.27	1.93	−6.86
	Lentil	0.20	−2.24	**1.36**	5.15	0.01	0.41
	Lupin	**19.17**	22.72	3.49	−8.47	0.06	−1.03
	Pea	1.12	5.40	**13.22**	16.23	3.40	7.62
	Quinoa	0.05	−1.11	3.26	8.25	**9.30**	−12.93
European countries	Northern Europe	3.43	9.43	**22.96**	21.32	0.13	1.50
	Central Europe	**21.75**	23.78	2.79	−7.45	0.63	−3.28
	Southern Europe	**3.38**	−24.52	0.72	−9.92	0.02	1.36
Climatic zone	Cfa	0.06	1.27	1.53	-5.44	**2.72**	6.71
	Cfb	**17.60**	22.60	0.18	1.99	0.50	−3.07
	Csa	**4.57**	−19.90	0.16	−3.27	1.93	−10.48
	Csb	0.04	−0.99	0.28	−2.34	**17.23**	17.03
	Dfb	0.66	4.01	**20.34**	19.54	1.45	4.83
Agronomic management	A	0.003	0.31	0.12	1.59	**2.07**	6.26
	AB	0.84	−4.71	0.22	2.11	**15.55**	−16.40
	AD	**0.18**	−2.10	0.09	−1.27	0.24	−1.99
	B	0.05	−1.10	**0.07**	1.14	0.90	−3.79
	C	1.25	−6.40	0.19	−2.17	**0.63**	3.67
	CD	0.12	−1.71	0.38	−2.68	**12.98**	14.50
	D	1.31	−6.21	0.22	−2.23	**3.03**	−7.65
	E	**1.48**	6.11	1.41	−5.21	2.09	5.86
	EF	**18.73**	21.74	3.23	−7.90	1.41	−4.83
	F	0.12	1.80	1.78	−6.09	**1.30**	4.81
	G	0.34	3.00	**19.37**	19.80	0.11	1.38

Boldface contributions indicate the most relevant characters for each dimension component. Different climatic zones: Cfa: humid subtropical; Cfb: Marin–mild winter; Csa: interior Mediterranean; Csb coastal Mediterranean; Dfb: humid continental mild summer, wet all year, different group of agronomic management A: deficit irrigation; AB: deficit irrigation and salinity; AD: deficit irrigation and fertilizer; B: salinity; C: tillage; CD: tillage and fertilizer; D: fertilizer; E: sowing density; EF: sowing density and sowing date; F: sowing date; G: weed control; [a] Absolute contribution, [b] Value test: V-test statistic asymptotically follows a standard gaussian distribution, a value below −1.96 or above 1.96 indicates that the category has a coordinate significantly different to 0 and each category has positive or negative value for each dimension.

4. Discussion

The area of protein crops in Europe declined almost continuously over the last five decades, from 5.8 million ha in 1961 (4.7% of the arable area), when recording began, to 2.0 million ha in 2014 (1.6% of the arable area) [26]. A major underlying driver behind the reduction in the proportion of arable land used for protein crops is the increased comparative advantage in the production of starch-rich cereals in Europe over the production of protein-rich grain legumes [27].

Protein crops may produce high-quality protein for food and feed, increasing soil fertility and yields in subsequent crops, potentially reducing greenhouse gas emissions and supporting biodiversity [27]. However, there are several reasons why farmers may be hesitant to grow them: the quality and quantity of the yield, and thus the financial return, vary depending on the region and weather conditions [28].

4.1. European Environments

According to Reckling et al. [29], especially in the north of Europe, where all grain legumes are spring-sown, they have generally more unstable yield than those of autumn-sown crops, because they can be constrained by water deficits during crop establishment and subsequent growth stages. Winter crops are instead established in autumn and regrow quickly after winter without any delays due to soil tillage and seedbed preparation that can also reduce soil moisture. Another factor that can contribute to yield instability in grain legumes is the indeterminate growth habit that allows the crop to respond to good conditions such as high-water availability and adequate temperature or to stop growing and reproducing under poor conditions [30]. Differently from legumes, cereals can compensate in conditions of sufficient or insufficient water and nutrient supply through modifications in tillering and flower initiation. Finally, the symbiotic nitrogen fixation affects yield and can be reduced or fail in poor conditions resulting in greater yield instability.

According to De Visser [31], the large diversity of pedoclimatic conditions all over Europe, and also the different end user needs (food, feed/ruminants, feed/monogastrics), determine which protein crops are most easily adopted. Therefore, most of the published cropping systems studies in Europe, with a high reporting standard suitable for a SR, are concentrated in Southern Europe; perhaps because the manufacturers do not consider these protein crops as having enough of a market to justify investing in research and development in all European countries.

The most commonly studied climate zones for protein crop cultivation were geographical areas with a marine mild climate with no dry season and warm summer (Cfb)—most of them in Demark, France, and Poland—and areas with a warm temperate climate with dry and hot summer (Csa) especially in southern Europe. According to Malezieux et al. [32], in some parts of Europe where winters are not severe, autumn-sown grain legumes can be grown. In Mediterranean regions, grain legumes, such as pea, are grown as a cool-season crop harvested before summer drought, or before planting an irrigated, warm-season crop such as maize.

4.2. Protein Crops

The most commonly studied crops were faba bean and chickpea. Beans are preferred by arable farmers because this crop is easier to grow, and has more steady yield levels [7].

The most important parameters to be considered by growers are straw height, earliness of ripening, disease resistance, and yield. Earliness of ripening is important in particular, under North European conditions to anticipate harvest and avoid cooler weather when drying of the crop in the field is slow [33].

In our review, we have focused on yield, as it is the most important parameter, but there is still lack of knowledge concerning protein content in Europe.

In south of Europe, studies on lentil, lupin, and faba bean showed the most variable yields with a coefficient of variation (CV) value of 77%, 54%, and 53% respectively (Table 2), indicating that broad-leaved crops indeed have more unstable yields than cereals [27]. In the south, average yield was 0.78 t ha^{-1} for lentil and 3.36 t ha^{-1} for faba bean. Highest yields were identified for pea and lupin in northern Europe. For central Europe, the average yield was relatively constant for different crops (chickpea, lupin, and pea).

The variation of yield between protein crops showed that faba bean, pea, and lupin were the most productive crops, and lentil the lowest yielding.

At the European scale, the yield levels of field broad beans seem to be showing much potential in North West Europe [34] and the yield level of field peas is high, while lupins yield are considerably lower and consequently lupin crops are considered less attractive [7].

White lupin (*Lupinus albus* L.), yellow lupin (*L. luteus* L.), and narrow-leaved lupin (*L. angustifolius* L.), are native European legumes with a seed protein content high (up to 44%) [35]. Lupin is mainly cultivated in North and Central Europe [36], but the results from this study show that it could be cultivated also in south European countries. Lupin was cultivated in ancient times but is currently neglected [37].

Among the grain legume species, peas are the main grain legume produced in Europe: they can be grown almost anywhere [34]. Their high yield potential makes profitable use of fertile soils, most of the new varieties are easy to harvest, and peas can be used for several purposes [7].

There is a large variation in yield across Europe and across the different protein crops. Protein crops suffer from yield instability compared to cereals or rapeseeds, and yield fluctuations are one of the main reasons farmers give for not growing these crops [10]. The latter is a major obstacle in further expansion and a main target for improving protein crop production. According to Stoddard et al. [38], a lack of breeding resources (indeterminate growth habit, stress resistance, etc.) and knowledge gaps (low agronomic expertise, insufficient cooperation between farmers and other actors, etc.) are responsible for the fact that only 1.6% of EU arable land is currently used for legumes, despite their agronomic and environmental benefits.

4.3. Agronomic Managements

Recent studies outline a comparative lack of breeding investment in Europe to improve protein crops adaptation to local agroclimatic conditions and management techniques [12,39,40], such as crop protection or density and plant spacing, irrigation, tillage, fertilization, and harvesting techniques [41–43]. It is important to highlight that a general lack of specific agronomic references to manage protein crops may be a barrier for farmers cultivating these crops in Europe [44].

In our SR, tillage (n = 211), fertilizer (n = 146), deficit irrigation (n = 130), sowing density, and sowing date (both the last treatments n = 158) were the most productive agronomic management for protein crops in European countries.

According to Christopher and Lal [45], the cultivation and cropping may cause significant soil organic carbon (SOC) losses through decomposition of humus. The shift from pasture to cropping systems can lead to loss of soil C stocks between 25 and 43 percent [46]. Furthermore, the EU's agricultural policy has rewarded a wider range of options to increase soil carbon [47].

There is a general agreement on the influence of grain legumes on the properties of rhizosphere in terms of N supply, SOC, and P availability [48], the extent of the impact varied across legume species, soil properties, and climate conditions.

The soil type is the main determinant of plant growth, nutrient dynamics of the rhizosphere and microbial community structure. The depletion and accumulation of some macro- and micronutrients also differed between crop systems (i.e., monoculture, crop rotations) and soil management strategies (i.e., conventional tillage, conservation agriculture).

Soil tillage methods have complex effects on physical, chemical properties of soil, which alter in turn the biological properties. Protein crops, and in particular grain legumes, possess certain characteristics particularly suitable for sustainable cropping systems and conservation agriculture, and making them functional either as cash crop or as crop residue [49]. Conservation agriculture (CA) is based on minimal soil disturbance and permanent soil cover combined with rotations [50] and in Europe, the CA is applied in regions where soil erosion mitigation and protection against land degradation are important objectives.

Also, legumes' biological fixation of atmospheric N_2 can be affected by "starter-N" and tillage; Torabian et al. [51–53] showed that conservation tillage typically enhances nodulation and nitrogen fixation, through increased soil moisture retention and soil temperature, and increased soil microbial biomass. According Krishna [54], there are several legumes as pea, faba bean, soy bean, and forage legumes that need no fertilizer-N supply, perhaps except a starter-N in some locations to induce rapid rooting at seedling stage. Kitamura [55] showed that legumes preferentially use available soil nitrogen rather than fix atmospheric nitrogen. Thus, high levels of available soil nitrogen will greatly reduce the amount of nitrogen fixed by the legume. However, in low nitrogen soils, a low rate of starter-N placed away from the seed may boost seedling growth of the legume prior to the establishment of fully functioning nodules. On the other hand, legume-based systems improve various aspects of soil fertility, including the amount of nitrogen fixed into the soil and the high quality of the organic matter released to the soil in term of C/N ratio [49].

Many countries already depend on conservation agriculture. The SR research results show that the grain legumes like lentil, chickpea, pea, and faba bean play a major role in conservation agriculture in Spain, Italy, and Turkey (96% of evidences of tillage treatments in SE).

According to Stagnari et al. [49], the expansion of ecological approaches such as conservation agriculture opens up opportunities for the use of food legumes in sustainable cropping systems. In general, conservation agriculture is an environmentally sustainable production system that can increase the incorporation of grain legumes within large and small-scale farming.

Protein crops require an adequate supply of readily available nutrients for optimum growth and yield [56].

According to Da Silva et al. [57], considerable N is required in grain legumes at the beginning of pod fill as the translocation of N from vegetative parts to the pods is intensive. Studies on soybean have shown that this N drain may be high enough to decrease photosynthetic activity [58], induce premature leaf senescence, and reduce root activity [59,60]. Nutrients supplied through leaves may supplement rapidly those transferred from stems and roots, thus avoiding early leaf senescence [61].

By means of the inoculation of rhizobia or the application of N fertilizer with the use of ^{15}N labeled urea, during the late stages of growth, it was possible to enhance grain legume yields without necessarily inhibiting N_2 fixation [56]. According to the screening review results, these two methods were the most frequently studied treatment on SE especially in Italy and Spain.

Since indigenous rhizobia are not always in sufficient numbers, effective enough, or compatible with the specific legume crop to stimulate biological nitrogen fixation (BNF) and increase yields, inoculation of legumes with rhizobia is an important option for enhancing BNF in crop production systems [62]. The effectiveness of BNF is affected by agro-ecological factors. For instance, poor nodulation and poor plant vigor in beans grown in soil with low extractable P led to a poor BNF [63]. The idea of applying N through leaves to maximize bean yield is not recent [64,65]. The advantage of using urea is that it facilitates the accumulation of other nutrients such as Mn^{2+} and permits the transport of nutrients through a more permeable cell cuticle [66].

Seed yields of high-quality protein crops like quinoa strongly respond to N fertilization [67]; for this reason, the main field trials carried out in Europe during last years to evaluate adaptability of different quinoa varieties were also focused on the assessment of nitrogen requirements [68].

Sowing date is one of the most important management factors affecting protein crops production and quality [69]. In a given region, the optimum sowing date depends mainly upon the timing of rainfall [70]. In most cases, delaying sowing beyond the optimum period reduces crops yields [71,72]. As a consequence, delaying sowing date can cause significant differences of environmental conditions during grain filling, usually causing grains to grow with increasing temperatures and diminishing moisture conditions [73,74].

A number of studies, from our SR, has reported on the optimum sowing dates for legumes. Yield variation as a function of sowing date and sowing density ranged from 1.01 to 3.65 t ha^{-1} and from 1.45 to 2.29 t ha^{-1}, respectively. Furthermore, the early winter sowing date in Spain, and March sowing date in Greece, seemed to ensure the highest response for chickpea in the southern Europe. In general, early sowing resulted in seed yield increases and there was a frequency for seed yield to decrease with delay of sowing [56]. Quinoa grown under Mediterranean conditions produce higher seed yields if sown in April compared to May [75].

In addition, the sowing density is an important factor-affecting yield of grain legumes according to many studies, from inside and outside EU [76–78]. Therefore, yield response of seed legumes to seeding rates was discussed by several authors, and a significant effect of seeding rate on seed yield was found [79,80].

Water resources in the EU and especially in Mediterranean region become more and more scarce because of high demand for water due to population growth and increasing demand for food. Climate change has also aggravated the situation because of erratic rainfall and the succession of drought years [81].

This challenge is further compounded by the severe competition for land and water from industry and urban development [82]. Such competition pushes agriculture to marginal areas, where water-limiting conditions often constrain crop productivity. In these marginal areas (e.g., semi-arid environments), water limitation and year to year fluctuations of meteorological conditions tend to be large, and these variations significantly affect food security in rain-fed systems [83].

Droughts can negatively impact the yield of most protein crops, from C4 plant (e.g., amaranth) to C3 (e.g., quinoa and legumes) [84–86]. The yield of food legumes grown in arid to semi-arid environments or drylands such as the Mediterranean (e.g., faba beans, chickpea, and lentil) is usually variable or low due to terminal droughts that characterize these areas [87,88].

Currently, the economically viable approaches to support crop production under drought are still limited [89]. More importantly, it remains unclear how the impact of drought on legume production varies with legume species, regions, agroecosystems, soil texture, and drought timing.

The results of our systematic review and drought manipulation experiments across the EU region will allow to better characterize the factors that determine the magnitude of yield loss in legumes due to drought stress, which must be considered in agricultural planning to increase the resilience of legume production systems.

5. Conclusions

This systematic review details the setting for a large number of studies across a broad range of agronomic management, protein crops, and geographical locations.

The EU depends on imported high-protein plant products. The main reason for this is that protein crops in the EU are not competitive with the crops currently being produced. However, the competitiveness of crops can be expected to differ between regions within Europe because local conditions have a high influence on yield levels [3]. In addition to higher yield potential of cereals in Europe, farmers who grow protein crops face up to a range of agronomic challenges. The evidence from this SR confirms that protein crop yields are considered unstable, as pointed out in many studies [10,43,90].

Therefore, as in most of the cultivated areas, legume yield is unstable, legume production is limited. This constraint is explained by many other external factors, such as the historical dependence to the Common Agricultural Policy measures; low level of production of processed products; competition with soybean imports from the Americas or with protein-rich byproducts derived from non-legume crops. It is also possible that European farmers are not motivated to cultivate these species on soils of good quality in appropriate environments, and that they prefer growing more profitable major crops in these environments (e.g., wheat, maize, and rapeseed).

These agronomic challenges highlight a need for research to support crop development in order to increase and stabilize yields in relation to those of other crops. To do this we should answer this question: What are the main research needs (technical, social-economic) for protein crops to be competitive?

A useful approach to achieve this aim could be represented by exchange between several regions across Europe which will also contribute to increase the profitability of EU protein crops. Sharing knowledge on the use of varieties and best practices, even worst practices, is a key to success.

Access to practical knowledge and best practices of protein crop production is required. A useful approach to achieve this aim could be represented by a meta-regression analysis of mixed effects using the relative yield as effect size estimator. An effect size estimator is an index which allows us to compare the experimental treatment mean to the control treatment mean [91] and to quantify the magnitude of a treatment's effect. Because all of the studies we used did not report any measure of variance, an unweighted meta-regression could be performed. The meta-regression analysis would allow to investigate the interaction between different protein-crops, European region, and agronomic management and the effect of these factors on yield response.

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