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Review

Organic Greenhouse Production: Towards an Agroecological Approach in the Framework of the New European Regulation—A Review

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Abstract: The next challenge of organic farming, according to many authors, is to overcome the horizon of a method of agricultural production towards a wider agroecological perspective whose main objective is to change the dominant agri-food system. In parallel with the discussion on the future of organic farming, in the European Union (EU), the more intensive systems of organic production in protected conditions have been the object of debate among the main actors of organic farming in the Member States (MS). The introduction of common measures for greenhouse production in the new European regulation on organic production represents the first important step in the implementation of more resilient cropping systems in protected conditions. This paper has the ambition of describing the evolution of the scientific and technical debate on organic greenhouse production in Europe over the last decade, and aims to show how the new regulation on organic farming has partially embedded some of the conclusions of the multi-actor discussion on the main production issues in protected conditions.

Keywords: agroecology; agri-food system; protected condition; input substitution

1. Introduction

Many scientific papers and reports have been written during the last few years on the need for transforming food systems to meet the next global challenges. Starting from different viewpoints, they often reach the same conclusions. Food should be produced respecting the planetary boundaries to reach the UN Sustainable Development Goals (SDGs) while reducing agriculture's environmental footprint [1–3]. Similarly, at the European level, a comprehensive analysis of the EU food system came to the conclusion that, as a consequence of the high import of soybean for animal feeding, it is increasingly outsourcing its environmental footprint and is not sustainable any longer [4]. According to Eyhorn and co-authors [2], while the analysis of the global food system is widely shared, the way to achieve the global food transformation needed to feed the increasing world population while reducing the environmental footprint of food production, is debated and controversial. From one side, conventional agriculture, characterized by high productive performance, is suggested as a solution by improving resource use efficiency while reducing its negative externalities. On the other side, a transformative redesign of farming systems based on agroecological principles is proposed. In this framework, an organic farming method of production, which has been proven—in respect to conventional agriculture—to improve soil quality [5–7], to reduce the rate of biodiversity loss [8,9] and to reduce the environmental impact in terms of greenhouse gases (GHG) emissions [10], represents one of the viable alternatives.

Even though organic agriculture, at a global level, still represents no more than a niche sector of agricultural production systems, it has passed through different stages, over time [11]. Organic

1.0 is the period during which the vision of organic agriculture developed, Organic 2.0, which has characterized the last three decades, is the period of the rapid growth of organic agriculture, due to the activities of organic associations and the development of organic research institutions and regulations. Organic 3.0 refers to a new period in which organic agriculture is globally diffused and contributes to solving the global challenges of agri-food systems in the near future [11]. So, the next most important challenges of organic agriculture will be to overcome the horizon of a method of agricultural production, to embrace the wider perspective of a new approach to the whole agri-food system, from producers to consumers, from farm to fork. An agroecological perspective that takes into account not only the primary production, but the entire supply chain (processing, transportation and logistics), encompassing health, cultural, social and ethical aspects of the agri-food systems needs to be adopted [4,12–16].

In the last decade, in parallel with the debate on the need of an agroecological approach to organic production, a strong discussion on the principles of organic farming has been carried out by the main actors of the sector (producers, consumer association and policymakers) as a consequence of the diffusion of organic systems of production characterized by a high level of intensification.

The main objective of this paper is to describe the evolution of the scientific and technical debate in Europe on organic greenhouse production systems and the regulatory development in EU organic regulation regarding this specific subject. It is known that organic production systems in protected conditions implement some of the more intensive systems of production and, despite their relatively low agricultural area in Europe (estimated around 6000 ha, according to Tittarelli and co-authors [17]), play a pivotal role in the trading of organic vegetables within EU boundaries. Their economic value in some European regions and the concern relative to their more intensified systems of production have induced the research for alternatives, adapted to specific local climatic conditions, and the introduction of specific rules in the new Regulation on organic production (EU) 2018/848 [18].

2. Input Substitution Approach/Conventionalized Organic Methods of Production

In the European Union, Article 5 of Reg (EC) No 834/2007 [19] on organic production and labeling of organic products states that " . . . *organic farming shall be based on the following specific principles:*

a. the maintenance and enhancement of soil life and natural soil fertility, soil stability and soil biodiversity preventing and combating soil compaction and soil erosion, and the nourishing of plants primarily through the soil ecosystem;

b. the minimisation of the use of non-renewable sources and off-farm inputs;

c. the recycling of wastes and by-product of plant and animal origin as input in plant and livestock produce;

d. taking into account of the local or regional ecological balance when taking production decisions;

f. the maintenance of plant health by preventative measures, such as the choice of appropriate species and varieties resistant to pests and diseases, appropriate crop rotations, mechanical and physical methods and the protection of natural enemies of pests . . . ".

Nevertheless, especially in the more intensified organic systems of production, the limitless use of off-farm inputs often takes over the agronomic practices and organic principles reported in the European Regulation on organic production. This is the basis of the so-called "input substitution" approach [20].

In systems of production mainly based on input substitution, soil fertility is managed only with the use of off-farm fertilizers listed in Annex I of Reg (EC) No 889/2008 [21]. Plant nutritional needs are treated on a case by case basis by "substituting" off-farm synthetic inputs (typically used in conventional agriculture) with off-farm organic inputs. Even though this method of production is based on the application of products allowed by the ruling standards of organic farming (and can be certified as organic), it is often considered by organic stakeholders as an imitation of conventional methods of production [22]. That is why it is often referred to as a "conventionalized" organic farming system [23]. Of course, the level of "conventionalization" can differ from one system to the other over

a wide range of possibilities and is reasonable to think that the more "conventionalized" systems of production cannot be considered environmentally friendly just because they are certified organic if the main difference respect to a conventional system of production is the simple substitution of a synthetic fertilizer with a certified organic fertilizer [24,25].

3. Intensive Systems of Production and Their Compliance with Organic Principles

Vegetable production in protected conditions (plastic tunnels or greenhouses) is probably the most intensive agricultural system of production both in conventional and organic conditions. High productive performances are obtained in a heated greenhouse by a high level of energy use. The climatization of greenhouses is responsible for great part of energy consumption, mainly by fossil fuel. Organic greenhouse production, to reduce the risk of fungal diseases, requires even more accurate climatic management—for humidity control, with higher energy consumption with respect to conventional production [26]. The use of renewable energy is technically feasible, but its economic sustainability is still debated. Moreover, the use of fossil fuel is often preferred because CO_2 produced by its combustion can be used to enrich atmospheric air (up to 1200 ppm) with a significant increase in productivity [27]. Energy consumption in high-tech greenhouses depends on many factors, but mainly by the insulation of the greenhouse and by the difference between the internal required temperature and the external temperature. Of course, different cultivated crops have different heat requirements, being, for example, leafy vegetables more resistant to low temperatures, as reported by Theurl and co-authors [28], with respect to other commonly cultivated vegetables like tomato, sweet pepper or eggplant. Stanghellini and co-authors [26] reported that the yearly energy consumption for tomato in high-tech greenhouses is around 36 m^3_{gas} m^{-2}_{soil} (corresponding to around 360,000 m^3_{gas} ha^{-1}) with a yield of around 500 t ha^{-1} [29]. Unheated greenhouses have lower energy consumption, of course, but relatively lower productivity because growing conditions cannot be optimized like in the high-tech heated greenhouses. Moreover, a widespread and increasing concern all over Europe is related to the high amount of copper-based fungicides which are usually sprayed in unheated greenhouses, especially in Mediterranean regions, and is responsible for copper contamination of food and soil.

In any case, both heated and unheated organic greenhouses are characterized by highly intensified systems of production. According to Reg (EC) No 834/2007 [19] and to Reg (EC) No 889/2008 [21], the approach to soil and to soil fertility management is what discriminates more conventional systems from the organic systems of production. Based on what is written on the "Whereas" section of (EC) No 889/2008, which states as follows:

> *"(4) Organic plant production is based on nourishing the plants primarily through the soil ecosystem. Therefore hydroponic cultivation, where plants grow with their roots in an inert medium feed with soluble minerals and nutrients, should not be allowed."*

Soil grown crops are the only ones that can be labeled as organic. The use of fertilizers and organic amendments listed in Annex I—Fertilizers and soil conditioners referred to in Article 3(1) of (EC) No 889/2008 [21], fixes further boundaries between conventional and organic production.

At the same time, such a "simplified" approach to organic production, according to which an agricultural system of production can be defined "organic" by substituting the not allowed inputs with the allowed ones, simply does not work or generates unbalanced systems.

In their work, Zikeli and co-authors [30] clearly explained why the input substitution approach to organic production, in protected conditions, increases the risk of negative externalities on the environment. Organic greenhouse production is characterized by high yields of high nutrients demanding crops. Huge amounts of animal manure and compost with slow-release N and low N/P ratio, respect to crop needs, are applied and integrated with high supply of organic fertilizers rich in easily mineralizable organic N. Input–output balances of nutrients for organic greenhouse production carried out in Germany and the Netherlands put in evidence nutrients imbalances with high surplus

of N, P and S [30,31] which can negatively affect the environment by soil nitrate leaching and possibly by the emission of nitrous oxides.

To maintain soil fertility and avoid negative environmental impacts, organic farmers can use a wide range of soil fertility management tools such as soil tillage practices, crop rotations, organic amendments and agroecological services crops (ASCs) [17], but to be effective, they must be applied to less intensive production systems.

If the main objectives of organic greenhouse production are the same of conventional greenhouse production (i.e., to maximize the yields of few fruit vegetables) and the agronomic practices adopted are based on a simple substitution of synthetic inputs with allowed organic inputs, the negative consequences of unbalanced systems of production cannot be avoided. Moreover, the application to soil of huge quantities of organic amendments derived by the transformation of agricultural wastes can also have a negative environmental effect on soil and reduce the level of sustainability of such practice.

The maximization of yields per square meter and the need for rapid economic returns for the high investment costs in greenhouse construction are important aspects to be taken into account for assessing the economic sustainability of organic greenhouse production, but are responsible for unexpected side effects. In particular, the process of "conventionalization" of organic greenhouse production has led to the peculiar situation, within the greenhouse sector, in which "conventional" producers, who use less water and in a more efficient way, fewer nutrients and substitute fossil fuel with renewable energy, affirm to be more sustainable than some organic producers who implement more intensive systems of production [32]. Furthermore, the lack of specific standard rules for organic greenhouse production in the European regulation has been filled up with different interpretations of Reg (EC) No 834/2007 [19] by the Member States of the European Union and mutual blame of unfair competition among producers [32]. The real challenge was to set common rules that were compliant with the principles of organic farming and that took into account the climatic differences among the European Union countries, respecting the cultural diversity of people and accepting agricultural practices and methods based and developed on the sustainable exploitation of local natural resources. In case this challenge is not taken up, the risk could be the weakening of standards for organic production with an immediate effect in lowering the bar to entry to the organic market allowing the inclusion of industrial models of agriculture [33].

4. The Report on Greenhouse Production (Protected Cropping)

In 2009, the European Commission established the expert group for technical advice on organic production (EGTOP) with the main tasks, among the others, of " . . . *assisting the Commission in evaluating products, substances and techniques which can be used in organic production taking into account objectives and principles laid down in Regulation (EC) No 834/2007 and in improving existing rules and developing new production rules*" [34]. In 2012, the Expert Group for technical advice on organic production, under a specific mandate, was requested to elaborate a report on the more controversial aspects of organic greenhouse production in the European Union.

The final report on greenhouse production [27] starts with the consideration that, at the moment, EU regulation on organic farming contains no specific rules for greenhouse production, apart from a ban on hydroponic production. The lack of specific rules has led the Member States and national organic associations to adapt general rules to their own climatic conditions and geographical position, with the consequence that practices implemented in one region are often banned in another one. On the basis of this premises, even though the report stated that organic greenhouse production must comply with the principles and rules of organic farming reported in Reg (EC) No 834/2007 [19] and (EC) No 889/2008 [21], some specific rules for organic production in protected conditions are needed. In particular, the report claimed that organic greenhouse production had an "outstanding performance" in the responsible use of energy, water, soil and organic matter because they play an important role in the environmental sustainability of the adopted organic cropping system. Moreover, EGTOP expressed

its concern on the high level of cropping intensification of some organic greenhouse production systems which could reduce the public trust in their sustainability.

In the following sections, conclusions and recommendations are presented regarding just three of the main controversial issues discussed in the report on Greenhouse Production (soil fertility management, energy use and use of growing media for plant production), because they were the object of strong debate after the publication of the report.

4.1. Soil Fertility Management

As a general consideration, in organic greenhouses, the same criteria applied for open-field plant production (laid down in Reg (EC) No 834/2007 [19] and (EC) No 889/2008 [21]) can be used. Anyway, even though the inclusion of legumes and green manures in crop rotations is explicitly mentioned in Art. 12(b) of Reg. (EC) 834/2007 [19], according to EGTOP, these practices were intended for arable cropping and are inadequate for other production systems such as permanent crops, pastures and greenhouse production. Starting from the consideration that greenhouse rotations are simpler than arable rotations, the cultivation of annual legumes and green manure crops cannot be proposed for greenhouse production, *" . . . but shorter-term green manure crops including legumes can be grown"*.

4.2. Energy Use

As pointed out above, in greenhouses, light, temperature and CO_2 concentration can be strongly modified and controlled by farmers. The added value of controlling the greenhouse environment is to optimize the growing conditions of cultivated crops with a significant increase in yields. The side effect is potentially high energy consumption. Article 3 (iii) in Reg (EC) No 834/2007 [19], generically mentions the environmental issue of energy use by inviting farmers to a "responsible use of energy", while the need of reducing the consumption of fossil fuels comes from the request of minimizing the use of non-renewable resources and off-farm inputs (Art 5 (b) in Reg (EC) No 834/2007) [19]. The need for artificial light and heating varies greatly among different geographical areas in Europe and EGTOP recognized that different strategies can be utilized to reach the objective of a responsible use of energy. In any case, the report put in evidence that since CO_2 enrichment is more effective, in terms of productivity, in summer rather than in winter, it is quite common that farmers use fossil fuels not only in winter (for heating), but also in summer to obtain CO_2: *" . . . in this case, the main purpose of fossil fuel burning would be CO_2 production and the heat produced would represent a by-product"*. The EGTOP also observed that the lack of the added value of CO_2 emission, as a consequence of fossil fuel combustion, could prevent farmers from switching to the use of renewable sources of energy like geothermal, wind and solar power. This would be a clear conflict with the organic principles of the minimization of the use of non-renewable resources and of a responsible use of energy.

In order to induce a more responsible use of energy, EGTOP proposed to allow greenhouse heating to 5 °C, without limitation, to guarantee frost protection (derogation to higher temperatures are allowed if greenhouses are insulated).

4.3. Use of Growing Media for Plant Production

Article 4 of Reg (EC) No 889/2008 [21] clearly states that hydroponic production is prohibited. Reg (EC) No 889/2008 [21] does not explicitly ban plant production in organic substrates and some Member States see no contradiction with organic principles in cultivating on active organic substrates [32]. Moreover, some authors published papers on the environmental sustainability of demarcated bed-grown vegetable crops and on the quality of vegetables grown on organic substrates [35–37].

In its report, EGTOP started from the consideration that production of organic plants should take place in soil, and then, to reduce the degrees of freedom in the interpretation of the word "soil" reported that *" . . . 'soil' means that the upper soil is in contact with the subsoil, so that roots can grow into the subsoil"*.

At the same time, EGTOP individuated exceptions to this general rule, accepting the cultivation in substrates for seedlings and transplants (for organic plant nursery), and, to preserve the common habit of many consumers to buy herbs and ornamentals in pot, for plants which are sold to the public together with the pot in which they were grown.

The criteria at the basis of this derogation from the soil-grown condition are that, for consumers, it is very clear that the plant they are buying was grown on a substrate. As a consequence of this derogation, EGTOP clarified that "*. . . organic produce harvested out of sight of consumers should always come from plants grown in soil, and not from horticultural substrate cultures*". In this way, consumers buying organic products seen on the shelves of a supermarket or of a greengrocer are sure that they were produced in soil.

A special issue, in the framework of plant production on substrate, is the production of vegetables in so-called "demarcated beds" "*which is a form of substrate culture, where the plants are grown in large containers, bags or beds surrounded by plastic sheets/fleece where the roots may or may not be in contact with the soil*" [27]. This is a method of vegetable production that is quite diffused in northern European countries like Sweden, Norway, Finland and Denmark, where it is certified as organic [38]. The EGTOP recognized that production on the demarcated bed had been locally certified organic for a long time, but, at the same time was concerned by the fact that this method of production is in contradiction with the principles and objectives of organic farming. Since the total area covered by greenhouses where this production method was implemented was quite small (around 18 ha), it was decided to keep the organic certification to those farms which had used demarcated beds in the past (before 2013, date of publication of the report), but EGTOP opposed, for the future, to any enlargement of such area in any European Union Country.

5. The New Regulation (EU) 2018/848 on Organic Production and Labeling of Organic Products

The new Regulation (EU) 2018/848 [18] on organic production and labeling of organic products shall apply from the 1st of January 2021. After many years of debates, the new regulation on organic production has not even mentioned the problem of energy consumption in an organic greenhouse. Just a generic "responsible use of energy" is mentioned in the General Principles paragraph (Article 5—letter c). Anyway, apart from the aspect of energy consumption, some of the more controversial issues regarding organic greenhouse production have been included in Reg (EU) 2018/848 [18]. A comparison with the main rules on soil management and fertilization in Reg (EC) No 889/2008, is reported in Table 1.

Common rules were set to reduce the interpretation and adaptation of general rules for organic farming to the climatic condition of each Member State. The more relevant changes respect to the previous regulation on organic production are reported in Annex II—Part I: Plant production rules, as follows:

1.1. Organic crops, except those which are naturally grown in water, shall be produced in living soil, or in living soil mixed or fertilized with materials and products allowed in organic production, in connection with the subsoil and bedrock;

1.4. By way of derogation from point 1.1, the following practices shall be allowed:

- *(a) growing plants for the production of ornamentals and herbs in pots to be sold together with the pot to the final consumer;*
- *(b) growing seedlings or transplants in containers for further transplanting.*

1.5. By way of derogation from point 1.1, growing crops in demarcated beds shall only be allowed for the surfaces that have been certified as organic for that practice before 28 June 2017 in Finland, Sweden and Denmark. No extension of those surfaces shall be permitted.

That derogation shall expire on 31 December 2030.

By 31 December 2025, the Commission shall present a report to the European Parliament and the Council on the use of demarcated beds in organic agriculture. That report may be accompanied, where appropriate, by a legislative proposal on the use of demarcated beds in organic agriculture.

1.9.2. The fertility and biological activity of the soil shall be maintained and increased:

(b) in the case of greenhouses or perennial crops other than forage, by the use of short-term green manure crops and legumes as well as the use of plant diversity.

Table 1. Comparison of main criteria for soil management and fertilization in Reg (EC) No 889/2008 and Reg (EU) 2018/848.

Reg (EC) No 889/2008—Plant Production	**Reg (EU) 2018/848—Annex II—Part I: Plant Production Rules**
Art. 3—Soil Management and Fertilization	**1.9. Soil Management and Fertilization**
1. Where the nutritional needs of plants cannot be met by measures provided for in Article 12(1)(a), (b) and (c) of Regulation (EC) No 834/2007, only fertilizers and soil conditioners referred to in Annex I to this Regulation may be used in organic production and only to the extent necessary. Operators shall keep documentary evidence of the need to use the product.	1.9.1. In organic plant production, tillage and cultivation practices shall be used that maintain or increase soil organic matter, enhance soil stability and soil biodiversity, and prevent soil compaction and soil erosion.
2. The total amount of livestock manure, as defined in Council Directive 91/676/EEC (8) concerning the protection of waters against pollution caused by nitrates from agricultural sources, applied on the holding may not exceed 170 kg of nitrogen per year/hectare of agricultural area used. This limit shall only apply to the use of farmyard manure, dried farmyard manure and dehydrated poultry manure, composted animal excrements, including poultry manure, composted farmyard manure and liquid animal excrements.	1.9.2. The fertility and biological activity of the soil shall be maintained and increased: (a) except in the case of grassland or perennial forage, by the use of multiannual crop rotation including mandatory leguminous crops as the main or cover crop for rotating crops and other green manure crops; (b) in the case of greenhouses or perennial crops other than forage, by the use of short-term green manure crops and legumes as well as the use of plant diversity; and (c) in all cases, by the application of livestock manure or organic matter, both preferably composted, from organic production.
3. Organic-production holdings may establish written cooperation agreements exclusively with other holdings and enterprises which comply with the organic production rules, with the intention of spreading surplus manure from organic production. The maximum limit as referred to in paragraph 2, shall be calculated on the basis of all of the organic-production units involved in such cooperation.	1.9.3. Where the nutritional needs of plants cannot be met by the measures provided for in points 1.9.1 and 1.9.2, only fertilizers and soil conditioners that have been authorized pursuant to Article 24 for use in organic production shall be used, and only to the extent necessary. Operators shall keep records of the use of those products.
4. Appropriate preparations of micro-organisms may be used to improve the overall condition of the soil or the availability of nutrients in the soil or in the crops.	1.9.4. The total amount of livestock manure, as defined in Directive 91/676/EEC, used in the in-conversion and organic production units shall not exceed 170 kg of nitrogen per year/hectare of agricultural area used. That limit shall only apply to the use of farmyard manure, dried farmyard manure and dehydrated poultry manure, composted animal excrement, including poultry manure, composted farmyard manure and liquid animal excrement.
5. For compost activation appropriate plant-based preparations or preparations of micro-organisms may be used. (d) wood, not treated with chemical products after felling; (e) mineral products referred to in Annex I, water and soil.	1.9.5. Operators of agricultural holdings may establish written cooperation agreements exclusively with operators of other agricultural holdings and undertakings which comply with the organic production rules, for the purpose of spreading surplus manure from organic production units. The maximum limit referred to in point 1.9.4 shall be calculated on the basis of all of the organic production units involved in such cooperation.
	1.9.6. Preparations of micro-organisms may be used to improve the overall condition of the soil or to improve the availability of nutrients in the soil or in the crops.
	1.9.7. For compost activation, appropriate plant-based preparations and preparations of micro-organisms may be used.
	1.9.8. Mineral nitrogen fertilizers shall not be used.
	1.9.9. Biodynamic preparations may be used.

So, the new regulation on organic production has tried to give an answer to some of the more debated agronomic issues regarding organic greenhouse production. In particular, the clear definition of soil as "living soil in connection with subsoil and bedrock" does not leave any margin for interpretation. Only soil-grown crops can be defined as "organic" (apart from some little derogations made to respect consumer habit to buy organic herbs or ornamentals in a pot).

The connection of soil with subsoil and bedrock clarified that any soilless method of production or methods in which soil is taken out of the site where it naturally developed from the bedrock and is utilized, in any form of container, alone or in mixture with other materials (mineral or organic, natural or synthetic), to grow plants, cannot be certified as organic. A special derogation to this rule, for a limited period of time, is given to crops grown in demarcated beds in Sweden, Finland and Denmark, in order to take into account that this method of production has been traditionally used in these countries for many years and is widely accepted by the local population.

But the introduction of short-term green manure crops and legumes as valid agronomic practices to maintain and increase fertility and biological activity of soil also in organic greenhouse is probably the more relevant measure, in the new regulation, to start the implementation of more resilient cropping systems and to reduce the level of intensification of organic greenhouse production.

6. Knowledge Gaps and Research Needs

Agroecological service crops (ASC) can be defined as "all crops used in agroecosystems to provide or enhance its environmental functions (i.e., as buffer zones, living mulches and break crops), irrespective of their position in the crop rotation and/or independently of the method (green manure vs flattened crop) that can be applied to terminate them" [39]. ASCs improve long-term soil fertility and reduce potentially negative environmental impacts. So, the cultivation of plant species not for yield purposes, but for the ecosystem services they provide is one of the pillar of organic soil management. At the same time, their introduction in organic greenhouse production is challenging [17] because of the high investment costs, high organic matter turnover [31], the high nutrients demand and the high risk of unbalanced fertilization [29,30]. In southern and central European countries, the introduction of ASCs in the rotation is a common practice also in organic greenhouses [40–44] and in Italy is reported in the recent decree from the Italian Ministry of Agriculture [45] as one of the alternative agronomic practices to reduce the level of crop intensification in organic farming in protected conditions. The effects on fruits and vegetable yields and quality and on soil arthropods biodiversity of the introduction of ASCs in the rotation of organic fruits and vegetables cultivated in protected condition have been recently investigated. For strawberry, no significant differences on yields were observed in the comparison of organic systems at different levels of intensification [24], while for kohlrabi, zucchini, lettuce and lamb's lettuce in rotation, more intensive systems of production showed yields significantly higher than organic systems where agroecological practices were implemented [25]. In the same compared organic systems, on the other side, results demonstrated high potential of ASC cultivation as a technique for beneficial soil arthropod conservation in protected conditions. Moreover, functional group analysis revealed that systems where agroecological practices are implemented show a strong potential for pest suppression and for higher resilience in a long-term evaluation respect to more intensive organic systems [46]. In the same experimental site, the economic viability of introducing agroecological practices within a two-year organic greenhouse rotation was also demonstrated [47]. It could also be interesting to investigate more in-depth on water management, organic amendment application and its environmental impact. Furthermore, the assessment of the effects of introducing short-term green manure crops on soil microbial activity and diversity, on nematode biodiversity and on soil suppressiveness, is needed for a comprehensive evaluation of cropping system resilience and sustainability. Very little has been studied on the environmental impact of soil-grown winter leafy crops systems of production in unheated greenhouses [28] and very often studies have been carried out in a perspective of comparison between organic and conventional systems of production [48,49] and not of comparison among different organic production systems.

The new perspective of an agroecological approach to organic greenhouse production has been the object of discussion among researchers during the meetings organized in the framework of COST Action FA1105 "Towards a sustainable and productive EU organic greenhouse horticulture– Biogreenhouse" (2012–2016). Furthermore, more recently, the viability of implementing resilient agroecosystems in protected conditions was considered as one of the strategic research topics in Europe [50] and recently funded in the framework of the Core Organic Cofund research program [51]. But more general considerations, actions and studies are requested for the implementation of a real agroecological approach to organic greenhouse production. As well described by Levidow and co-authors [52], a transformative perspective of agroecology takes into account the integration of its three main forms: the scientific discipline, the agricultural practices and the social movements with the main aim of changing the food system. In this conceptual framework, the introduction of some agricultural practices in greenhouses as mandatory measures to be certified as organic is just a first step in the implementation

of an agroecological approach to organic greenhouse production. The social dimension of sustainability complying worker rights and gender issues [53], consumer-citizens involvement through a process of increasing awareness on the sustainability of different production systems (food citizenship), the ethical aspects of the values of human health and of natural resources, the individuation of short food chains alternative to dominant food system and a sort of farmer–scientist cooperation to promote agroecological knowledge exchange are some of the actions and studies requested, in the future, for a real implementation of an agroecological approach to organic greenhouse production and for finally "lift the bar of what is acceptable in farming in the twenty-first century" (Figure 1) [2].

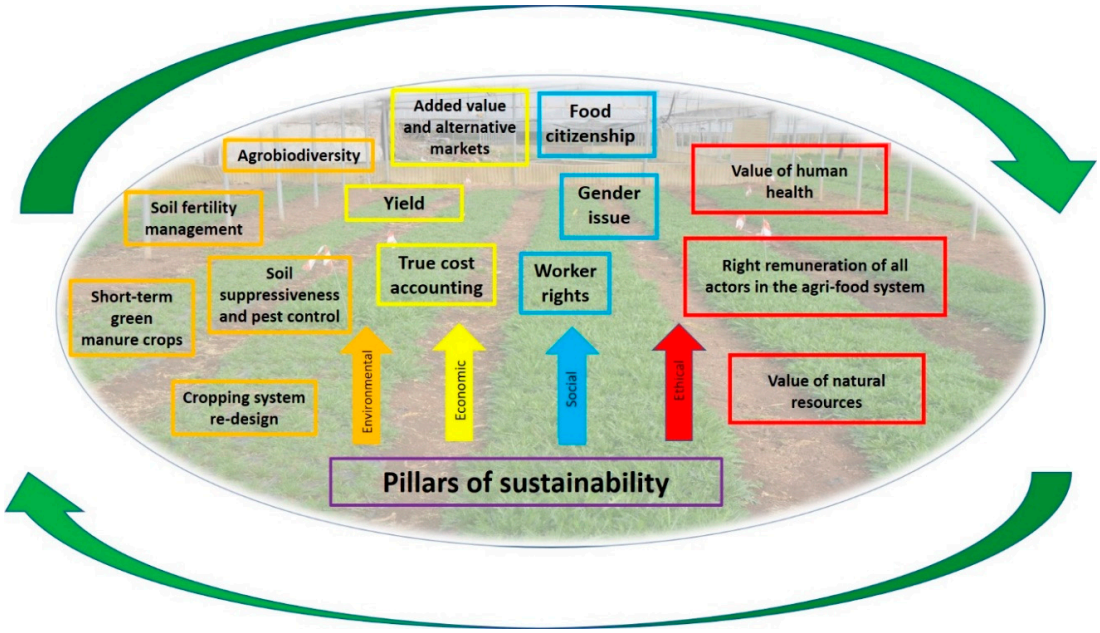

Figure 1. Multidimensional components of sustainability in an agroecological approach to organic greenhouse production.

7. Conclusions

According to some actors, organic production is moving towards a new stage in which it is globally diffused and contributes, in an agroecological perspective, to solve the global challenges of agri-food systems. At the same time, organic greenhouse production has been the object of discussion for the implementation and wide diffusion in the European Union of some of the more intensive systems of production, which can affect the consumer trust in organic food. The lack of specific rules for crop production in protected conditions in the existing regulation on organic production (Reg (EC) No 834/2007 [19] and (EC) No 889/2008) [21] has induced Member States to adapt general rules to their own climatic conditions and geographical position, implementing sometimes practices which are banned in other countries of EU, exacerbating the commercial conflicts within the EU and favoring the contraposition among farmers and organic associations of different European regions. A long debate, lasting an entire decade and involving all the actors of organic production sectors has led to the identification of the more controversial issues and to proposals for overcoming them. The concern relative to some very intensified systems of production has induced a request for applied research for alternative organic greenhouse production systems and, more recently, the introduction of specific rules in the new regulation on organic production (EU) 2018/848 [18]. Important aspects of organic production, which have been disregarded in protected conditions during the last decade, are now common criteria for the certification of organic production. Although some encouraging results have been reported in the scientific literature for the Mediterranean countries, knowledge gaps on the economic, social, ethical and environmental sustainability of organic greenhouse production still exist and researches on cropping system redesign for the individuation of innovative cropping systems at

different latitudes and climatic condition are needed. In order to move towards an agroecological approach, organic greenhouse producers should and can participate to a new agri-food system in which the complete redesign of the cropping system is associated with a deep change in processing, logistics and transport for the implementation of short food chain, in a framework of increased consumer awareness on food quality production and environmental sustainability.

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