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Diversification and Management Practices in Selected European Regions. A Data Analysis of Arable Crops Production

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Abstract: In the European Union, various crop diversification systems such as crop rotation, intercropping and multiple cropping, as well as low-input management practices, have been promoted to sustain crop productivity while maintaining environmental quality and ecosystem services. We conducted a data analysis to identify the benefits of crop associations, alternative agricultural practices and strategies in four selected regions of Europe (Atlantic, Boreal, Mediterranean North and Mediterranean South) in terms of crop production (CP). The dataset was derived from 54 references with a total of 750 comparisons and included site characteristics, crop information (diversification system, crop production, tillage and fertilization management) and soil parameters. We analyzed each effect separately, comparing CP under tillage management (e.g., conventional tillage vs. no tillage), crop diversification (e.g., monoculture vs. rotation), and fertilization management (e.g., mineral fertilization vs. organic fertilization). Compared with conventional tillage (CT), CP was higher by 12% in no tillage (NT), in fine- and medium-textured soils (8–9%) and in arid and semiarid sites located in the Mediterranean Region (24%). Compared to monoculture, diversified cropping systems with longer crop rotations increased CP by 12%, and by 12% in soils with coarse and medium textures. In relation to fertilization, CP was increased with the use of slurry (40%), and when crop residues were incorporated (39%) or mulched (74%). Results showed that conversion to alternative diversified systems through the use of crop rotations, with NT and organic fertilization, results in a better crop performance. However, regional differences related to climate and soil-texture-specific responses should be considered to target local measures to improve soil management.

Keywords: diversification; arable crops; tillage management; crop production; fertilization management

1. Introduction

In the last decades, modern agriculture in the European Union (EU) has become highly specialized in either livestock or arable crop production to meet political and economic demands and targets, since the main agricultural challenge has been to increase crop productivity per hectare and per unit of labor, as well as the efficiency of the agri-food sector at all organization levels [1,2]. This simplification has led to the conversion of crop rotations to monocultures, and the intensification of arable farming using mainly mineral fertilizers and deep ploughing, with significant environmental impacts on groundwater pollution, greenhouse gas emissions, soil erosion, loss of biodiversity, and reduction in agroecosystem services [3]. Therefore, there has been a growing awareness that the preservation of environmental quality is crucial, besides the production of food [4]. Further, it has been also argued that the diversification of production systems can lead to better food security [5] and the economic sustainability of farms [6], since it contributes to natural pest control, pollination, nutrient recycling, soil structure and fertility conservation, carbon sequestration, and water provision.

Diversification can occur in many forms (e.g., genetic variety, species, structural) and can be created temporally and over different spatial scales (e.g., within crop, within field, and landscape level), as extensively explained by Lin [7]. Crop diversification [8] at the field scale is the practice of growing more than one crop species within a farming area in the form of rotations (two or more crops on the same field in different years), multiple crops (more than one crop in the same season on the same field) or intercropping (at least two crops simultaneously on the same field). Moreover, the environmental impact of agricultural intensification can be alleviated by alternative management practices like minimum tillage, organic and mixed fertilization, crop residue management, and optimizing water use efficiency for irrigated systems.

As a highly populated area, Europe is facing the pressure to intensify production sustainably. However, the opportunities and means for this differ among regions and the actual effects of diversification on crop production still need more investigation [9,10]. A mapping study concluded that 34% of European arable area has high opportunities for sustainable intensification through e.g., multiple cropping or no tillage (NT) farming [5]. Understanding the expected effects of diverse management options on the resilience and sustainability of agroecosystems in different regions may promote the adoption of less conventional practices and help to select a suitable method for each production system and environment. Therefore, the adoption of crop diversification strategies and alternative management practices may allow to achieve sustainable systems and food production with lower inputs, and minimize the environmental and social impacts of agricultural practices without compromising crop yields and incomes [11]. Finally, diversification is more frequently implemented in the transition from conventional to organic or low-input agriculture [12,13] but its effects on conventional agriculture are less studied [14].

Our study aimed at increasing the knowledge to efficiently tailor the diversified cropping systems, and identifying the benefits of crop associations, alternative agricultural practices and strategies in different regions of Europe in terms of crop production (CP). To the best of our knowledge, this is the first comprehensive study addressing this specific topic at a wide European scale.

Accordingly, the specific aim of the present study was to analyze published field experiment studies providing environmental variables, soil characteristics, and CP (yield for cash crops or total biomass for fodder crops), for evaluating the effect of tillage management, crop diversification and fertilization management on CP, in four selected pedoclimatic regions of Europe.

2. Materials and Methods

2.1. Data Selection

A set of field studies were collected for four pedoclimatic regions of Europe (Figure S1) and in 10 countries: Atlantic (Belgium, parts of France and Germany, The Netherlands), Boreal (Finland, Latvia, parts of Norway and Sweden), Mediterranean North (Italy) and Mediterranean South (Spain). Specifically, we addressed fodder grains in the Atlantic region, fodder leys and mixtures in the Atlantic and Boreal regions, autumn–winter cereals in the Mediterranean North and South regions and spring–summer cereals in the North Mediterranean region.

Data were derived from the scientific literature cited in SCOPUS until August 2017, searching the title, abstract, and keywords of the reference for: "diversification", AND/OR "crop rotation", AND/OR "intercropping", AND/OR "multiple cropping", AND/OR "crop yield", AND/OR "biomass", AND/OR "production", AND/OR "country name", AND/OR "region name". Further results were derived from specific European projects and national reports. A dataset was compiled with relevant data extracted for: (a) site characteristics (region/crop, country, province, experiment site, elevation, mean annual temperature, total rainfall and aridity class [15]; (b) crop information (main and secondary crop production, fertilization and tillage management, crop diversification, i.e., monoculture, rotation, intercropping or multiple cropping); (c) soil characteristics (main chemical parameters and texture group).

After the first search, we further examined the references to be included in the data analysis considering only field experiments with at least one full year. The final selected comparisons were 750 (317 for tillage, 159 for diversification, 220 for fertilization) from 54 references [16–69].

2.2. Data Analysis

We considered the crop production (CP) in the diversified treatments (D) and that of the control (C) of each study. In particular, to eliminate the differences derived from the different CP levels among crops, we evaluated the ratio between the difference (D − C) and the C treatment [70] given by the equation

$$\text{Percentage change (CP)} = 100 \times (CP_D - CP_C)/CP_C \quad (1)$$

We analyzed each effect separately, comparing CP under: (a) tillage management (conventional tillage vs. no tillage (NT), minimum tillage (MT), and rotational tillage (RT) where tillage is implemented at different depths in different phases of a crop rotation); (b) crop diversification (monoculture vs. rotation, intercropping and multiple cropping systems); (c) fertilization management (mineral or no fertilization vs. mixed and organic fertilization). Changes in CP (Equation (1)) were further analyzed by environmental (e.g., climate) or soil parameters (e.g., texture).

To compare the average CP changes (%) among the case studies, we represented all results by Box—Whisker plots (points are mean values, extremes correspond to confidence intervals, CI, at 95%), already adopted in previous data analyses [70,71]. Significance of responses can be considered different if their 95% CIs do not overlap, and different from the control treatment if the 95% CIs do not overlap with zero [72–74]. A stepwise multiple regression using the full dataset was performed to estimate the main effects on crop production changes (%) considering climate (aridity class), region/crop, tillage, crop diversification, fertilization practices, residue management and soil texture, as well as their interactions, based on 16 qualitative variables used as predictors (Table S1). Probability for variable entry was set to 0.05, probability for removal at 0.1. Statistical analyses were performed using Statistica 7.0 (Statsoft, Tulsa, OK, USA).

3. Results

3.1. Tillage Management

Considering conservation tillage systems, CP was higher in NT (12%) compared to conventional tillage (CT) but due to the large variation between soil types and climatic conditions the increase was not statistically significant (Figure 1). MT did not affect CP and RT showed negative average changes in CP. In addition, conservation tillage management as a whole proved to be soil and climate-specific and was more effective on CP in fine–medium textured soils (8–9%) (Figure 2) and in arid and semiarid climates (24%) (Figure 3).

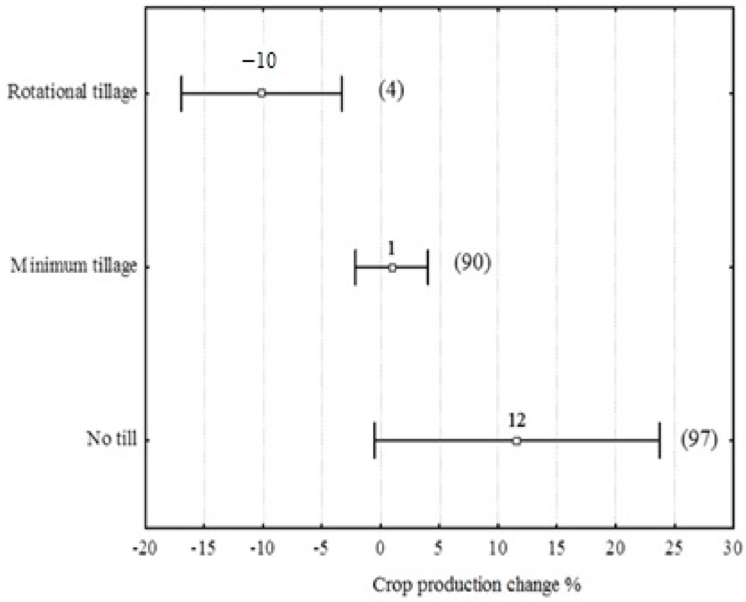

Figure 1. Mean plot of crop production change (%) in conservation tillage vs. conventional deep tillage grouped by tillage management. Box—Whisker plots represent central point means, and 95% confidence interval. Numbers in brackets represent the number of comparisons used in each category.

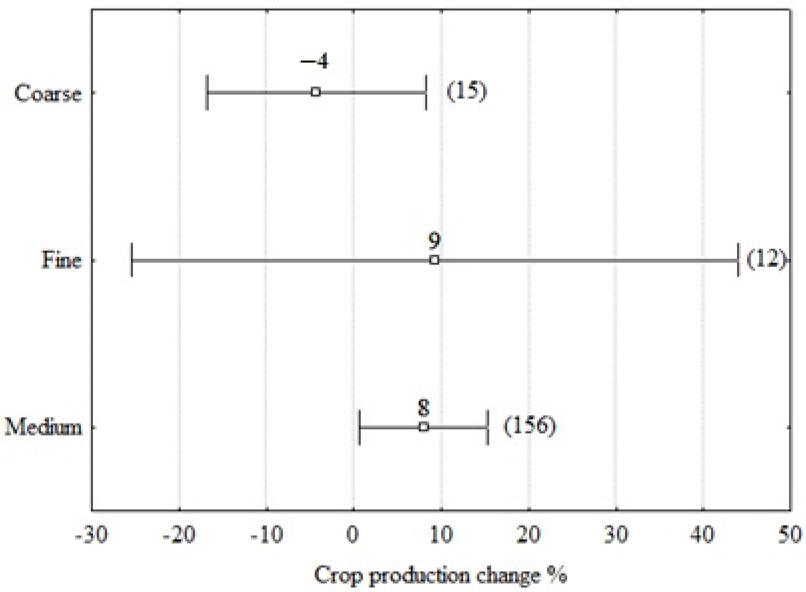

Figure 2. Mean plot of crop production change (%) in conservation tillage vs. conventional deep tillage grouped by texture group. Box—Whisker plots represent central point means, and 95% confidence interval. Numbers in brackets represent the number of comparisons used in each category. Coarse (sandy loam, sandy clay loam, loamy sand), Fine (clay, silt clay, sandy clay), Medium (clay loam, loam, silty clay loam, silt, silt loam).

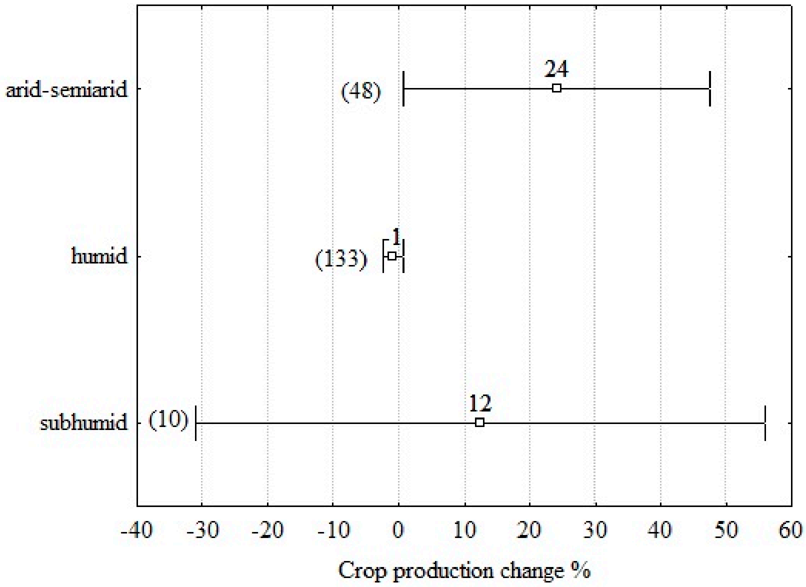

Figure 3. Mean plot of crop production change (%) in conservation tillage vs. conventional deep tillage grouped by aridity class [15]. Box—Whisker plots represent central point means, and 95% confidence interval. Numbers in brackets represent the number of comparisons used in each category.

3.2. Crop Diversification

Diversified cropping systems with long crop rotations (i.e., at least three years with more than two crops in the rotation) were significantly more effective (12%) than monoculture in increasing CP (Figure 4a), while this trend was not observed for the 2 years rotations (5%), intercropping (11%) and multiple cropping (1%). Crop production change differed among soils and was higher when textures were coarse and medium (12%) (Figure 4b).

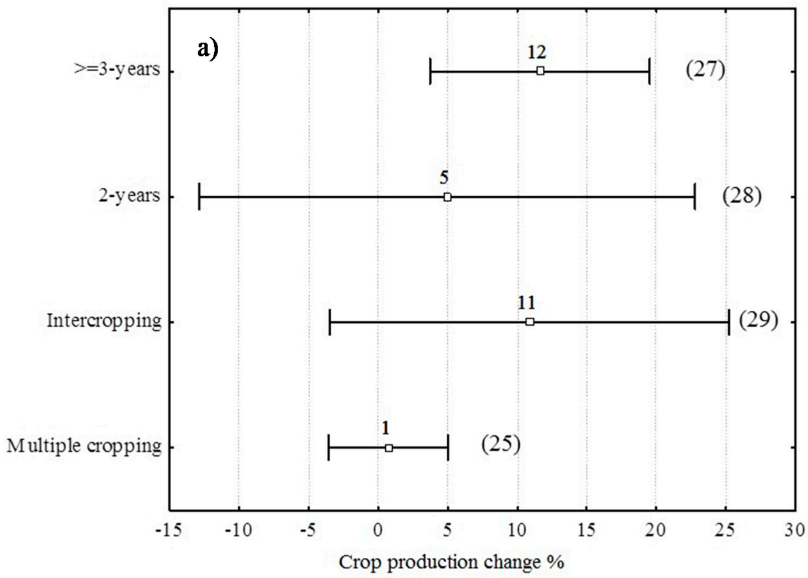

Figure 4. *Cont.*

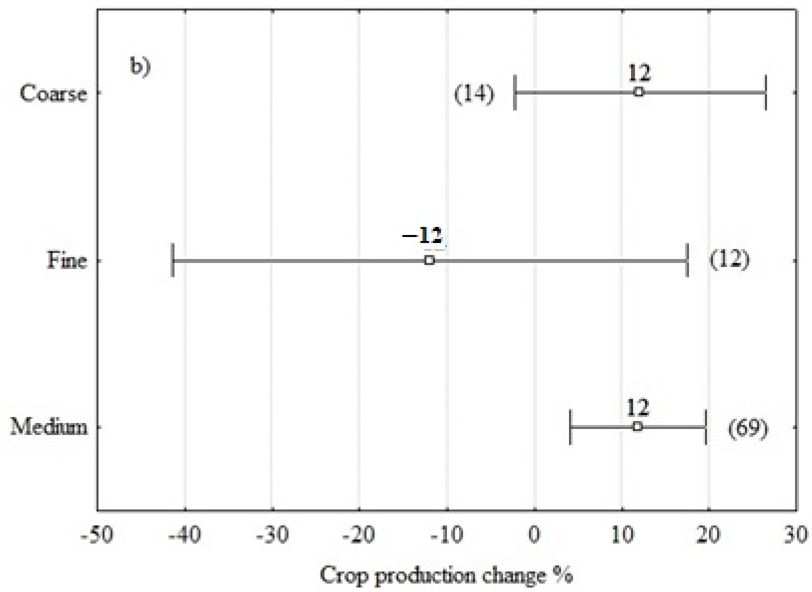

Figure 4. Mean plot of crop production change (%) of crop diversification vs. control management (monoculture) grouped by: (**a**) rotation length and main diversification groups, (**b**) soil texture. Box—Whisker plots represent central point means, and 95% confidence interval. Numbers in brackets represent the number of comparisons used in each category. Coarse (sandy loam, sandy clay loam, loamy sand), Fine (clay, silt clay, sandy clay), Medium (clay loam, loam, silty clay loam, silt, silt loam).

3.3. Fertilization Management

In relation to fertilization management, mineral fertilization improved CP by 61% as an average compared to the unfertilized control treatments. The use of organic fertilizers in the form of slurry was highly sustainable in terms of CP, with an average 40% increase compared to mineral fertilization (Figure 5a). Significant CP increases by fertilization were obtained with crop residue management (Figure 5b) when residues were incorporated into the soil (39%) or mulched with conservation tillage systems (74%), as well as with crop diversification (Figure 5c) with long crop rotations (39%) and intercropping (60%). CP changes compared to the control fertilization were also significantly higher in arid and semiarid climates (64%) and in sub-humid conditions (56%) compared to humid climates (9%) (Figure 6). Actually, overall productivity was higher in humid (7 t ha^{-1}) and sub-humid regions (5.4 t ha^{-1}) compared to arid/semiarid regions (3.5 t ha^{-1}), as a consequence of the different cropping systems (e.g., fodder crops, cereals, sugar beet, irrigated summer cereals in the former, and autumn–winter rainfed cereals in the latter).

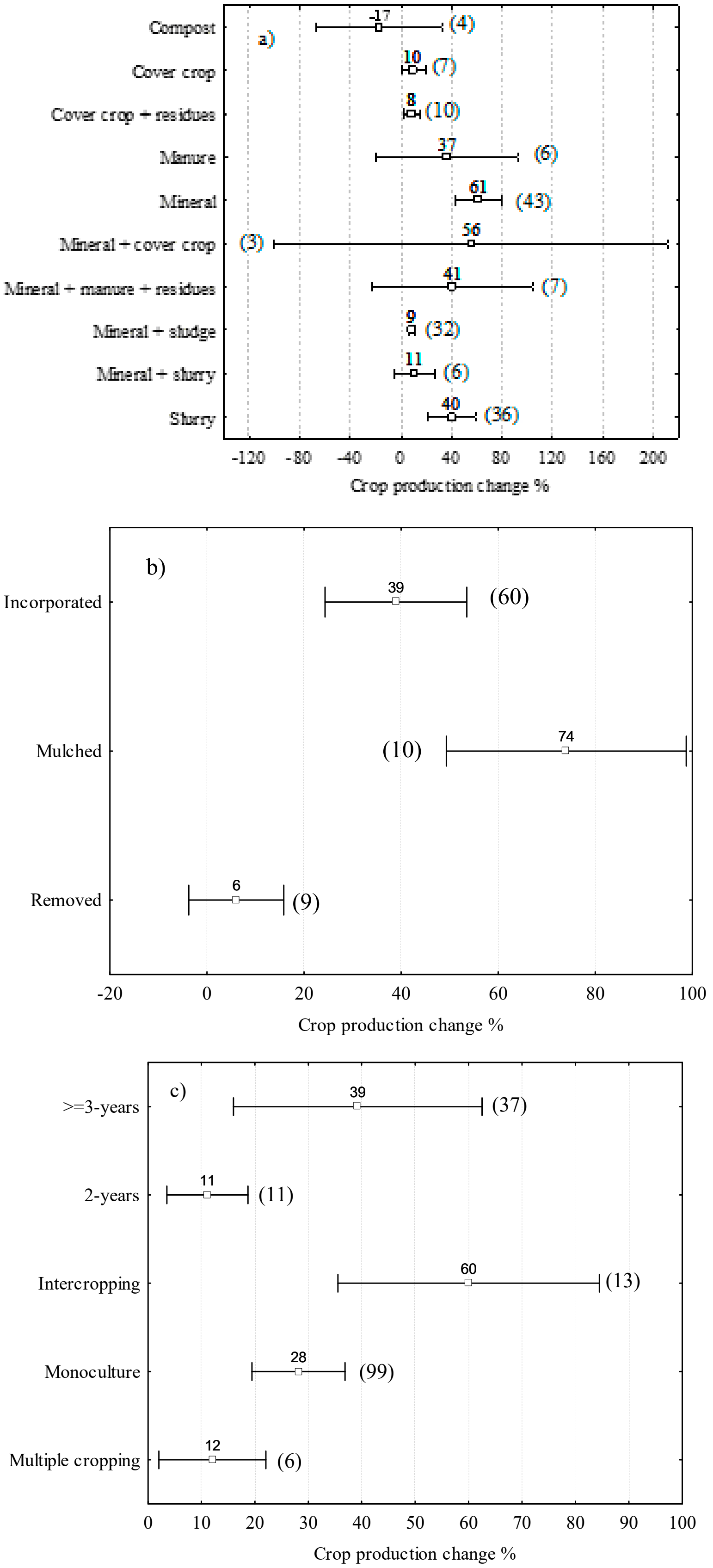

Figure 5. Mean plot of crop production change (%) in fertilization management vs. control fertilization grouped by: (**a**) fertilization type, (**b**) crop residue management, (**c**) crop diversification. Box–Whisker plots represents central point means, and 95% confidence interval. Numbers in brackets represent the number of comparisons used in each category. Note: the literature from the boreal zone was not as inclusive as for the other regions.

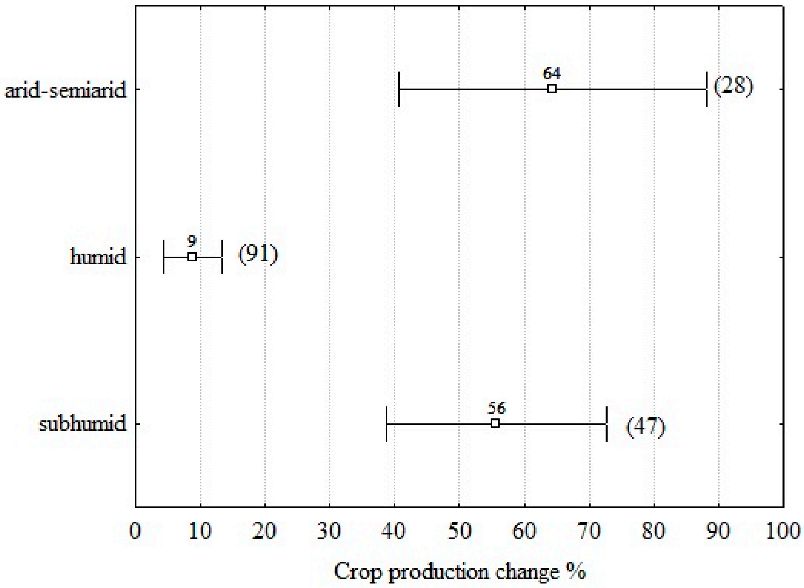

Figure 6. Mean plot of crop production change (%) in fertilization management vs. control fertilization grouped by aridity class [15]. Box–Whisker plots represent central point means, and 95% confidence interval. Numbers in brackets represent the number of comparisons used in each category. Note: the literature from the boreal zone was not as inclusive as for the other regions.

3.4. Stepwise Multiple Regression

Using the stepwise multiple regression method, the variability of the dependent variable crop production change was explained by the following variables and interactions (Table S2): Organic fertilization, Humid, Arid-Semiarid, Fine texture, No tillage × Mediterranean South, Minimum tillage × Organic fertilization, Organic fertilization × Humid, Organic fertilization × Mediterranean South, Organic fertilization × Medium texture, Mixed Fertilization × Humid, Mixed Fertilization × Atlantic-Boreal, ≥3-years × Mediterranean South, 2-years × Mediterranean South, Multiple cropping × Arid-Semiarid, Mulched × Arid-Semiarid.

Model results indicate that crop production changes increased with organic fertilization, under arid–semiarid climate conditions and in fine textured soils, while it decreased under humid climate conditions. A positive interaction was found between no tillage and cereal crops in the Mediterranean South Region and between minimum tillage and organic fertilization. Organic fertilization had a positive interaction with humid climate conditions, cereal crops in the Mediterranean South Region, and medium textured soils. Negative interactions were found for mixed fertilization (e.g., mineral + green manuring of cover crops or residue incorporation) both for humid climate conditions and Atlantic—Boreal cropping systems. A positive interaction was found between the rotations with 3 years of crop diversification and cereal crops in the Mediterranean South region, while negative interactions were found between 2 years rotations and cereal crops in the Mediterranean South region, as well as between multiple cropping and arid-semiarid climate conditions. Mulching of residues had a positive interaction with arid–semiarid climate conditions.

4. Discussion

4.1. Tillage Management

Crop production ranked in the order NT > MT > RT compared to the control with conventional deep tillage (CT). The effectiveness of conservation tillage practices showed a high variability among soil parameters (i.e., soil texture) and climate conditions [15], but as an average of all studies changes were higher in fine–medium textured soils and in arid and semiarid sites located in the Mediterranean

Region. In the data analysis for Mediterranean conditions, Plaza-Bonilla et al. [53] indicated that the average barley grain yield in NT was 2.8 times higher than in CT with disk harrowing to 25 cm depth, and harvest index was 1.3 times higher. These results were explained by the higher soil water storage observed in NT until tillering, that also enhanced the number of spikes. Lampurlanés et al. [36] also concluded that soil water storage increased under rainfed conditions with the use of conservation tillage systems and was amplified with the degree of aridity of the site. Other researches indicated that NT can perform best under rainfed conditions in dry climates [75], in drier years compared to wetter years [26], but also in temperate climates when rainfall is a limiting factor during the grain filling period, matching conventional tillage yields on average [45]. Conversely, differences in CP relative to CT were close to zero (−0.9%) in humid climates where water is usually not a limiting factor, as reported in the two studies included in the present data analysis by Singh et al. [57] for long-term cereal monoculture systems of the Boreal region, and van Faassen and Lebbink [66] for cereals, sugar beet and potatoes in the Atlantic region. Our results are supported by other research [76] stating that crop productivity is modulated by soil texture and yearly climate conditions.

4.2. Crop Diversification

In our data analysis, longer crop rotations resulted in higher CP compared to monoculture, and crop production ranked in the order ≥3 years rotations > Intercropping > 2 years rotations > Multiple cropping. For example, Bonciarelli et al. [23] reported an average yield increase of 18% in a long-term crop rotation in Central Italy (Perugia) with winter and summer cereals in rainfed humid conditions. In the semiarid conditions of Southern Italy, Martiniello et al. [43] showed that crop rotations with an introduction of legume crops were more effective in increasing CP compared to wheat monoculture, both in rainfed (48%) and irrigated conditions (37%).

Intercropping was mainly adopted in the humid conditions of the Atlantic and Boreal regions and showed a general lower effect on CP compared to traditional rotations. In a German study comparing rye and rye–legume crops intercropping [35], included in the present data analysis, the average CP increase compared to monoculture was 18%, while a French study of pea–wheat intercropping showed only a 4% CP increase [51]. Multiple cropping systems rely on plant interactions to increase CP with lower inputs of water and nutrients [77]. However, these systems result in equal or less CP if nitrogen or phosphorus supply is not properly managed, as indicated by other researches [78,79]. In our data analysis, the average effect on CP of multiple cropping with corn and winter crops (e.g., barley, rape) was close to zero (−0.4%) in the Mediterranean region under arid conditions [30,31,54], however, average CP decreased under CT (−6.6%) and increased with NT (5.8%). In the Boreal region and under humid climate conditions, the average CP effect of multiple cropping with different species of fodder crops was 1.3% and ranged from −4.3% with mineral fertilization [34] to 12.6% with organic fertilization, including cover crops and residue incorporation [58]. These results indicate the need for further improvements in the management of multiple cropping systems.

4.3. Fertilization Management

In the present study, average CP change by fertilization diversification was 31.4%, higher in Mediterranean cropping systems based on cereals (51.3%) compared to Atlantic and Boreal regions with fodder grain and mixtures (21.6%). Considering the aridity classes [15], CP changes ranked in the order Arid—Semiarid > Subhumid > Humid. Production change was higher on average with the addition of manure and slurry (39.7%), and in Mediterranean conditions (74.1%) than in Atlantic and Boreal sites (13.8%). Nitrogen mineral fertilization differed by crops and pedoclimatic regions, with the maximum amounts observed in the Mediterranean regions for corn in Italy and winter wheat and barley in Italy and Spain (160 and 108 kg N ha^{-1} respectively). Intermediate amounts were applied in the Atlantic region on fodder grains and cereal mixtures (86 kg N ha^{-1}) and the lowest in the Boreal region (48 kg N ha^{-1}) for fodder grains and cereal mixtures. However, the use of manure and slurry in Atlantic and Boreal regions might cause potential risks of surface and groundwater pollution, mainly with late autumn application when nutrient uptake by crops is low and runoff is high. Consequently, matching the timing of nutrient availability with crop uptake is needed for higher CP increases [80].

Crop production increased more when fertilization management was coupled with mulching, a common management practice under NT, and the incorporation of residues, that is widely adopted in conservation tillage management, as reported in the different studies included in the data analysis, both in Mediterranean [53,62,68,69] and in Atlantic and Boreal regions [32,50,58,67]. In addition, the data analysis indicated that diversified cropping systems with longer rotations and intercropping showed higher CP increases with fertilization [27,37,47,69].

4.4. Benefits and Limitations of the Study

This is the first data analysis of crop production changes in European arable systems, performed in an attempt to consider as many variables as possible that could affect crop production at the farm level for diversified cropping systems, and alternative tillage and fertilization management. We also introduced an environmental parameter (i.e., the aridity index summarizing the rainfall and temperature conditions of a site) and, additionally, we would expect that crop production changes could be different due to local differences in soil texture, a parameter regulating many important soil processes such as water retention and water availability for crops. However, our data analysis was limited to four European pedoclimatic regions, i.e., Atlantic, Boreal, and Mediterranean North and South (Figure S1), but excluded Continental, Lusitanian and Pannonian regions that did not have partners in the project for research on arable systems.

Extension services could benefit from this data-analysis by providing guidance to target the local adoption of measures to improve soil management by tillage, crop diversification and fertilization. No tillage can be promoted in the Mediterranean South areas under the cultivation of autumn–winter cereals, while higher benefits will derive from organic fertilization in association with minimum tillage. Long crop rotations (at least 3 years with more than two crops in the rotation) should be suggested as an alternative to more traditional 2 years rotations or monoculture in the Mediterranean South areas, while no crop production change improvement would derive from multiple cropping. Organic fertilization has an overall benefit in all regions, but particularly on medium-textured soils. Conversely, mixed fertilization (e.g., mineral fertilizers + green manuring of cover crops or residue incorporation) is less effective under humid climates (e.g., Atlantic and Boreal regions) and in fields cultivated with fodder crops and fodder mixtures. Mulching of crop residues can be promoted under arid and semiarid climates (in association with no tillage). The same targeted measures could be promoted in other European regions with similar characteristics in relation to climate, soil texture and arable cropping systems.

Furthermore, results could be biased from some implicit limitations of the examined literature, that did not report some of the basic information required to evaluate the factors and may result in heterogeneous outcomes among the different studies [81]. This is the case of the nutrient supplies in the different treatments that would have allowed a quantitative comparison of mineral fertilization with organic inputs based on the equivalence of their nutrient supply. Actually, many studies were excluded from the data analysis, which limited the number of references examined in some regions, due to the lack of basic information, such as deficiencies in data reporting (no raw data or summary statistics presented for the response of both the control and treatment groups), data presented as figures (their extraction with software would introduce further uncertainties), missing geographic location and information on climate, soil and elevation, missing units (e.g., no indication if crop production given as dry or fresh weight), no study design reporting control and treatments (as already provided in other papers with no or limited data accessibility). Suggestions on data sharing and standardization are reported in other studies [81,82]. The best option may be to provide all the data that cannot be included in the published study as Supplementary Materials. In addition, participants to H2020 projects are bound to Open Access publishing and raw unprocessed data (e.g., xls, csv, shp) must be stored on public repositories (e.g., Zenodo).

5. Conclusions

The data analysis of some European arable systems showed that conversion from traditional monocropping systems with intensive tillage and mineral fertilization to alternative diversified systems using crop rotations, together with no tillage and organic fertilization, results in a better crop performance. Increases in crop production were observed especially when longer crop rotations (≥3 years) and no tillage were adopted, and particularly on medium-textured soils and dry climates. Furthermore, the results suggest that organic fertilization with manure and slurry is a recommendable practice to enhance crop productivity, with the greatest positive impact observed in Mediterranean areas and on medium soil textures.

Notwithstanding, crop diversification and environmentally sound farm management strategies are often negatively perceived by farmers due to a possible decrease in yield and economic benefits, that are often coupled with higher machinery investments. But a major strength to encourage adoption is that the crop species adopted for diversification are already cultivated as monocultures since these are well suited to the local pedoclimatic conditions and provide good production levels. Therefore, farmers just need to learn how to use them in combination as rotations, multiple cropping or intercropping. On the other hand, a major weakness is that few farmers are experts in crop diversification. Thus, providing adequate training for public officers and agricultural technical advisors is crucial for successfully implementing diversified cropping systems among farmers. Additionally, the identified low-input farming practices (e.g., organic matter application, and crop residues mulching with no tillage or incorporation with minimum tillage) are easy to implement, are not costly, and do not require either major investments in new machinery or great farming skills to learn. This suggests a further significant potential for their implementation at the technical level. However, regional differences related to climate and soil-texture-specific responses should be considered to target local measures to improve soil management.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/10/2/297/s1, Figure S1: European pedoclimatic regions and crop diversification systems addressed in the data-analysis, Table S1: Predictive variables considered in the stepwise multiple regression analysis, Table S2: Results of the stepwise multiple regression analysis between crop production changes and predictive variables.

Author Contributions: Data analysis and methodology, R.F.; Data search and collection, R.F., J.Á.-F., C.D.B., L.G., K.R., and E.T.; Writing—review and editing, R.F., J.Á.-F., C.D.B., K.R., and E.T. All authors have read and agreed to the published version of the manuscript.

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