agronomy

Systematic Review

Agronomic Practices to Increase the Yield and Quality of Common Bean (*Phaseolus vulgaris* L.): A Systematic Review

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Abstract: Common bean (*Phaseolus vulgaris* L.) is the most important legume for human consumption worldwide and an important source of vegetable protein, minerals, antioxidants, and bioactive compounds. The N_2-fixation capacity of this crop reduces its demand for synthetic N fertilizer application to increase yield and quality. Fertilization, yield, and quality of common bean may be optimised by several other agronomic practices such as irrigation, rhizobia application, sowing density, etc. Taking this into consideration, a systematic review integrated with a bibliometric analysis of several agronomic practices that increase common bean yield and quality was conducted, based on the literature published during 1971–2021. A total of 250 publications were found dealing with breeding ($n = 61$), sowing density and season ($n = 14$), irrigation ($n = 36$), fertilization ($n = 27$), intercropping ($n = 12$), soilless culture ($n = 5$), tillage ($n = 7$), rhizobia application ($n = 36$), biostimulant/biofertilizer application ($n = 21$), disease management ($n = 15$), pest management ($n = 2$) and weed management ($n = 14$). The leading research production sites were Asia and South America, whereas from the Australian continent, only four papers were identified as relevant. The keyword co-occurrence network analyses revealed that the main topics addressed in relation to common bean yield in the scientific literature related to that of "pod", "grain", "growth", "cultivar" and "genotype", followed by "soil", "nitrogen", "inoculation", "rhizobia", "environment", and "irrigation". Limited international collaboration among scientists was found, and most reported research was from Brazil. Moreover, there is a complete lack in interdisciplinary interactions. Breeding for increased yield and selection of genotypes adapted to semi-arid environmental conditions combined with the suitable sowing densities are important agronomic practices affecting productivity of common bean. Application of fertilizers and irrigation practices adjusted to the needs of the plants according to the developmental stage and selection of the appropriate tillage system are also of high importance to increase common bean yield and yield qualities. Reducing N-fertilization via improved N-fixation through rhizobia inoculation and/or biostimulants application appeared as a main consideration to optimise crop performance and sustainable management of this crop. Disease and weed management practices appear neglected areas of research attention, including integrated pest management.

Keywords: common bean; *Phaseolus vulgaris* L.; legume; agronomy; yield; yield qualities; nitrogen fixation; rhizobia

1. Introduction

Climate change related stresses, such as drought, salinity, soil compaction and heat, along with environmental pollution related stresses, limit the world's crop yield and yield qualities, thereby leading to major socioeconomic and food insecurity [1]. Considering an estimated global population of 10.4 billion by 2067, with Asia and Africa accounting for 81% of this growth [2] and the global food demand projections for this future [3], effective measures to increase crop production need to be adopted quickly. By developing efficient resource use and sustainable agronomic practices for crop-fertilization, irrigation and protection, a significant reduction in the demand for synthetic chemical fertilizers, fresh water and chemical pesticides in agriculture could be achieved without compromising yield and quality [4]. Bio-based agronomic practices for primary production, offering a more-positive impact on ecologically functions and economical sustainability, could also serve as excellent strategies towards achieving the United Nations Sustainable Development Goals (UN SDGs), i.e., limiting malnutrition and achieving food security [2]. Such practices can preserve natural resources, natural functions, and reduce crop management costs in agriculture.

Intercropping, organic agriculture and minimum- to no-tillage management are some of the most important sustainable agronomic practices, with applications that resulted in increased soil biodiversity and improved soil structure and health [5]. Moreover, reduced tillage demands a drastic decrease in the use and size of farm machinery and fuel, with consequent reduction in Greenhouse Gas (GHG) Emissions and management costs [6]. Irrigation management, especially during flowering or reproduction, is also crucial for crop productivity and quality in most parts of the world [7–10]. Introduction of high yielding cultivars with superior product qualities and increased tolerance to biotic and abiotic stresses, as well as application or/and encouragement of beneficial microorganisms (e.g., bacteria, algae, fungi) with the potential to increase nutrient and water uptake without compromising environment functions should also be considered as viable sustainable agronomic practices to improve plant performance and productivity [11,12]. Application of soil-borne biocontrol agents (e.g., *Trichoderma, Beauveria, Bacillus, Pseudomonas*) may also help ensure plant protection against several diseases. Consequently, the use of chemical pesticides is significantly reduced, with potential benefits for beneficial microbes and the environment [13,14].

Soilless culture (hydroponics) is becoming increasingly important in protected cultivation systems, both in modern high-tech glasshouses, but also in simple greenhouse constructions. Soilless culture has the potential to improve yield and product quality due to better control of the conditions which prevail in the root environment [15]. Besides, legal restrictions in the application of soil fumigants and pesticides to combat soil-borne diseases makes soilless culture even more important for food security.

Common bean (*Phaseolus vulgaris* L.), as a grain legume, enriches the soil via biological nitrogen fixation (BNF), through the symbiosis with bacteria, such as the *Rhizobium leguminosarum bv. phaseoli* [16] thereby reducing the need to apply nitrogen (N) fertilizers. The BNF capacity of this legume crop depends on the genotype, the rhizobia strain, the growth climatic conditions, and the amount of the additional synthetic N fertilizer applied [17,18]. Given the low BNF capacity of this crop in comparison to other legume crops such as soybean and faba bean [19], the identification of cultivars exhibiting high BNF capacity is of high importance.

Common bean is also characterized by seed and pod high protein content [20]. This nutritional provision is allied to high levels of essential minerals, vitamins, fibers, antioxidants, and polyphenols—as just some of the nutritional components provided through common bean (and immature pod) consumption [21]. However, non-nutritional factors, such as phytic acid, lectins and saponins have also been found in the pods and dry seeds of this crop [22].

Here we highlight the results of a systematic review conducted to answer the following question: which agronomic practices increase the yield and quality of common bean (*Phaseolus vulgaris* L.)? To address our research question, the protocol defined four PICO (population, intervention, comparator, and outcome) elements, which were used to review the research published over the last fifty years (1971–2021). The relevant literature was assessed following the already peer-reviewed and published protocol which was developed according to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines [23]. A full bibliometric analysis of the relevant literature was then carried out to identify the main research foci, and their efficacy, to increase common bean yield and yield qualities.

2. Methods

2.1. Literature Research

All databases described in the original protocol were queried. However, during the implementation of the protocol, only two bibliographic databases (ISI Web of Science™ and Scopus™) were used to identify studies related to the agronomic practices that increase the yield and yield qualities of common beans (*Phaseolus vulgaris* L.). This was ascribed to the fact that by searching in all the other databases that were described in the initial protocol, we could not identify any paper that was not already included in either Web of Science and/or Scopus. The studies were reported in English by peer-reviewed journals in the period between 1971 and 2021 (inclusive). The search of academic databases was performed on 20 November 2021. The strings combined with Boolean operators used as "topic words" are provided in Table 1. Each term was used to address each PICO element of the research question as described in Table 2 of the published protocol [23]. The terms used for the Population element were "common bean" or "*Phaseolus vulgaris*".

Table 1. Search scientific terms applied to the selected databases in terms of the agronomic practices. A wildcard (*) was used to enable the inclusion of multiple word endings.

Agronomic Practice	Topic Words
Breeding	genetic * or genotype * or landrace * or breed *
Sowing density and season	sowing date or plant density or sowing rate or sowing season
Irrigation	drought or water stress or deficit irrigation or irrigation or salinity or saline or salt stress or irrigation quality or water quality
Fertilization	organic or conventional or fertilizer or inorganic or nutrition or nitrogen or potassium or phosphorus
Intercropping	intercrop *
Soilless culture	hydroponic * or soilless or floating or nft or nutrient solution or vertical
Tillage	Till *
Rhizobia application	rhizob * or inocul *
Biostimulant/biofertilizer application	arbuscular mycorrhizal fungi or PGPR or azospirillum or plant growth-promot * or rhizobacteria or alga * or amino or biostimulant * or fulvi * or humi * or pgpb or biofertili *
Disease management	Fung * or biotic or virus or pathogen or bacter * or disease
Pest management	Insect *or pest * or acari *
Weed management	Weed * or herbicide *

Table 2. Studies reporting results from two or three agronomic practices. The √ denotes the duplicates studies and * denotes the one triplicate study.

Agronomic Practice	**Breeding**	**Sowing Density and Season**	**Irrigation**	**Fertilization**	**Intercropping**	**Soilless Culture**	**Tillage**	**Rhizobia Application**	**Biostimulant/ Biofertilizer Application**	**Disease Management**	**Pest Management**	**Weed Management**
Breeding		√			√					√		
Sowing density and season	√		√									
Irrigation		√		√								
Fertilization			√					√	√		√	
Intercropping	√							√	√			
Soilless culture												
Tillage								√				
Rhizobia application				√	√		√		√ *	√ *		
Biostimulant/biofertilizer application				√	√			√ *		*		√
Disease management	√							*	*			
Pest management				√								
Weed management					√							

2.2. Inclusion and Exclusion Criteria

We included studies conducted under open-field and greenhouse conditions. All included studies reported on approaches that influenced crop yield (pods and dry seeds) and yield quality parameters (protein, amino acids, carbohydrates, essential minerals, vitamins, antioxidants, carotenoids, phenolics).

2.3. Screening

The papers from which the yield and quality data were extracted were accepted following the procedure described in the published protocol [23]. Mendeley online bibliographic management software (www.mendeley.com, last accessed on 22 December 2021) was used for the removal of duplicates. All the publications included in this review study are given in the Supplementary Materials (Excel File S1).

2.4. Bibliometric and Concept Network Analysis

The full records of Scopus and Web of Science databases were exported to Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA) for further analysis. The final database consisted of 228 articles (see Section 3.1) with a wide range of variables such as publication year, title, abstract, authors and co-authors institutions and affiliations countries. A network analysis was performed to identify research collaboration patterns, analyse the leading countries in the research topic and discover the research trends based on the frequency of terms in titles and abstracts. This analysis was conducted through the VOSviewer software (version 1.6.15; Leiden University, Leiden, The Netherlands) that is widely used for bibliometric analyses [24].

3. Results

3.1. Subsection

The screening process of this systematic review is schematically presented in Figure 1. We ultimately identified and screened 1030 sources of literature (after removal of 404 duplicates or nonjournal papers), of which 250 were subsequently selected and analysed. However, during the screening process for duplicates among the different treatments, 21 studies reporting results from more than one treatment were identified and were therefore considered as one; thus, the sum of the publications appearing in the 12 treatments (250) is greater than the total number of publications included in the systematic review (228).

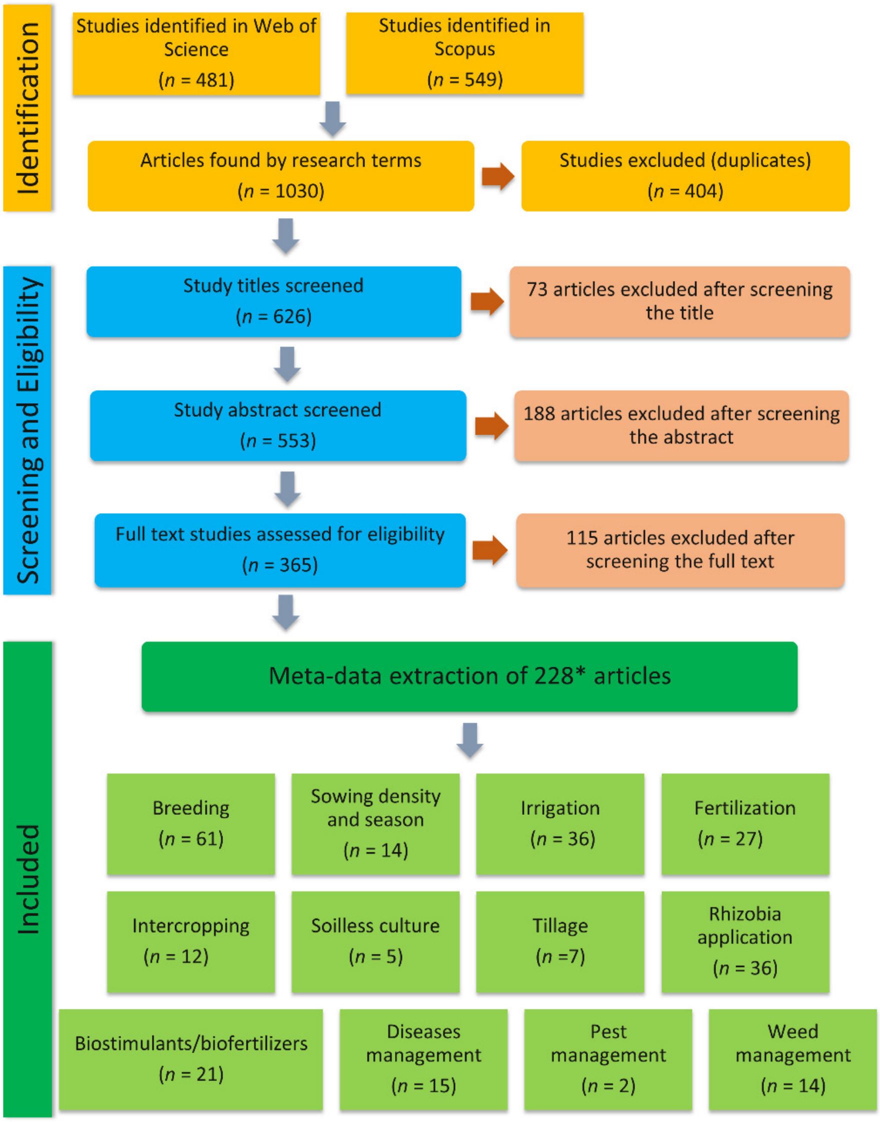

Figure 1. Flow chart of the screening and selection process followed for the inclusion of the studies in the systematic review. Where *n* denotes the number of studies results for each treatment. * Some studies reported results from more than one treatment and therefore the sum of the publications appearing in the 12 treatments (250) is greater than the total number of publications assessed in the study (228).

Twelve main treatments (practices) were identified to have been applied in the selected papers: breeding (Treatment A; $n = 61$), sowing density and season (Treatment B; $n = 14$), irrigation (Treatment C; $n = 36$), fertilization (Treatment D; $n = 27$), intercropping (Treatment E; $n = 12$), soilless culture (Treatment F; $n = 5$), tillage (Treatment G; $n = 7$), rhizobia application (Treatment H; $n = 36$), biostimulant/biofertilizer application (Treatment I; $n = 21$), disease management (Treatment J; $n = 15$), pest management (Treatment K; $n = 2$), and weed management (Treatment L; $n = 14$). The number of studies reporting investigations of each group of treatments is shown in Figure 1, whereas the percentages of each intervention reported across the relevant studies are shown in Figure 2.

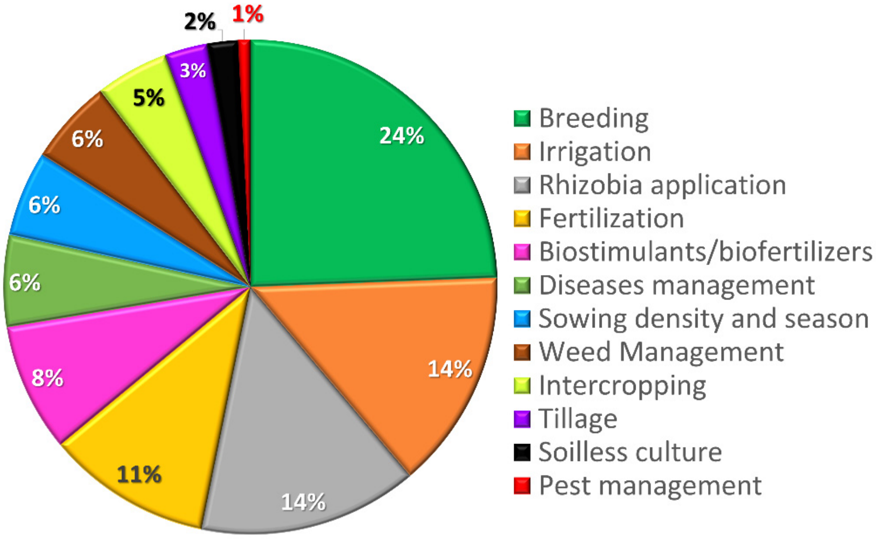

Figure 2. The percentage (%) of the studies of the twelve main agronomic practices that were identified during the screening and included in the systematic review.

Twenty (20) studies assessed the impact of two agronomic practices, and one study assessed three practices. The duplicates were breeding plus disease management (1); breeding plus intercropping (1); breeding plus sowing density and season (1); sowing density and season plus irrigation (1); fertilization plus rhizobia application (2); fertilization plus pest management (1); fertilization plus biostimulants/biofertilizers application (1); rhizobia plus biostimulants/biofertilizers application (6); rhizobia application plus tillage (1); rhizobia application plus disease management (1); intercropping plus rhizobia application (1); intercropping plus biostimulants/biofertilizers application (1); intercropping plus weed management (1); irrigation plus fertilization (1); and the triplicate biostimulants/biofertilizer application plus rhizobia application plus diseases management (Table 2).

3.1.1. Breeding for Increased Yield and Quality

The literature search on Scopus and Web of Science returned 111 different articles. Fourteen (14) of these articles were excluded because, although the abstract was written in English, the main body of the article was written in Portuguese or Spanish. Then, six (6) more articles were excluded because they were either review articles (3), conference papers (1), or book chapters (2). Moreover, according to the protocol, 30 articles were excluded because screening of the abstract revealed that they were irrelevant to breeding or/and they did not report information on yield. Finally, 61 articles were included in this review (Excel Files S1 and S2).

3.1.2. Sowing Density and Season

Thirty-six (36) articles were found based on the title search in the Scopus and Web of Science literature databases, of which eleven (11) were excluded as duplicates, two (2) of them were written in Portuguese and Spanish language, three (3) were either notes or meeting abstracts, and one (1) article concerned pot experiment. After full-text screening, two (2) articles were rejected as the data were expressed as interaction with different irrigation management. Additionally, three (3) studies were further excluded because the impact of either sowing density or season was not well documented (Excel Files S1 and S2). Of the 14 accepted articles, eight (8) were related to the sowing rates and five (5) to the sowing season, and one (1) referring to both.

3.1.3. Irrigation

The initial screening process based on the title identified 84 articles dealing with the effect of irrigation regimes on yield and quality of common beans. However, the final number of accepted articles was 33 because 51 of them were excluded because 20 were considered irrelevant, as most of them were focused on improving the drought tolerance of common bean (breeding programs, biostimulants application, etc.); 13 were not accessible, 7 were written in a language other than English, 5 were conference reports, 2 were dealing with the common bean canning process, and 4 reported unclear results (where the effect of different irrigation managements was either not well documented or was expressed only as interactions with other applied factors) (Excel Files S1 and S2).

From the total of the articles included in the study, 18 of them examined the effects of different total irrigation-evaporation levels, 9 studied the effects of deficit irrigation at different growth stages and 5 involved different irrigation intervals. Finally, 29 articles studied the impact of different irrigation managements on seed-grain yield, 4 on green pod yield, and 5 on quality of either fresh pods or grains.

In terms of irrigation quality, the initial search yielded 11 articles; however, only 3 met the criteria of this topic. A further three documents were not considered because two of them were not accessible, and one document did not evidently indicate the influence of salt stress on common bean productivity. Five more articles were also excluded as the individual common bean crops were established at saline or contaminated soil, and thus did not report on the quality of the irrigated water. Eventually, all the included studies concerned common bean cultivated only for fresh pod production.

3.1.4. Fertilization

The screening process applied to both databases returned 161 documents, of which only 27 articles were selected for this review study. Among the excluded documents, 17 were written in languages other than English, 23 were either not accessible or not found and 8 were either review or conference paper or notes. Additionally, 68 articles were also excluded as they were irrelevant to the fertigation managements that benefit the yield and the quality of common beans. Finally, 18 articles that study the responses of plants productivity under N-P-K deficit conditions were not considered (Excel Files S1 and S2). Concerning the accepted articles, 7, 19 and 5 articles were focused on the effect of different fertigation managements on fresh pod yield, seed-grain yield, and quality of either fresh pods or grains (respectively).

3.1.5. Intercropping

The initial search returned 24 documents, half of which were selected for further reviewing. In addition, 12 studies were excluded because 2 were not written in English language, 2 were not found and 2 were not in a suitable document type (Excel Files S1 and S2). In addition, six articles focusing on intervention impact intercropped common bean, focused on the nonlegume crop productivity, i.e., the common bean crop having a supportive contribution, and so were also excluded. Among the included articles, all studies concerned common beans cultivated for production of grains, while only one (1) involved quality parameters. Most studies (6) assessed different common bean cultivars as a management option to enhance productivity under intercropping (as a mixture).

3.1.6. Soilless Culture

The screening process identified 40 documents; however, only 5 of them met the acceptance criteria. Thirty-five studies were excluded because they were either considered irrelevant (21), were not accessible (4), were written in language other than English (4) or were not journal articles (6). In addition, eight studies that did not report yield or yield quality parameters, and in three studies, plants were not grown under soilless cultivation systems (Excel Files S1 and S2).

3.1.7. Tillage

The initial search for relevant articles returned thirty-four (34) articles. Sixteen (16) of these articles written in languages other than English (i.e., Portuguese or Spanish) were excluded. Then, during the full text screening, eleven (11) articles were excluded because they were not related to the effects of tillage on common bean yield and/or quality but examined the impact of other cultural practices on common bean yield usually under no-tillage system (Excel Files S1 and S2). The review at the full text level revealed that the tillage systems that were examined in the included studies were conventional tillage (n = 5), deep tillage (n = 1), minimum tillage (n = 1) or no tillage (n = 6).

3.1.8. Rhizobia Application

The initial search for relevant articles returned fifty-three (53) possibilities. Five (5) of these articles were written in languages other than English (i.e., Spanish or Portuguese), and so were excluded. One (1) article was also excluded because it was a conference abstract. Then, during the full text screening, ten (10) studies were excluded because they were conducted in pots, or the control (non-inoculated) treatment was missing or not relevant. One (1) more article was excluded because the full text could not be accessed (Excel Files S1 and S2). It is also noted that the common bean yield impacts of *Rhizobium* strains co-inoculated with plant growth promoting rhizobacteria (PGPR) were examined in twelve articles published between 2008 and 2021.

3.1.9. Biostimulant/Biofertilizer Application

The results of the search on Scopus and Web of Science returned forty-eight (48) published articles, on screening these twenty (20) were duplicates, and four (4) articles were not written in English, and so were excluded. Then, one article was excluded because it was a conference paper. One (1) article was excluded because screening of the abstract revealed it was irrelevant. Therefore, twenty-two (22) articles were accepted (Excel Files S1 and S2). The most studied practices were the applied bioagents PGPRs (n = 9) and humic acids (n = 4). The more recent studies also assessed the impact of amino acid application.

3.1.10. Diseases Management

Thirty-one (31) papers were identified through the screening process four (4) were written in Portuguese and so were excluded. During abstract screening and full text screening, six (6) and two (2) articles, respectively, were excluded because they were not relevant to the research question. Three (3) articles were also excluded because they were conference abstracts (published in scientific journals), while one (1) more study was excluded because it was conducted in pots (Excel Files S1 and S2). In the selected articles, the effects of several pathogens [including, *Rhizoctonia solani* J.G. Kühn 1858 (n = 3), *Macrophomina phaseolina* (Tassi) Goid. (1947) (n = 1), *Fusarium oxysporum* Schlecht. emend. Snyder and Hansen (n = 1), *Fusarium solani* (Mart.) Sacc. (1881) (n = 2), *Ascochyta phaseolorum* Sacc. (1878) (syn: *Phoma exigua* var. *exigua*) (n = 1), *Isariosis griseola* Sacc. (n = 1), *Pseudomonas syringae* pv. *syringae* (Van Hall, 1904) (n = 1), *Xanthomonas campestris* pv. *phaseoli* (Smith 1897) Dye 1978 (n = 3), *Colletotrichum lindemuthianum* (Sacc. And Magnus) Briosi and Cavara, (1889) (n = 2), *Pseudocercospora griseola* (Sacc.) Crous and U. Braun 2006 (n = 3), bean common mosaic virus (BCMV; n = 1), bean golden mosaic virus (BGMV; n = 1)] and fungicides on the yield and/or quality of common bean were examined.

3.1.11. Pest Management

During the title screening stage, five (5) papers were selected. One (1) of these articles written in Portuguese was excluded, while during the abstract or full text screening, two (2) studies were excluded because they were not relevant to pest management, or they were conducted in pots (Excel Files S1 and S2). In the selected studies conducted in Africa, the effects of insects such as the bean leaf beetle (*Ootheca bennigseni* Weise), the bean flower thrips (*Taeniothrips sjostedti* Trybom), the legume pod borer (*Maruca testulalis* Geyer), the cotton bollworm (*Heliothis armigera* Hübner, 1808) ($n = 1$), and the black bean aphid (*Aphis fabae* Scopoli, 1763) ($n = 1$) on the yield of common bean were examined.

3.1.12. Weed Management

During the title screening process, twenty (20) articles were selected. Five (5) of these articles, written in languages other than English (i.e., Spanish or Portuguese), were excluded. During the abstract screening, one (1) more article was excluded because it was not relevant to the topic of this article (Excel Files S1 and S2). The reviewing at the full text level revealed that the weed control methods examined in the selected twelve studies were chemical weed control ($n = 5$), planting pattern ($n = 3$), hand hoeing ($n = 2$), mechanical weeding ($n = 2$), intercropping ($n = 2$), planting date ($n = 2$), mulching ($n = 1$), irrigation level ($n = 1$), solarisation ($n = 1$), and AMF (arbuscular mycorrhizal fungi) inoculation ($n = 1$) (some of the methods can be found in more than one of the selected papers).

3.2. Evolution Articles over the Years

The publication annually of scientific publications relevant to the research question is shown in Figure 3, highlighting that research interest for this crop has gained popularity in the last decade. Indeed, 65% of the research papers included in this review were published between 2011 and 2021, reaching a peak of 33 publications in 2020, which clearly demonstrates the increasing interest of scientists in this area of research and development for common bean. The increase in open-access publishing, which accelerates the advancement of scientific knowledge by making it freely accessible to all the stakeholders, helped towards this direction.

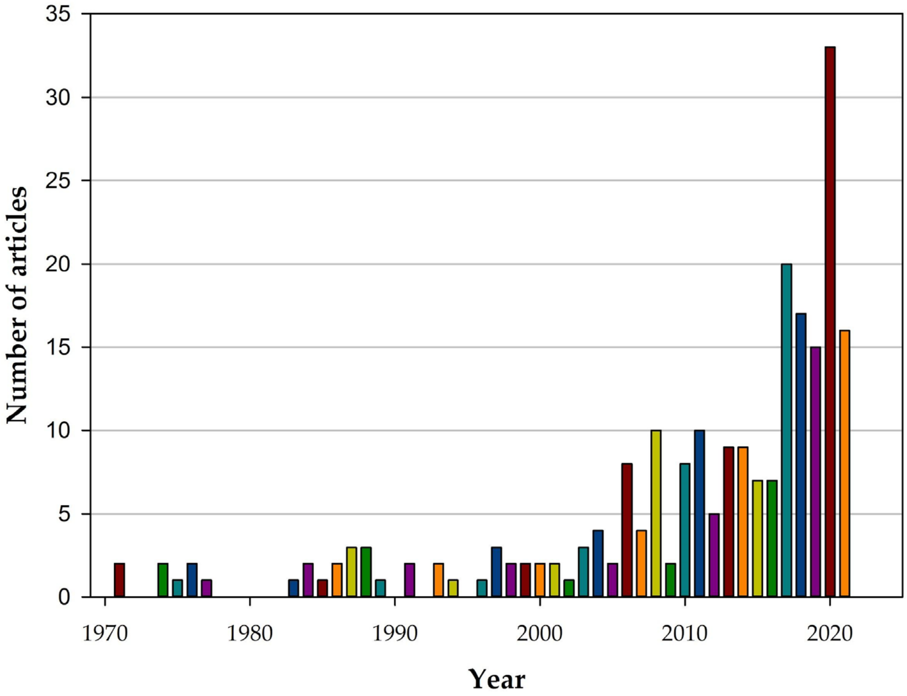

Figure 3. Annual production of scientific publications included in the systematic review.

3.3. Geographical Distribution of Articles

The identified research was concentrated in Asia (65 articles, 28.5%), followed by South America (54 articles, 23.7%), Africa (50 articles, 21.9%), North America (29 articles, 12.7%) Europe (26 articles, 11.4%) and Oceania (4 articles 1.8%) (Figure 4).

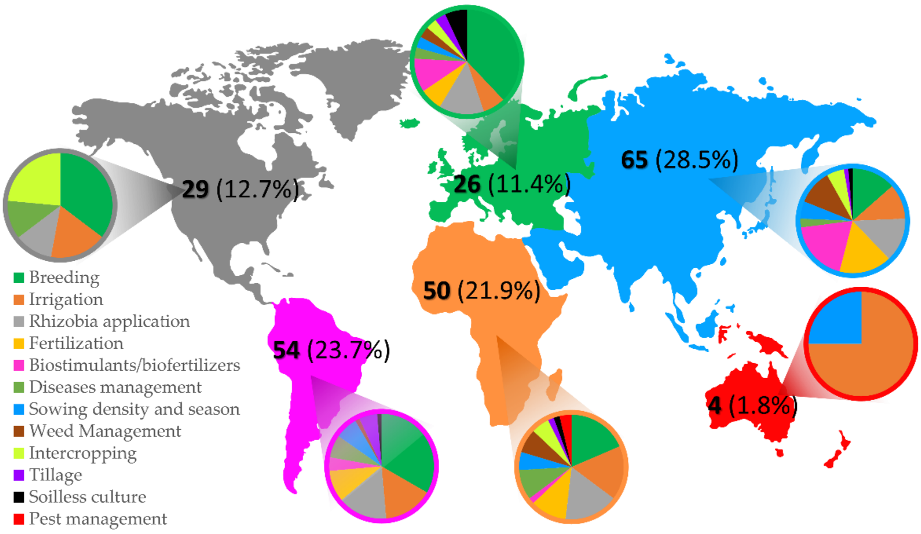

Figure 4. World map showing the number and the percentage (%) of publications per continent. The colour in each pie chart represents the % of publications for each category of agronomic practices (breeding, sowing density and season, irrigation, fertilization, intercropping, soilless culture, tillage, rhizobia application, biostimulant/biofertilizer application, disease management, pest management and weed management, respectively). (Basic map: © Copyright Showeet.com, last accessed on 22 December 2021).

Oceania, semi-arid land and desert region offered relatively few (2%) accessible published papers on this research area, and of the four (4) studies conducted, three (3) were associated with irrigation (published in 1988, 1999 and 2000, respectively) and one (1) with sowing density (published in 1971). Within Europe and North America, the most popular treatments related to breeding trials. A comparison among the different continents revealed that the highest number of publications featured fertilization, biostimulant/biofertilizers and weed management from Asia, while South America focused more on breeding, disease management and tillage, and North America focused on intercropping. Soilless culture seems to gain popularity in Europe, compared to the other continents. Breeding, irrigation, and rhizobia application are the categories that can be found in all continents except for Oceania where only irrigation and sowing density and season had been assessed (Figure S1).

The leading research country addressing the research question was Brazil. Out of the 228 papers included in the study, 44 originated from Brazil, 23 from Iran and 18 from India, followed by Turkey, Ethiopia, Mexico, and USA with 15, 15, 10 and 9 papers, respectively (Figure 5).

3.4. Network Analysis Subsection

3.4.1. Term Analysis

A network analysis was performed to identify trends in scientific research as revealed from the publications used for the systematic review. The analysis using VoSviewer was performed on the text from titles and abstracts. Terms that did not contribute to the analysis, i.e., the words "experiment", "selection", "interaction", etc. were discarded and terms with the same meaning were combined, e.g., the terms "pod yield" and "pod". The frequency threshold (the minimum number of occurrences) of a term to be incorporated in the graphic analysis was set to 10. This threshold was met by 39 terms out of the total number of 5590 terms counted in the reviewed publications. The top-10 terms with the highest frequencies were "yield" (206 occurrences), "pod" (83), "grain" (80), "growth" (86), "cultivar" (63), "genotype" (49), "soil" (44), "quality" (43), "N" (40) and "inoculation" (40).

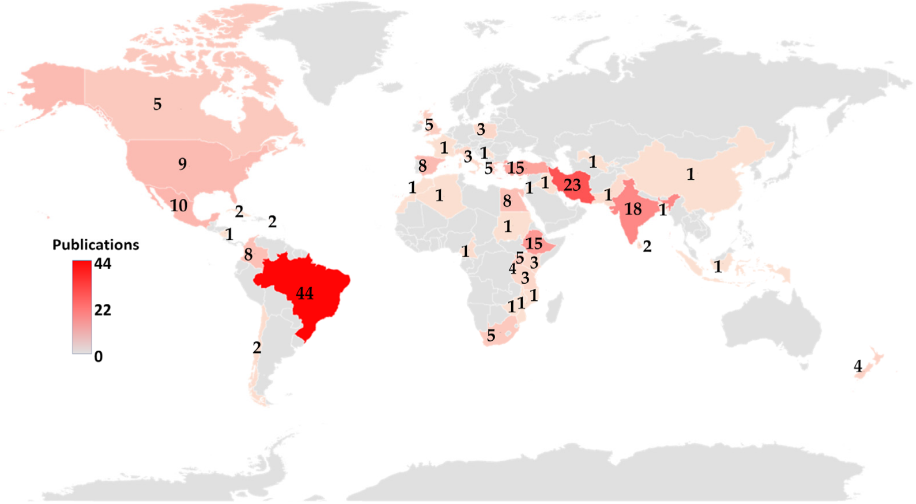

Figure 5. The number of publications included in the study per country (Basic map: © Copyright: Australian Bureau of Statistics, GeoNames, Microsoft, Mavinfo, TomTom, Wikipedia).

The VOSviewer software presented the interactions of the 37 most relevant terms grouped in four clusters (Figure 6A). The larger the circle, the more frequently it occurred. The shorter and/or thicker the line indicates high co-occurrence of interconnected terms. The analysis of the clusters formed by the terms in titles and abstracts allowed the classification of the different groups. The red cluster consists of 12 terms and is linked to yield. The main keywords of this cluster are "growth", "soil", "N", "inoculation", "rhizobia", "phosphorus", "dry weight", and "PGPR". The green cluster is linked to the cultivar topic, which is reflected in the main keywords: "genotype", "population", "region" and, "environment". The main term of the blue cluster is "pod". Terms that belong to the blue cluster are "plant height", "irrigation", "drought", "harvest index", "flowering", and "pod length". The yellow cluster is linked to quality, which is reflected in the main keywords, namely "grain", "quality", "protein", "variety", "intercropping" and "maize".

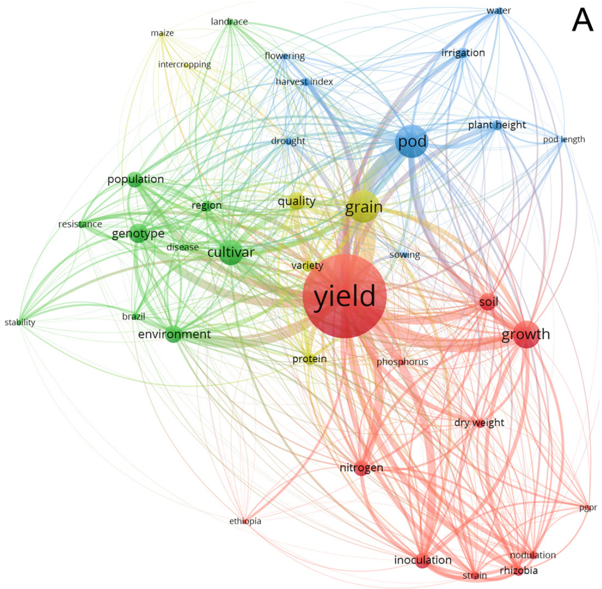

Figure 6. *Cont.*

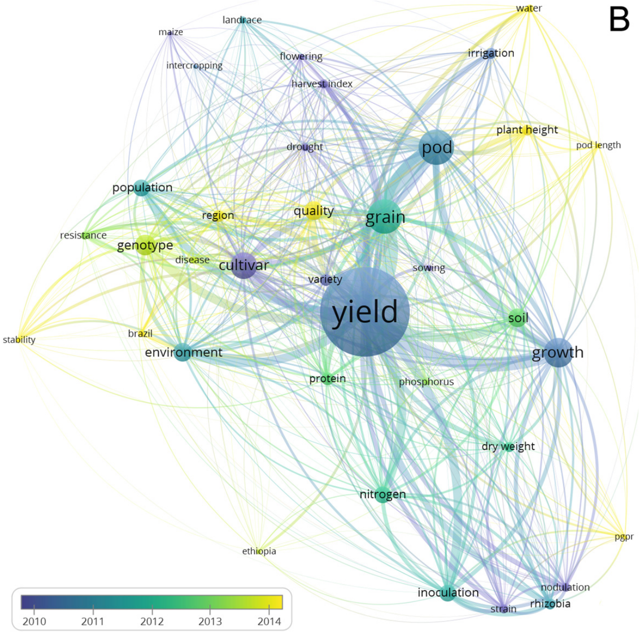

Figure 6. Concept network map produced by VOSviewer for terms counted more than 10 times in the titles and/or abstracts across the 228 publications, which were included in the systematic review. The size of the circle indicates the frequency of the term appearance. The connection of the terms with a line shows co-occurrence. Thin lines indicate low co-occurrence while thick lines indicate high co-occurrence of the interconnected terms. (**A**) Network visualization of terms co-occurrence coloured by co-occurrence and (**B**) thematic evolution of terms in the field of research on agronomic practices that increase yield and quality of common bean, coloured by year.

Classifying the most frequent terms in the title and abstract according to the year of article publications indicated that these terms were primarily used in articles published from the years 2010 to 2014 (Figure 6B). From this analysis, we could see that the terms related to "genotype", "quality", "PGPR", "disease", "stability", "Brazil" and "water" appear after 2013. On the contrary, the terms "cultivar" and "pod" appeared before 2011.

3.4.2. Authors and Countries Network Analysis

To examine the author collaboration networks of this systemic review, the threshold minimum number of publications for an author to be included in the graphic analysis was set to two. This threshold was met by 87 authors of the 847 who appeared in the publications included in the systematic review. The illustrated network revealed 18 clusters of collaborative author schemes and 16 clusters with no collaboration with other research groups (Figure 7A). The largest collaboration cluster (coloured red) consists of nine authors. The main author of the red cluster is L.C. Melo with eight articles, followed by H.S. Pereira with seven articles. The second cluster (coloured in green) is formed by seven authors, and it is closely related with the yellow cluster through the authors S. Nkalubo and C. Mukankusi. In the green and yellow clusters, no central author is identified.

When the author collaboration networks were arranged by the year of article publication, the teams of Mukankusi and Gepts and Javanmard and Morshedloo had the most recent publications (Figure 7B). The publications of the most productive authors go back to 2000. Further author collaboration networks arrangement by the number of citations from each published paper indicated that the team with J.D. Kelley as the lead author had the most cited articles (Figure 7C).

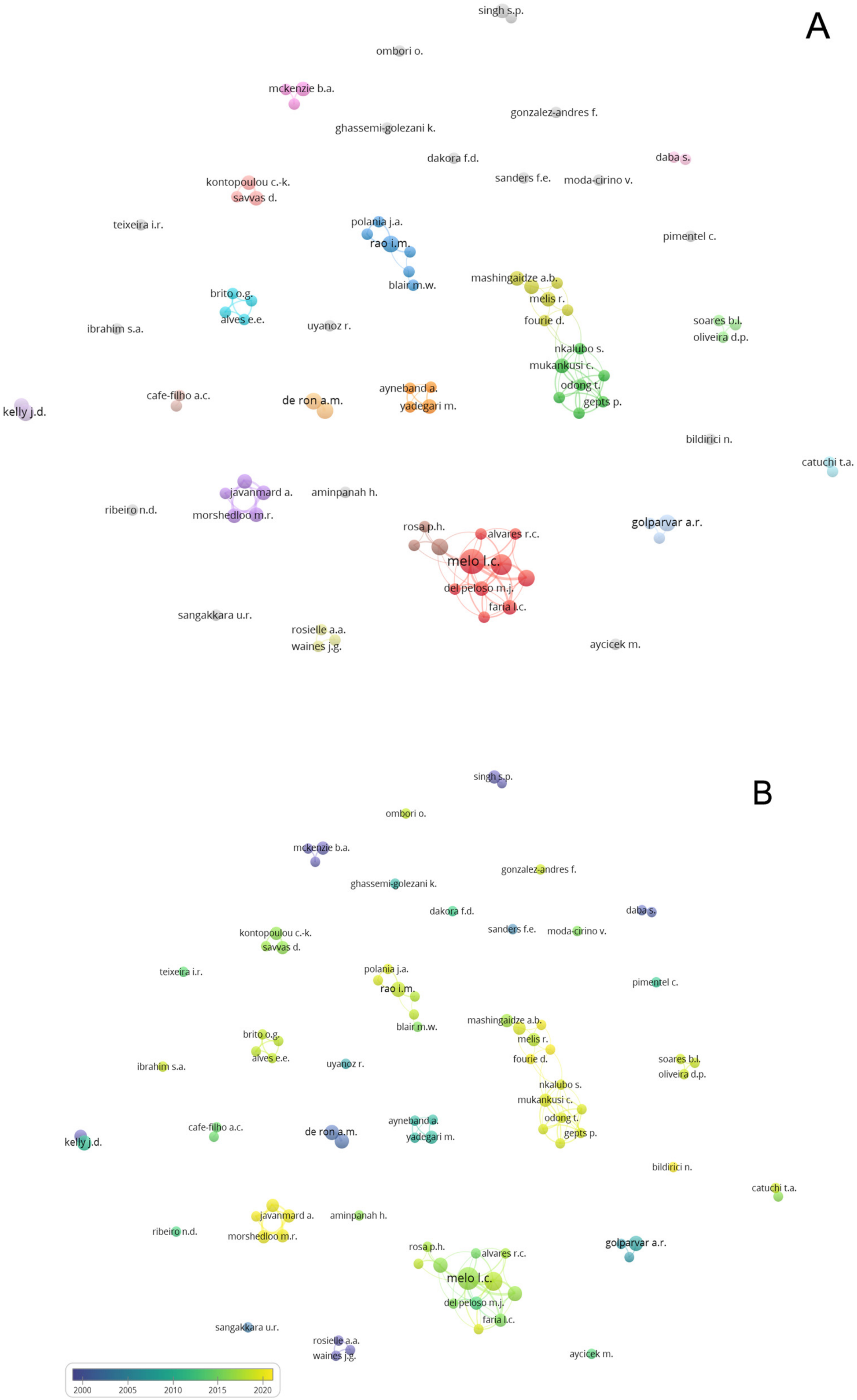

Figure 7. *Cont.*

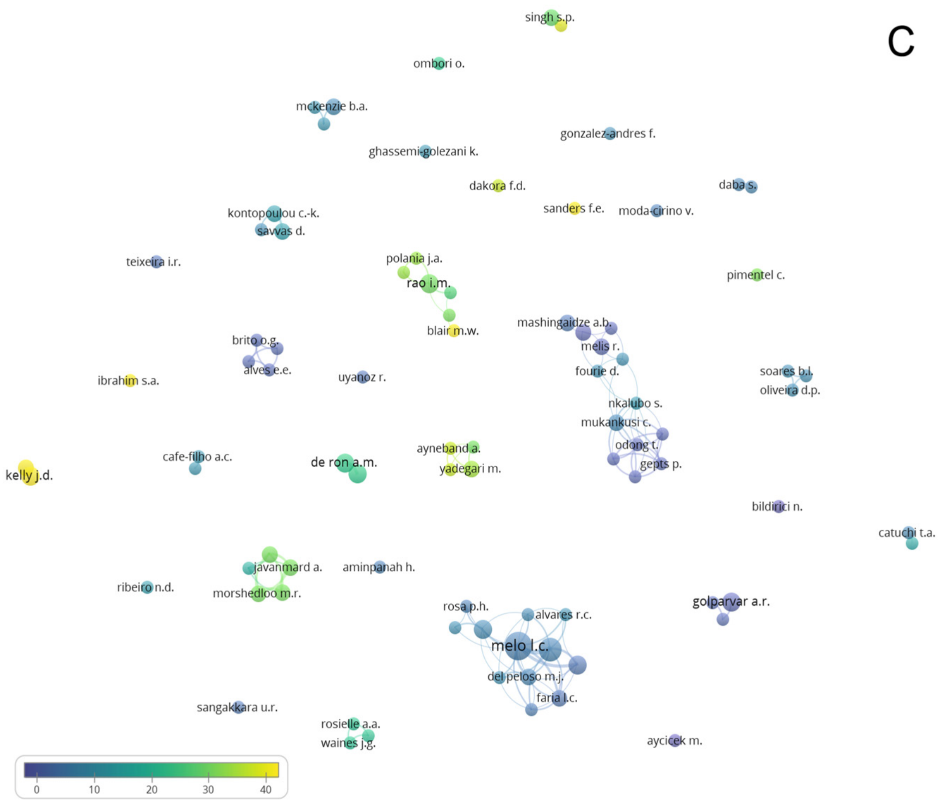

Figure 7. Network map produced by VOSviewer with the collaborations and the number of documents of the authors with more than 2 documents in the 228 publications included in the systematic review. The size of the circle under the author's name indicates the number of publications. The connection of the authors with a line shows co-authoring. (**A**) Network visualization of authors' collaborations. Different colours represent different clusters of collaborative author schemes. (**B**) Thematic evolution of authors in the field of research on agronomic practices that increase yield and quality of common bean coloured by the publication year, or (**C**) coloured by the citations received.

The network of collaboration of affiliating countries for all authors that participate with more than 3 publications in the 228 articles included in the systematic review was illustrated by VOSviewer. Of the 103 countries that participated in the published articles, 24 participated with more than 3 publications, and only 3 countries were not connected to each other (Figure 8A). The illustrated network consists of five clusters coloured blue, green, red, purple, and yellow (Figure 8A). Countries belonging to the same cluster have common publications. Moreover, the most productive countries in terms of co-authored publications are Brazil and the United States, both belonging to the purple cluster. The United States are also collaborating with other countries, such as Mexico, India, Colombia, and Ethiopia. On the contrary, there are scientists, such as from the United Kingdom or Canada, that collaborate with other teams from only one country (Iran and Australia, respectively).

Classifying the affiliating countries for all authors according to the year of article publications, indicated that South Africa, Brazil, India, and Iran participate with more recent studies compared to the United States, Colombia and Mexico (Figure 8B). Further affiliating countries' networks arrangement by the number of citations from each published paper indicated that the citation of a paper is strongly correlated with the publication year, with the oldest publications receiving more citations than those published after 2014 (Figure 8C).

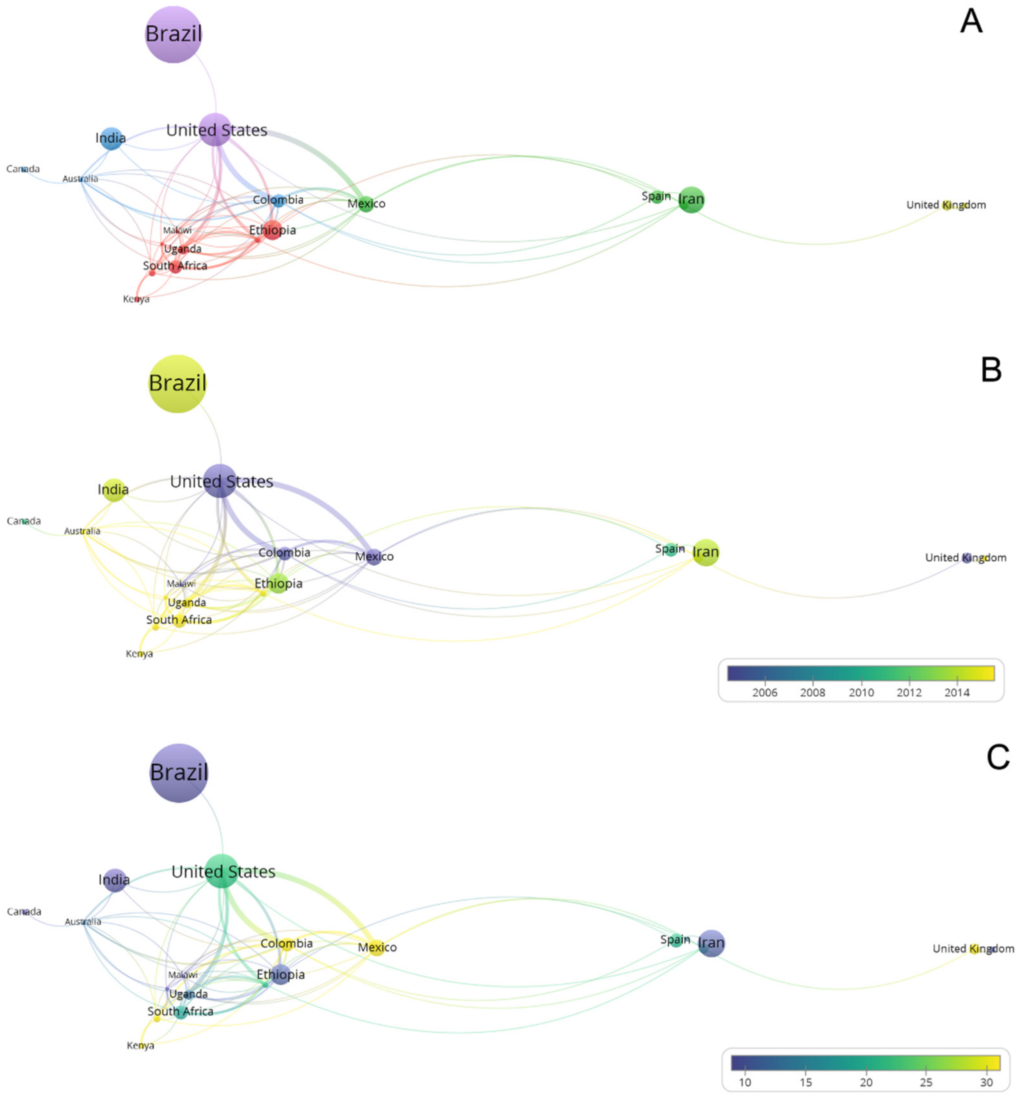

Figure 8. Network of collaboration based on co-authorship between countries that participate with more than 3 publications in the 228 articles included in the systematic review. The size of the circle under the country indicates the number of articles. The connection of the countries with a line shows co-authoring by scientists from the connected countries. (**A**) Network visualization of countries coloured according to the collaborations. Different colours represent different clusters of collaborative countries. (**B**) Evolution of countries in the field of research on agronomic practices that increase yield and quality of common bean coloured by the publication year or (**C**) coloured by the citations received. Produced by VOSviewer.

4. Discussion

4.1. Screening and Bibliometric Analysis

To identify the agronomic practices that affect common bean yield and yield qualities, a systematic review was performed. Integrating this review with bibliometric analysis, we found gaps in (a) the research on the different agronomic practices applied and (b) scientists' networks around the globe. The analysis of the terms in titles and abstracts indicated that the scientific community is interested in the topic related to common bean yield, growth and rhizobia, genotypes, environment, and yield qualities. Over the last 50 years, the research was primarily focused on these topics because of the top 39 terms in the 5590 used in 228 articles, these ten (yield, grain, growth, cultivar, genotype, soil, quality, N, and inoculation) registered the highest co-occurrence frequency. Though common bean is a legume which is cultivated worldwide mainly for dry seeds [25], nowadays growers also produce crops for their fresh pods for food consumption due their high nutritional value [26].

More recently, due to rising need for more sustainable and healthy diets, the scientific community is trying to increase productivity by using either (a) common bean genotypes of increased tolerance to biotic stresses [11,26] and/or (b) by applying PGPRs which increase plant tolerance to biotic stress, enhance plant nutrient uptake, and increase soil fertility [12]. This is also evident in this review because the recent scientific interest is focused on genotypes, yield stability, quality in terms of protein content, disease management, biostimulant application, and irrigation.

The results of this review revealed that the identified research is concentrated in Asia, South America, and Africa because these three continents together represent 75% of the published research papers. This is because grain legumes are the major source of protein for human consumption in many countries in these three continents [25]. However, the high variation in several growth and yield characteristics of common bean constitutes it as a crop with the ability to be cultivated in a wide range of cropping systems and diverse environments around the globe, and especially in countries characterized by a hot and arid climate or at risk of irrigation water deficit (e.g., Brazil, Iran, India, Turkey, Ethiopia, Mexico, and USA). Many of the studies in these countries were related to the evaluation of fertilization, biostimulant/biofertilizer application, weed management, breeding, disease management, tillage, and intercropping. Soilless culture seems to gain popularity in Europe, compared to the other continents. A detailed description of the impact of these agronomic practices on common bean yield and quality attributes is given below.

The bibliometric analysis of the authors through their number of publications and impact on the scientific community shows that the teams consist of only a small number of individuals, which are not connected. This highlights the necessity to develop a global research network for knowledge exchange of agronomic practices that aim to increase the yield and stability of common bean. Interestingly, the most cited author has recent publications, which shows that the impact of the newly applied techniques is increasing. The strong increase in the number of studies after 2010 may also be ascribed to the increasing levels of funding for legumes in the last decade. Moreover, the declaration by FAO of the year 2016 as the International Year of Pulses (IYP) might have also helped towards increasing public awareness of the essential foundation legumes provide to deliver food security due to their capacity to deliver nutrient-dense and environmentally sustainable food.

4.2. Breeding for Increased Yield and Quality

Common bean is considered one of the most diverse crops with varying growth habits, heights, pods, seeds, etc. [27]. Thus, breeding can take advantage of this rich genetic pool to increase yield and yield qualities of this crop. Mesoamerica and the Andes (and their subdivisions) are two distinct regions of origin and domestication for common bean [28]. The independent and parallel domestication resulted in separate gene pools [29]. Beans of Andean origin are less productive compared to the Mesoamerican cultivars when cultivated in warm, tropical environments [27]. However, a significant yield increase could be achieved through crosses between gene pools [30]. Yield in *P. vulgaris* L. may be characterised by three components: pods per plant, seeds per pod, and seed weight. All of which should be maximized for optimum yields. In common bean breeding, the most important attributes for high yield are pod numbers and/or seed per pod, followed by stress tolerance. As a result, breeding programs aim to identify yield-promoting genes and combine them with those governing tolerance to different environmental stresses. Furthermore, Corte et al. [31] studied the correlations of seed morphology (length, width, thickness) with yield and concluded that higher grain yield was produced by shorter seeds.

The first step of breeding programs is to evaluate the existing genetic pools and create a baseline from well-performing and disease-resistant genotypes. Genetic resource evaluation aiming to select high-yielding, resistant germplasm has been addressed by many authors [32–43]. These evaluations revealed that the number of pods per plant were negatively correlated with the days to flowering [28]. Other authors showed that pod yield per plant was significantly and positively correlated with the number of pods per plant (0.833, $p = 0.01$), flower ($r = 0.376$ or 0.379, $p = 0.01$) and pod set ($r = 0.360$ or 0.363, $p = 0.01$) per inflorescence, plant height ($r = 0.291$ or 0.293, $p = 0.05$), number of leaves per plant ($r = 0.277$ or 0.285, $p = 0.05$), and leaf area ($r = 0.50$, $p < 0.05$) [44,45]. According to Zilio et al. [46], when the common bean cycle length is reduced, a yield increase can be achieved. Crossing a determinate and an indeterminate *P. vulgaris* genotype may also increase due to increased number of seeds per pod and pods per plant [27]. The above findings are critical for future population development and the selection of higher yielding common bean lines. Genotype and environment interactions have been thoroughly examined, aiming to identify cultivars of high adaptability and yield stability [47–52]. Among others, Bulyaba et al. [53] reported that seed yield and weight is influenced by the location x variety interaction. Specifically, the highest yield (4402 kg ha^{-1}) was recorded in Michigan and was 23 to 81% higher than other locations. Nicolleto et al. [49] revealed the positive impact of high altitude on the nutritional quality of common bean, strongly linking this effect with the common bean genotype as well. Growing common bean in greenhouse can be a possible solution to overcome the impact of the environment and increase yield and quality, as proposed by Meena et al. [54].

The screening of article titles revealed 17 studies from Brazilian Institutes, which is the largest consumer and third-highest producer-country of common beans worldwide [43]. In Brazil, the breeding strategies for high yielding common bean cultivars development resulted in significant yield gain of around 0.7% a year [11] or a mean of 37.81 kg ha^{-1} $year^{-1}$ [55]. Recently, Zeffa et al. [56] quantified the genetic progress on seed yield and N use efficiency of carioca bean cultivars, using Bayesian statistics to predict breeding value. This approach also resulted in genetic progress for seed yield under high and low N inputs. The United States also shows a great interest in common bean breeding [39,53,57,58]. In Turkey, an increase in common bean yield has been observed during the last decades due to breeding programs that considered the impact of the environment [59–62]. Moreover, 365 genotypes and landraces from Central Africa were also evaluated, revealing a high level of genetic diversity of this crop, and pointing out the differences in the nutritional quality of several landraces in terms of seed iron and zinc concentration [63]. Twenty (20) *P. vulgaris* landraces of South Africa were also studied [64] and the variation in the pod characteristics (number, length and width) was determined. The traits revealed vigorously growing and high yielding varieties for future breeding programs in South Africa. The taller landraces from KwaZulu-Natal province showed the highest pod and seed yield. In Greece, seven (7) common bean genotypes were evaluated in two (2) field experiments for two years [38]. The number of pods per square meter was calculated and found to vary from 72.74 to 247.05. The analysis indicated two cultivars, namely Lida and Mirsini, as superior genotypes that combine stability, high yield (237.8 and 239.2 g m^{-2}), short cooking time (29.0 and 30.3 min) and high protein content (24.51 and 24.79%). The experiments showed that the number of pods was highly associated with seed yield and could be proposed as an indirect selection criterion for increasing yield. The shoot total-N and the number of nodules per plant can also be considered as indirect criteria for such selection [65,66]. It is also worth noting that characteristics related to the consumer market such as hydration capacity, cooking time, shape, size and percentage of grain husk of common bean genotypes must also be taken into consideration [67,68].

High-yielding combinations may also be identified by using either more-traditional crossbreeding methods [57,69–71], or more-recently, molecular markers [41,72,73] or even near-infrared spectroscopy (NIRS) [74]. Molecular marker assisted breeding efforts of Raatz et al. [75] characterised 708 bean varieties, landraces, and breeding lines using Single Nucleotide Polymorphism genotyping markers. The development of such data serves as an important reference guide for scientists and can speed up the delivery of outputs from breeding programs and boost downstream research and development.

4.3. Sowing Density and Season

Plant density is also a key factor that significantly affects yield and yield qualities of common bean. High plant densities can result in increased grain yield due to the sub-branches that grow at the lower part. A crucial factor for maximum yield is the determination of the life history stages of early flowering and pod formation [76]. This is because full light interception by the crop must be reached before the onset of this stage. For common bean, when the density was set to 28.8 plants m^{-2}, the light interception was optimum (95%), just after the onset of flowering [76]. However, the genetic potential for pod formation can be obscured by the competition for space and nutrients that high density causes [77]. In the study of Musana et al. [78], where common bean plants were grown under four different plant densities (20, 25, 30, and 35 $\times 10^4$ plants ha^{-1}), grain yield was restricted at the two higher plant densities. The above study is in agreement with the reports of Mahdi Babaeian [79] and Kouam and Tsague-Zanfack [80] where higher plant densities restricted yield components, and therefore final grain yield. However, the response of common bean to sowing density is cultivar-dependent and closely related to dry matter distribution, growth rate, radiation use efficiency, and harvest index [81]. In terms of crude protein concentration in the seed, no effect of plant density was found [82,83]. On the other hand, pod protein and N, phosphorus (P) and potassium (K) concentrations increased under low planting densities [84] due to low competition for water and nutrients.

Sowing season may also affect yield due to the temperature and rainfall that prevail at critical developmental stages, specifically flowering and pod-filling. For higher grain yield of spring–summer cultivation of common bean, the optimum period for sowing is from early to mid-May [85–87]. Being a C3-cycle plant, cultivation in high temperature environments results in decreased photosynthesis, mainly due to increased respiration and photorespiration. In summer (June–August), the seed yield decreases as the sowing is delayed [71]. Mahdi Babaeian [79] studied two sowing dates one on 2nd June and one on 14th June noticing that sowing on 2nd June increased the seed yield by 9.17% compared to the sowing on 14th June, while the yield components were also higher in the first sowing date. This can be ascribed to the fact that night and/or day temperatures above 25 and 30 °C, respectively, may adversely affect flower buds and pod formation [86] thereby resulting in decreased grain yield. For autumn–winter cultivation of common bean in a tropical climate zone, the suitable time for sowing is the middle to end of October [88].

4.4. Irrigation

Limited irrigation regimes have various effects on both yield and quality of common bean, cultivated for either its fresh pods or dry seed (Table 3). In the rainfed-only cropping systems which are widely adopted in semi-arid and tropical regions, common bean productivity can be severely restricted to levels which are 50% below what could be achieved without water deficit [89–92]. The harmful effects of water deficit on grain yield were also reported in several other studies [82,93–98], where reduced irrigation also lowered yield and yield components. Additionally, limited water availability (i.e., soil moisture levels) due to high levels of evaporation also negatively impacts yield components [10], fresh pod [7,9] or grain yields [8,99]. The detrimental effects of prolonged water deficit stress were also recorded in the studies of Dapaah et al. [100,101] and Love et al. [102], where common bean plants were exposed to no irrigation during the whole cultivation period. Conversely, excess application of water, i.e., to levels above the plant requirement, also limits yield [95] and introduces favourable conditions for disease proliferation, such as that of white mould [103].

In addition to the quantity of water that is applied by irrigation, irrigation interval also plays a major role in common bean productivity because more frequent applications of water can benefit grain yield considerably [104–106]. For example, a high frequency of low volume applications can maintain available soil water above 60% in a 0.60 m depth root zone, thus boosting productivity [103]. Hosseini and Shahrokhnia [107] recommended eight (8) days as the optimum time interval because more frequent irrigation failed to benefit yield and so presented water resource use inefficiency. Conversely, Okasha et al. [108] identified that water supplied every five days restricted the pod number of common bean. The optimum volume and rates will therefore be specific to the prevailing environmental conditions including climate, soil type, crop variety, and irrigation water qualities.

In contrast to the above studies, where the crops were permanently exposed to limited water supply throughout the growing season, other authors focused on the responses of common bean to deficit irrigation at different developmental stages to identify the most resource use efficient irrigation regimes for yield. According to the studies of Santos et al. [109], González de Mejía et al. [110], Boutraa and Sanders [111] and Mathobo et al. [112], water deficit stress induced during reproductive stages including flowering and pod-filling significantly reduced common bean grain yield. Mouhouche et al. [113] proposed that the flowering to fruit setting stage is the most susceptible to drought, where limited water supply restricted grain yield due to the reduction in pod number and seed number per pods—compared to seed filling and maturation phases that appeared to be less sensitive. Contrary to the above findings, Acosta Gallegos and Kohashi Shibata [114] stated that drought during reproductive stage, specifically flowering is responsible for further limitations in grain yield due to the restriction of seed size. By comparison, drought induced at vegetative-growth stage reduced only the pod number. Drought during early growth stages did not substantially affect the grain production of common bean in the studies of Simsek et al. [115] and Peña-Cabriales and Castellanos [116].

Unlike productivity, the impact of different irrigation managements on yield qualities is not commonly documented. According to Smith et al. [89], the limited supply in rainfed common bean systems enhanced N, amino acid, and sugar content of grain. On the other hand, Silva et al. [98] supported that limited irrigation levels restrict the quality of common bean grains by decreasing micronutrient, lipid, carbohydrates, and ash content. Moreover, deficit irrigation can benefit the seed crude protein content [82,98,110]. According to Silva et al. [98], water stress restricts the seed size but not the N translocation to the seeds, resulting in nitrogen accumulation in pods and thus greater protein content. González de Mejía et al. [110] ascribed the higher seed protein levels under deficit irrigation to the increased *de novo* synthesis of drought proteins. Contrary to these reports, Sejal K. Parmar et al. [96] supported that the adequate water supply benefits crop N-utilization and therefore the seed crude protein.

High drought stress and water salinity levels also negatively affect common bean productivity as both cause a significant osmotic stress for the crop, and concomitantly significantly restrict fresh pod yield [117–119] despite the greater protein content and antioxidant capacity of those pods [117].

Table 3. A summary of the impact on common bean yield of varying irrigation regimes and intervals applied to different crop life history stages. The ND denotes nondefined. The ↓ denotes the decrease in crop yield and the ↑ denotes the increase in crop yield.

Treatments		Yield Components					References
		Pod Yield	Seed Yield	Pod Nitrogen	Number Seeds/Pod	100 Seed Weight	
Irrigation regimes	rainfed	ND	↓	ND	ND	ND	[89]
		ND	↓	ND	ND	ND	[90]
		ND	↓	↓	↓	↓	[91]
		ND	↓	ND	ND	ND	[92]
	deficit irrigation	ND	↓	ND	ND	↓	[98]
		ND	↓	ND	ND	↓	[93]
		ND	↓	ND	ND	ND	[94]
		ND	↓	↓	↓	↓	[95]
		ND	↓	↓	↓	↓	[82]
		ND	↓	ND	ND	ND	[96]
		ND	↓	ND	ND	ND	[97]

Table 3. *Cont.*

Treatments		**Yield Components**					**References**
		Pod Yield	**Seed Yield**	**Pod Nitrogen**	**Number Seeds/Pod**	**100 Seed Weight**	
	deficit evaporation	ND	↓	↓	ND	ND	[8]
		ND	↓	↓	–	–	[99]
		ND	–	–	↓	↓	[10]
		↓	ND	ND	ND	ND	[9]
	deficit soil moisture	↓	ND	↓	ND	ND	[7]
Irrigation impact on different growth stages	flowering	ND	↓	↓	ND	ND	[109]
	flowering/ pod filling	ND	↓/↓	↓/↓	–	–	[111]
		ND	↓/↓	↓/↓	↓/↓	↓/↓	[112]
	bud to pod filling	ND	↓	↓	ND	ND	[113]
	reproductive stage	ND	↓	ND	ND	ND	[110]
	vegetive/ reproductive	−/↓	ND	−/↓	−/↓	ND	[115]
		ND	−/↓	ND	ND	ND	[116]
	vegetive/ flowering/ reproductive	ND	↓/↓/↓	↓/↓/↓	−/↓/↓	−/−/↓	[114]
Different irrigation intervals	5, 7, 9 d	ND	↓ (9d)	↑ (7d)	↓ (9d)	↓ (9d)	[108]
	6, 12, 18 d	ND	↓ (d > 6)	↓ (d > 6)	↓ (d > 6)	↓ (d > 6)	[104]
	4, 8, 12 d	ND	↓ (12d)	↓(12d)	↓ (12d)	–	[107]
	7, 14 d	ND	↓	↓	↓	–	[106]

4.5. Fertilization

High productivity of common bean mainly relies on external N inputs due to its poor BNF capacity. The productivity of common bean crops appeared compromised in organic cultivation systems [118,120], where the timing of N supply is remarkably challenging because the mineralisation rates of organic manures is weather- and soil-dependent. In contrast, no significant variations in yield of common bean were found in organic or inorganic fertigation managements in the studies of Uyanoz [121], Karunji et al. [122], and Magalhaes et al. [123]. Karunji et al. [122] reported that the effects of organic fertilizers on soils and plants are detectable in a long run because the differences in yield were significant in the second and third season of cultivation. The soil properties should be taken into account prior to crop establishment and application of a specific fertilization scheme. According to Magalhaes et al. [123], the different farming systems (organic vs. conventional) do not influence the yield when the crop is established in infertile soil with good crop-nutritional provisions. Application of more-complex organic or naturally occurring N source alternatives to chemical fertilizers, which improve soil fertility, function, and resilience, should also be considered as a restorative fertilization management practice. For example, the application of farmyard manure (FYM) equivalent to 75 to 100% of recommended nitrogen increased yield of common bean compared to solo NPK fertilizers [124] due to the beneficial effects of organic manure which included improved crop growth and (so) nodulation (BNF). Moreover, Fernández-Luqueño et al. [125] supported that application of organic waste products (e.g., vermicompost and wastewater sludge) increased yield of bean plants by 20.7 to 37.8% compared to those fertilized with urea due to improved physicochemical characteristics of soils and/or increased the nutrient bioavailability. Additionally, according to Etminani et al. [126], the organically amended soils indirectly enhance the productivity of common bean by decreasing the weed pressure. Eventually, the productivity of crops fertilized with organic or inorganic amendments is largely dependent on the prevailing environmental conditions or pedoclimate because in the study of Kawaka et al. [127], common bean crops responded differently to the above fertigation regimes under short and long rainy seasons.

Mixed or integrated regimes comprising organic and inorganic fertigation schemes are also advocated as adept fertigation regimes, which can optimize common bean yield with fewer environmental burdens. The study of Kumar et al. [128] applied an organic–inorganic (1:3) fertilizer using FYM without limiting yield relative to the 100% inorganic treatment. Furthermore, additional inputs of FYM to standard inorganic inputs increased the yield by 30%. Similarly, Sharma et al. [129] observed that grain yield with application of vermicompost + 75% N was equal to that of recommended application of N, thus reducing mineral fertilizer application by 25%. Such mixtures take a diversity of forms and may comprise NPK + vermicompost + crop residues [130] or moderate P inputs + manure + biofertilizers [131,132]. Moreover, Saikia et al. [133] reported the positive effect of the application of *Rhizobium*, *Azotobacter* and *Azospirillum* on organic fertilizers through the improvement of soil microbial and enzymatic activities. Da Silva et al. [134] reported that the application of organomineral fertilizer (from biosolids) significantly increased yield when combined with 50% recommended dose of inorganic N, compared to control-crop treatments comprising 100% rates of organomineral, or inorganic fertilizers. Musse et al. [135] also highlighted that greater pod yield was obtained by bioslurry amendments under limited N inputs. D'Amico-Damião [136] also found that the straw of maize intercropped with crotalaria enhanced yield and crude protein of common bean grains; however, the agronomic efficiency of this system is higher under limited rates of mineral N supply. All such integrated approaches may be considered as a low cost and efficient strategy for sustainable production of common bean.

Considering the different N managements of conventional cropping systems, Patel et al. [137] advocated the application of a 50% mineral N rate at cropping establishment and the remaining 50% at the crop-branching stage as efficient means to optimize grain yield and benefit–cost ratio. Garcia et al. [138] indicated that split application of N enhanced the seed yield of common bean compared to a single/broadcast application. According to Suárez et al. [139], the response of common bean to N supply is also genotype-dependent and mainly ascribed to the increased photosynthetic N use efficiency (PNUE) and the ability to partition photosynthates to grain. However, N additions may not affect common bean yield where the soil fertility is already high prior to crop establishment [140]. Moreover, Ovacikli et al. [141] concluded that calcium ammonium nitrate, as N source, indirectly benefits yield compared to ammonium nitrate because it encourages PGPR including indigenous rhizobia. In addition, its application in alkaline soil did not restrict crop yield by increasing soil pH due to the Ca inputs. Abebe et al. [142] recommended a combined P plus N amendment comprising 67 kg P_2O_2 ha^{-1} and 27 kg N ha^{-1} = as an optimum fertigation scheme for high common bean yields under good soil moisture conditions, where better utilization of the fertilizer is achieved. Carvalho et al. [143] concluded that the ideal P:K ratio requires more detailed investigation. Additionally, Bildirici et al. [144] recorded a positive correlation between P inputs and crude protein content of grains. However, excess application of P may restrict Zn uptake, thus compromising common bean yield.

Da Silva et al. [145] also reported that foliar application of N, using urea as N source, enhanced yield and N translocation in seeds compared to soil-targeted application. Beneficial effects of foliar application were also observed in the study of Aslani et al. [146] where the plants were treated with different organic-chelate fertilizers. In particular, the foliar application of the organic-chelate products benefited yield, soluble solids, vitamin C, and protein content of fresh common bean pods compared to the plant that were treated with standard soil NPK regime—sprayed either with macro- and micro-nutrient mixtures or not. Finally, Khaber et al. [147] introduced the foliar application of nano-potassium fertilizer as a sustainable fertigation management that optimizes yield and quality of common bean fresh pods.

4.6. Intercropping

Most of the accepted studies implemented heritability and genetic correlation of yield components as tools to optimize the productivity of common bean in intercropping systems. In particular, Balcha [148] recommended grain yield and pod number per plant as the selection criteria to enhance productivity of common bean in both sole and maize intercrop systems, highlighting also the genotypes DAB243 and DAB245 as a breeding material for both systems. Similar interactions among genotypes of common bean and cultivation systems was reported by Zimmermann et al. [149].

Common bean grain yield is higher in monoculture system compared to those which are intercropped [150]. According to Atuahene-Amankwa and Michaels [32], intercrop resulted in 32% grain yield reduction compared to sole crop, while Zimmerman et al. [151] reported significantly higher 100-seed weight for monocropped common bean. This is ascribed to the more controlled environment offered by monoculture systems, and conversely the higher interspecific competition of intercropping. Additionally, Santalla et al. [152] recorded a reduction in seed crude protein when common bean is intercropped with field maize. On the other hand, a yield advantage was found when common bean was intercropped with potato (1:1), compared to the respective monoculture and that the N level applied to common bean can be reduced to 50% without impairing NPK balance in the soil. The above intercropping scheme also provided greater net returns and benefit–cost ratio [153]. Similarly, management practices such as the use of willow as windbreak [154] and humic acid [150] and rhizobia [155] applications can benefit the yield of intercropped common bean.

Concerning the different plant densities, Abd El-Gai et al. [156] recommended the density of one (1) tomato to three (3) common bean plants as an ideal pattern because the increased bean density benefits the total yield of common bean plants without risking tomato production. This pattern was also the most efficient, in terms of common bean productivity, in the study of Sadeghi et al. [157] where common bean was intercropped with safflower, and the efficiency of this system was higher despite weed pressure. Summarizing, both studies revealed that increased population of common bean did not have a pernicious impact on its intercropped partner. This statement is also supported by Raey et al. [158], where a common bean was intercropped with potato as common bean yield was influenced by potato co-crop density due to interspecific interactions, while the productivity of potato was mainly affected by its own plant density (intraspecific interactions).

4.7. Soilless Culture

The dependence of common bean on external N inputs was also recorded in soilless cultivation systems by Kontropoulou et al. [159,160]. Here, N-free or deficit N supply greatly restricted yield of common bean. According to the same authors, inoculation with rhizobia mitigated the adverse effects of limited fertilizer-N conditions; however, the N requirements of the plants for an efficient soilless cropping system were not substantially compensated by rhizobia addition. To benefit from rhizobia inoculation, Kontopoulou et al. [159] also suggested an adequate supply of mineral N during the first three to five weeks of cropping, and a continuous supply of some NO_3 throughout the common bean cropping period in soilless culture.

Apart from N nutrition, Bildirici [161] supported that co-administration of Zn and Cu supply also helps optimise common bean production, compared to separate administration of these micronutrients. In addition, Da Silva et al. [162] recommended 12 different common bean genotypes for high yielding hydroponic common bean with less phosphorous (P) inputs. Azariz et al. [163] found that lead (Pb)-contaminated organic substrates do not restrict yield and yield qualities in terms of Pb accumulation in pod because this element was mainly accumulated in roots.

However, the relatively few research articles reported provide only limited evidence to direct farming practices that optimize the yield and qualities of common bean in soilless culture. This may be ascribed to the fact that in the countries where common bean is the predominant crop, such as India, Brazil and several African countries, hydroponics systems are not widely adopted for cultural and/or socioeconomic reasons. Therefore, soilless common bean production should be served as a research and socio-economic development focused arena for future food and environmental security efforts.

4.8. Tillage

According to Sangakkara [164], soil compaction reduces common bean yield, whereas soil tillage favours root branching and increased yield. In field experiments carried out in Brazil, Costa-Coelho et al. [165] reported that common bean seed yield was higher (627–1067 kg ha^{-1}) in conventional tillage (years 2005/16 and 2006/07) compared to no tillage (218–290 kg ha^{-1}), or minimum tillage (219–540 kg ha^{-1}). The same researchers observed that the severity of web blight (*Thanatephorus cucumeris*) was reduced by 30% under the no-tillage (NT) system. This reduction may be due to grass straw remaining on the soil surface in the no-tillage, which prevented the basidiospores spread of this pathogen via tillage. In contrast, de Toledo-Souza et al. [166] reported increased severity of *Fusarium wilt* (*Fusarium oxysporum* f. sp. *phaseoli)* and lower seed yield (1251–1821 kg ha^{-1}) under the NT system. In another study conducted in Spain, Mulas et al. [167] reported that the inoculation with *Rhizobium leguminosarum* (strain LCS0306) increased common bean yield in conventional tillage (CT) but had no impact in the NT system. In contrast to previous studies, in a rain-fed cropping system, Alguacil et al. [168] recorded the greatest yield (440 kg ha^{-1}) in the no-tillage system in comparison to that in the CT system (mouldboard ploughing). According to these researchers, the higher yield in the no-tillage system may be due to the greater roots colonization by arbuscular mycorrhizal fungi (AMF). Similarly, Fatumah et al. [169] observed that seed yield of common bean crop was approximately 45% higher in NT, and stubble-mulching tillage systems compared to CT and grain water use efficiency was about 56–83% higher under these two tillage systems compared to the CT system. The age of a no-tillage system is also an important factor, and in experiments conducted in Brazil over 23 years of an established NT system, Soratto et al. [170] observed that both seed yield (1786 kg ha^{-1}) and crude protein content (226 g kg^{-1}) were higher compared to a newly established NT.

4.9. Rhizobia Application

Rhizobium inoculation of legumes and concomitantly the nodulation and BNF potential offered is strain-genotype-dependent (Table 4) [18,167]. Da Silva et al. [145] showed that inoculation with *Rhizobium* (strains CM-05 and UMR-1899) increased BNF of common bean (to 70 kg ha^{-1}) and elevation of 55% compared to the non-inoculated plants. Koskey et al. [171] also reported that native rhizobia isolates can be used to enhance seed yield of common bean. *Rhizobium tropici* is widely used for common bean inoculation due to the positive impact on seed yield [132,172]. Similarly, *R. leguminosarum* bv. *phaseoli* strain LCS0306A application resulted in yield increase by 26.56% [16]. Contrary to this, Lucrecia et al. [173], Buttery et al. [174], Crespo et al. [175] and Karasu et al. [176] found that inoculation with *Rhizobium* had no significant effects on common bean yield. Similarly, Massa et al. [18], examined fifteen *Rhizobium* strains and no impact on seed yield was found. This may have been due to the low BNF ability of the examined *Rhizobium* strains, or prevailing environmental conditions (more than adequate soil N levels). The same experiments, however, indicated that the inoculation with the (already mentioned strain) PhVyNOD3 of *R. leguminosarum* increased seed protein content by 9% compared to non-inoculated treatment. A solution to overcome the problem of rhizobia populations, which are ineffective or inadequate in terms of BNF ability, is to identify efficient, competitive, and well-adapted rhizobial strains in different edaphoclimatic zones [177]. Bean breeding can also be an excellent tool towards identifying such strains [178].

Inoculation of common bean seeds with *Rhizobium* strains can have a cumulative effect with N fertilization and crop yield. According to Barros et al. [17], inoculation with *R. tropici* (strain SEMIA 4080) and N fertilization (20 kg ha^{-1} at sowing and 40 kg ha^{-1} at 25 days after emergence (DAE)) resulted in higher yield by 19.82–31.25% compared to that in the N fertilization treatment (20 kg ha^{-1} at sowing and 40 kg ha^{-1} at 25 DAE) without *Rhizobium* inoculation. In addition, Argaw and Muleta [179] reported that when the population of rhizobia in the soil is high, nodulation and BNF is improved, and therefore, the amount of applied N can be reduced.

Seed co-inoculation with *Rhizobium* strains and PGPRs can also be considered an agronomic practice that positively affects growth and yield of common bean. According to Pastor-Bueis et al. [16], co-inoculation of *Rhizobium* strain and *Pseudomonas brassicacearum* subsp. *neoaurantiaca* strain RVPB2-2 or the type strain of *Azotobacter chroococcum* Beijerinck 1901 (ATCC 9043T) increased seed yield by 37 and 28%, respectively, compared to the control treatment. Co-inoculation also of *Rhizobium etli* (strains CNPAF512 and 6bIII) and *Azospirillum brasilense* (strain Sp245) increased yield of the genotype DOR364 by 8–29% compared to single *Rhizobium* inoculation [180]. Last but not least, Filipini et al. [181] and Steiner et al. [182] found that co-inoculation of seeds with *R. tropici* and *A. brasilense* resulted in significantly higher yields too.

Table 4. Effects of Rhizobium species and plant growth promoting bacteria (PGPB) on common bean yield and protein content.

Bacterial Species	Strain	Yield Increase (%)	Protein Increase (%)	References
Rhizobium leguminosarum bv. *phaseoli*	LCS0306	26.56	-	[16]
	L-125	6.04–66.12	-	[183]
	L-125, L-78	34.55–42.49	-	[184]
		6.35	20.32	[185]
	CO5	no impact	-	[173]
	HB-429 or GT-9	30.56–33.59	-	[186]
Rhizobium leguminosarum	PhVyNOD3	-	9	[18]
	vicea	−10.90 (yield reduction)	9.75	[187]
Rhizobium leguminosarum bv. *phaseoli* + *Bacillus subtilis* (OSU-142) + *Bacillus megaterium* (M-3)	OSU-142*: B. subtilis* M-3*: B. megaterium*	6.18	23.13	[185]
Rhizobium phaseoli	HAMBI3570	15.26–78.12	-	[188]
	3644 and 3622	30.86–68.94		[189]
	-	21.56	-	[190]
	-	no impact		[176]
	-	no impact		[175]
Rhizobium phaseoli + *Pseudomonas fluorescens*	Rb-133 + P-93	13.90–54.20	-	[191,192]
Rhizobium etli	HAMBI3556	12.50–79.50	-	[188]
Rhizobium phaseoli, Azotobacter vinelandii, Pseudomonas putida, Pantoea agglomerans, Pseudomonas koreensis, P. vancouverensis	-	9.08	0.87	[193]

Table 4. *Cont.*

Bacterial Species	Strain	Yield Increase (%)	Protein Increase (%)	References
Rhizobium tropici	CIAT 899	no impact	-	[194]
		9.06	-	[17]
		37.57–43.77	-	[195]
	SEMIA 4077, SEMIA 4080, and SEMIA 4088	11.05–16.62	-	[182]
	SEMIA 4080	7.36–20.70	-	[196]
Rhizobium pisi *Pseudomonas monteilii*	R40982	41–59% (common bean genotype BAT-477)	-	[197]
Rhizobium sp.	CIAT isolates 384, 274, and 632	61.11–70.12	-	[198]
	B1	26.55	-	[14]
	Rb-133	9.38–23.50	8.97–21.93	[199]
Rhizobium sp.	CIAT isolates 384, 274, and 632	19.94–70.18 (common bean intercropping with *Sorghum bicolor*)		[155]

4.10. Biostimulant/Biofertilizer Application

Biostimulants are products that contain microbial and/or chemical compounds (i.e., bacteria, fungus, algae, proteins, or amino acids, humic, or fulvic acids) that stimulate plant nutrition processes independently of the product's nutrient content and promote plant growth or protection via improving (for example) nutrient uptake, yield quality traits, plus biotic and abiotic stress tolerance [200]. The application of humic acid improved nodulation by 18% and significantly increased common bean seed yield compared to the control [150]. Humic acid combined with phosphate rock (29.3% P_2O_5) and phosphate-solubilizing *Bacillus pumilus* C2 resulted in increased seed yield [201]. Common bean yield increase can also be obtained by humic acid application combined with zinc and chitosan [202] due to increased nutrient uptake and improved translocation of assimilates from source to sink tissues.

Biostimulant products may also contain AMF [203]. The most commonly used AMF is the *Glomeromycota phylum*, which acts as a photosynthetic activator [204]. Promising results were also recorded as a function of AMF application to alleviate drought stress [205]. Moreover, in the same study, the nutritional value and chemical composition of pods and seeds was positively affected by the AMF too, although this benefit was dependent on the irrigation regime and harvesting time of pods and seeds.

Seaweed extracts of brown algae, e.g., of the species *Ascophyllum nodosum*, and *Ecklonia maxima* have also been proven to increase yield and quality in terms of protein, polyphenols, and flavonoids [206] mainly due to the increased provision of proteins, enzymes, amino acids, phytohormones, vitamins, macro- and micro-elements, polysaccharides and -phenols. Increased dietary fibre content in bean seeds has also been found to result from the application of seaweed extracts and amino acids [20] Considering the biostimulant application method for seaweed extracts, it was found that they should be administered in the form of double spraying, with solutions having high concentration. In terms of amino acids (AAs), foliar application is considered the most effective means of administration, due to the increased tissue-permeation and concomitantly deeper nutrient penetration through the cuticle layer. Moreira and Moraes [207] showed that the productivity of common bean was significantly influenced by the AAs application dose, with the highest seed yield obtained at estimated concentration in 0.0094% of the product in foliar sprays. According to the same authors, the best developmental stage for AAs application is early flowering. The increases in the rates resulted in increased foliar N and zinc concentrations and decreased sulfur concentration. Furthermore, Tabesh et al. [208] used zinc-amino acid chelates (zinc-histidine and zinc methionine) in comparison with zinc-sulphate for seed priming (to improve germination and seedling establishment) and foliar application. Seed priming with these zinc sources was more effective than the foliar application in increasing yield.

According to Rezaei-Chiyaneha et al. [193] PGPR application increased seed yield (by 25%), root nodule number and dry weight, while Kumar et al. [209] showed that the combined application of silicon fertilizer (10 g kg^{-1} soil) and PGPR (4.5 × 107 cfu/g) maximized pod yield/plant (68 g) and antioxidant indicators such as SOD (120 µ/mg) and CAT (84 µ/mg) in saline soil. The positive yield effects are also confirmed by various other PGPR studies [191,192,199], although the mechanisms underpinning these positive impacts are not understood. Despite this, the underpinning mechanisms are hypothesised with the production of (a) indole acetic acid which promotes energy production in nodules [199], (b) phytoalexins and flavonoids which relate to plant protection mechanisms and root development [14], (c) insoluble nutrient mobilization which enhance plant uptake [209] and (d) pathogens inhibitors [203].

4.11. Disease Management

Several diseases have the potential to cause severe damage on common bean crops. The screening process revealed useful information about the effects of diseases and fungicides on yield and/or yield qualities of common bean crops. In a recent study conducted in East-Central Africa, Bruno et al. [210] observed that the severity of diseases caused by *Psuedocercospra griseola* (angular leaf spot), *Xanthomonas campestris* pv. *phaseoli* (common bacterial blight), and *Colletotrichum linemuthianum* (anthracnose), was negatively correlated with the grain yield of common bean. Similar results are also reported by Mongi et al. [211]. The latter found that angular leaf spot resulted in yield loss ranging between 6 to 61% in unsprayed plots, while in the plots sprayed with the fungicide azoxystrobin + difenoconazole the yield loss was lower. Gutiérrez-Moreno et al. [212], studied the effect of inoculating common bean seeds with four different *Trichoderma* strains and found that disease severity was strain-dependent. Moreover, some common bean varieties (e.g., BRS Notável) are reported to present diseases resistance (e.g., anthracnose), whilst maintaining high productivity [213].

Root rot pathogens can also cause severe damage to this crop, and Naseri et al. [214] reported that the infections (e.g., of *F. solani*, *R. solani*, *F. oxysporum*) reduced the pods number/plant and seeds number/plant by 3.3/67% and 3.8/76%, respectively, depending on disease severity. Recently, El-Mohamedy et al. [215] observed that the application of chitosan, humic acid and salicylic acid (plant resistance inducers) decreased the disease severity of *F. solani* and *R. solani* in common bean plants, and increased the pod yield by 8–13%. Moreover, treatment of seeds with beneficial microorganisms (e.g., *Trichoderma viride*, PGPR-1, and *Rhizobium* strain B1) caused a reduction in *R. solani* disease severity, while the crop yield was increased by 10 to 29% compared to that in the control treatment [14].

The fungicides application also contributes significantly to increasing common bean yield. Rodríguez and Meléndez [216] reported that the application of fungicides benomy, mancozeb and chloratholonil decreased the *A. phaseolorum* severity by 20–36%, while the yield of cv. Bonita was increased by 49–58%. In another study, Ellis et al. [217] reported that the application of fungicides (benomy, oxycarboxin) increased 1000-seed weight by 22–24%. In a recent study, da Silveira Cardillo et al. [194] reported that seed treatment with fungicides (e.g., difenoconazole, fludioxonyl + metalaxyl-M, captan) did not affect the root nodulation and the seed yield of common bean.

Common bacterial blight (CBB), caused by the bacterium *Xanthomonas campestris* pv. *phaseoli,* is an important common bean disease. In a recent study, Boersma et al. [218] reported that the CBB disease decreased seed weight by 2–5% on susceptible varieties of common bean. Similarly, Tefera [219] found that the seed yield loss increased as the common bacterial blight disease severity increased. Bacterial brown spot (BBS) caused by the bacterium *Pseudomonas syringae* pv. *syringae* causes significant yield loss in common bean crop. Salequa et al. [42] found that the genotypes of this crop differ in disease severity caused by *P. syringae* with the highest grain yield (1.8 t ha^{-1}) being recorded in the genotype G08 showing the lowest disease severity (22%). In addition, the yield in the genotype G14 with the highest disease severity (53%) was lower by 19% compared to that of G08 genotype.

It is also important to mention that several viruses significantly affect the bean yield and quality. Sarrafi and Ecochard [220] reported that bean common mosaic virus (BCMV) reduced seed yield and seed weight by 15–41% and 4–11%, respectively, depending on common bean variety. Bean golden mosaic virus (BGMV) is also a pathogen that can cause significant yield loss in common bean. Souza et al. [221] reported that seed yield of the resistant CNFCT 16205 line was 18% higher than that in the susceptible variety Pérola.

4.12. Pest Management

Only two papers assessed the impact of pests on common bean yield. According to Karel and Mghogho [222], beetle (*Ootheca bennigseni* Weise) and *flower thrips* (Taeniothrips sjostedti Trybom) incidence increased in non-pesticide-treated plots. Similarly, flower and pod damage caused by *Maruca testulalis* Geyer *and Heliothis armigera* Hübner were higher in non-pesticide-treated plots. However, spraying with the pesticide lindane resulted in significantly higher seed yield compared to the nontreated plants. In addition, organic fertilization increased *Aphis fabae* infestation by 17–50%, though common bean yield was not negatively impacted [122], thereby indicating the possible crop-protectant capacity of organic soil fertility amendments.

4.13. Weed Management

To achieve high yields in common bean crop, weed control is important because crop–weed competition can result in production losses ranging from 12 to 80% [223–226] and a deterioration in yield qualities too [227]. Not all weeds are equally perncious to yield; nevertheless, the broad-leaved weed species *Amaranthus retroflexus* L., *Chenopodium album* L. (Amaranthaceae), *Portulaca oleracea* L. (Portulacaceae), *Datura stramonium* L. (Solanaceae), *Convolvulus arvensis* L. (Convolvulaceae), the sedge species *Cyperus esculentus* L., *Cyperus rotundus* L. (Cyperaceae), and the grass weeds *Cynodon dactylon* (L.) Pers., *Sorghum halepense* (L.) Pers., *Echinochloa crus-galli* (L.) Beauv., *Eleusine indica* (L.) Gaertn., *Setaria viridis* (L.) P. Beauv., *Digitaria sanguinalis* (L.) Scop. (Poaceae) are commonly found in regions where common bean crop is cultivated [157,224,225,228–230]. Chemical control is the most popular method for weed management in common bean, with trifluralin, bentazon, pendimethalin, fomesafen, fluazifop-P-butyl, and quizalofop-p-ethyl being among the most common herbicides used [224,230–232].

According to Singh et al. [230], pendimethalin and quizalofop-p-ethyl significantly reduced weed biomass and density, while pendimethalin provided high efficacy against *C. album* L. resulting in 72% seed yield increase above untreated (control) crops [223]. Several other methods are applied for weed management in common beans and Dusabumuremyi et al. [233] reported that planting common bean in narrow rows (45 cm × 20 cm or 30 cm × 30 cm) increased seed yield by 7–27% in comparison to wide row planting (60 cm × 15 cm). This increase in seed yield is due to the reduction of weed biomass by 12–68%. With narrow-row spacing common bean plants cover the soil surface earlier than that in wide-row planting, i.e., the narrow-row approach serving as means of pre-emptive exclusion of weed growth from the life cycle onset. In another study, Jamali and Aminpanah [228] also reported that planting pattern of 40 cm (distance between rows) × 20 cm (distance of plants in the row) followed by two-hand-hoeing (weeding) at 20 and 45 DAS resulted in high pod yield in common bean crop. Sowing date can also affect the impact of weed density upon common bean yield. In a study conducted in East Africa, Byiringiro et al. [234] reported that the early sowing resulted in (a) an increase in common bean seed yield and (b) a decrease in weed density compared to delay sowing date.

Hand-hoeing (weeding) is a valuable and effective method for controlling weeds in this crop [223,225], though it is labour intensive. In a study conducted in India, Srivastana et al. [223] found that weed control by two-hand-hoeing at 30 and 60 DAS increased seed yield by 71%. Early weed control is also very important in achieving high yield. da Costa et al. [224] reported that one-hand-hoeing at V4 + 3 (stems with three nodes and trifoliate leaves) increased yield by 40% compared to untreated control.

Mechanical weeding between rows is considered common practice for this crop, but the effects on yield maintenance are lower than that of chemical control [232]. Moreover, intercropping is a cultural method used to increase the competitive ability of common bean, and Sadeghi and Sasanfar [157] examined the impact of different safflower (*Carthamus tinctorius* L.) and common bean intercropping patterns on yield of both crops. The results of this study revealed that when the common bean is cultivated as the main crop, the S1B3 treatment (one row of safflower and six rows of common bean) under weedy conditions was the best intercropping pattern to limit the negative effects of weeds on common bean seed yield. Another method that can be used for maintaining seed yield under weed pressure is soil solarization. Soil solarization is a nonchemical means of pest and weed control which involves the soil being covered, often a transparent polyethylene sheet, to trap solar energy. The extreme environmental conditions under the sheet, and at the soil surface, being the pest and weed limiting factors. According to Ngadze et al. [229], soil solarisation for eight weeks with clear plastic to control weed proliferation and resulted in an increase in common bean seed yield by 83%, compared to the untreated control. Mulching has also been examined as a weed management practice for common bean, and Rahman et al. [235] reported that in *Senna siamea* leaf mulch, the common bean yield was increased by almost 5% compared to rice straw mulch, while the weed dry biomass was decreased by 54%.

5. Conclusions

This systematic review identified twelve agronomic practices that affect common bean yield and product quality by analysing the production methods reported in the scientific peer-reviewed literature over the last 50 years. The increase in the number of studies published after 2010 may be ascribed to the increased funding for research projects on legumes due to the drive for more sustainable and healthy diets, demand for plant-proteins as food (as opposed to feed—common beans are rarely used as a feedstock), and as encouraged by the declaration of 2016 as the International Year of Pulses (IYP) by the FAO.

Most of the research was carried out in Asia, South America and Africa, who have a long cultural history of common bean consumption, but whose productivity is threatened because these countries are also characterized by a hot and arid climate with a high risk of experiencing (irrigation) water deficit conditions. These countries include, for example, Brazil, Iran, India, Turkey, Ethiopia, Mexico, and parts of the USA. The lack of international collaboration points to the necessity to establish global research networks that will include different scientists worldwide. This could be used as a call for more coordination at political levels to have more effective and coordinated international research effort to optimise common bean yield potential in an environmentally sensitive and socially equitable manner.

The analysis also revealed increased reporting of common bean breeding and the identification of trait associations between, for example, seed and pod yields with flowering time and plant height. Genotype and environment interactions must also be considered in common bean breeding, aiming to identify yield-promoting genes and combine them with those governing tolerance to different environmental stresses and synthetic nitrogen use.

The choice of the sowing season and density were also shown as important for common bean performance. Both have been shown as cultivar dependent, and therefore the importance of selecting genotypes adapted to semi-arid environmental conditions, combined with the suitable sowing densities, should be priorities for common bean producers. Most efficient fertigation schemes are comprised of the integration of both organic and inorganic amendments—particularly animal manure application during basal dressing because these promote common bean nodulation, BNF, and improve the physical and chemical soil characteristics, especially in semi-arid environments. The precise timing supply of nutrients through inorganic fertilization at different plant developmental stages also helps ensure nutrient requirements are met in a resource use efficient manner, especially for crops of large-scale industrialised or intensive production systems where highest yields are expected. Although, it is stressed that the most environmentally- and/or resource-sensitive fertigation management to optimise crop yields must be balanced in a complementary fashion with the local environmental conditions and soil properties where the crop will be established. As far as soilless culture is concerned, more research is required to identify specific fertigation schemes that optimize yield and yield qualities of common bean.

Because *Phaseolus vulgaris* sp. is susceptible to both osmotic (water) and saline (ionic) stresses, and high yields could only be achieved under levels of irrigation water at the best quantities and qualities. Under water limiting conditions, elevating the soil moisture levels during early flowering and pod filling stages could mitigate the adverse impact on common bean yield.

To optimize the productivity of intercropped common bean, high importance should be given to the density of the plant that common bean is intercropped with. In addition, the integrated fertigation management regimes recommended for common bean monocrops could be adopted to enhance the productivity of intercropped common bean. In addition, selection of the appropriate tillage system is also important for optimising common bean yield, and conservation (i.e., no- and minimum-) tillage practices where crop residues are maintained in field to serve as 'mulches' may also result in increased yield, reduced pest and weed incidence, while also optimising soil functions, including better maintenance of crop-available moisture levels.

Even though *Rhizobium* inoculation of common bean and concomitantly BNF ability is strain-dependent, this agronomic practice can reduce the need to apply synthetic (mineral) N fertilizers to this crop, and without compromising yield. Co-inoculation of rhizobia with PGPRs may also contribute to yield maintenance under reduced synthetic fertilizer use. In addition, biostimulants such as humic acids, seaweed extracts, AMF, and amino acids have also been tested in common bean. Their impact on yield and qualities including quantities and/or composition of those of proteins, enzymes, amino acids, phytohormones, vitamins, macro- and micro-elements, polysaccharides, and polyphenols. Benefits may also extend to increasing crop nutrient- and water-uptake and improved biotic- and abiotic-stress tolerance. The use of such biologicals and biostimulants facilitates a very large market interest and value because they are often perceived as 'natural solutions' to enable more environmentally friendly and resource-use-efficient production. Nevertheless, the very wide range of potential PGPRs, and so their even greater number of combinations, must be considered and tested carefully—including with respect to the method and timing if of applications.

Disease severity in common bean caused by pathogens can be controlled by the use of specific fungicides. Equally, application of beneficial microorganisms (e.g., *Trichoderma* and *Rhizobium*) and plant resistance inducers (e.g., chitosan, humic acid and salicylic acid) can also be effective measures against pathogens (e.g., anthracnose and root rot). Selection of common bean varieties resistant to anthracnose, common bacterial blight and bacterial brown spot should also be considered to avoid seed yield loss. In terms of weed management, and besides chemical control, narrow planting, sowing date, hand-hoeing, intercropping, soil solarization and mulching can all protect yield of common bean by levels of 4 to 80% compared to untreated controls. Additionally, reports of (integrated) pest management practices for common bean are scarce, with only one report on the use of organic soil amendments application and few on chemical control.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/agronomy12020271/s1. Excel file S1: Database of the results of the research. Excel File S2: The exclusion process followed for each treatment, where the columns indicate the exclusion criteria: (a) The topic (treatment/practice) for the search and selection of papers was conducted.

(b) The Initial number of articles found based on the title search in the Scopus and Web of Science literature databases. (c) The number of articles secluded because were either not found or not accessible. (d) The number of articles excluded because they were written in a language other than English. (e) The number of review or gray literature (Notes, abstracts or reports of conferences or other meetings) articles. (f) The number of articles excluded because they concerned investigation with plants cultivated in pots (not field experiments). (g) The number of articles that were excluded because it was clear from the abstract or from the full texts that they did not report results relevant to the treatment under consideration. (h) The number of articles reporting unclear or not well documented results. (i) The number of articles that did not reported results on yield in relation to the treatment under consideration. (j) The total number of excluded articles for any of the mentioned exclusion criteria (columns (c) to (i)). (k) The number of the articles finally selected and included in the review study related to the Treatment under consideration. Figure S1. The percentage (%) of publications per continent for each of the twelve categories of agronomic practices.

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