Chapter 19
Aquaponics: The Ugly Duckling in Organic Regulation

Paul Rye Kledal, Bettina König, and Daniel Matulić

Abstract Due to the cyclic or systemic nature of both aquaponics and organic production, organic certification appears to be a natural step for a researcher, system designer or commercial-oriented aquaponics producer to engage in. However, the underlying principles and justifications of aquaponics and organic production differ considerably between respectively a technological- and a soil-based understanding of nutrient cycles and long-term sustainability in food production. These principles are confirmed in both the organic regulation regime of the EU and USA, and presently leave the question ambiguously open as to whether aquaponics as a food production system can be recognized and certified as organic. Despite an openness in the organic regulation for new knowledge, adaptations and innovations, the organic sector itself has shown a reluctance to recognize more knowledge-based intensive speciality crops and technologies. This is particularly difficult with respect to small organic sub-sectors such as horticulture and aquaculture production. Both are very specific subsystems of the agricultural sector, where aquaponics potentially would belong at the intersection between organic greenhouse horticulture and organic aquaculture. Organically certified aquaponics would therefore need to establish a niche within the organic sector. So in order to move forward, there is a great need for a more serious but open-minded exchange and discussion among the aquaponics and organic sub-sectors themselves to explore the potential but also limitations of their respective production models. However, between the two food production systems, there should be room for debate with a view to finding new and feasible roles for aquaponics in the organic community.

P. R. Kledal (✉)
Institute of Global Food & Farming, Hellerup, Denmark
e-mail: paul@igff.dk

B. König
Faculty of Life Sciences, Thaer-Institute, Horticultural Economics and IRI THESys, Humboldt Universität zu Berlin, Berlin, Germany

D. Matulić
Department of Fisheries, Beekeeping, Game management and Special Zoology, Faculty of Agriculture, University of Zagreb, Zagreb, Croatia
e-mail: dmatulic@agr.hr

S. Goddek et al. (eds.), *Aquaponics Food Production Systems*,
https://doi.org/10.1007/978-3-030-15943-6_19

Keywords Aquaponics · Organic certification · EU organic regulation · US organic regulation · Recirculating aquaculture · Hydroponics

19.1 Introduction

Aquaponics is an integrated closed-loop multi-trophic food production system that combines elements of a recirculating aquaculture system (RAS) and hydroponics (Endut et al. 2011; Goddek et al. 2015; Graber and Junge 2009). Aquaponics is therefore discussed as a sustainable eco-friendly food production system, where nutrient-enriched water from fish tanks is recirculated and used to fertilize vegetable production beds, thus making good use of the valuable nutrients that in conventional aquaculture systems are discarded (Shafahi and Woolston 2014) and presents a potential solution to an environmental problem usually referred to as eutrophication of aquatic ecosystems.

Organic agriculture is also based on natural principles of recirculation and resource minimization as defined by the International Federation of Organic Agriculture Movements (IFOAM 2005):

> *Organic Agriculture is a production system that sustains the health of **soils, ecosystems** and **people**. It **relies on ecological processes, biodiversity and cycles adapted to local conditions**, rather than the use of inputs with adverse effects. Organic Agriculture combines **tradition, innovation** and **science** to benefit the shared environment and promote **fair relationships** and a good **quality of life** for all involved.*

Due to the cyclic or systemic nature of both production systems, obtaining organic certification could appear to be a natural step for a researcher, system designer or commercially oriented aquaponics producer to engage in. On the other hand, the underlying principles of aquaponics and organic production differ considerably. From a research perspective, one could argue that the discussion on aquaponics being organic or not demonstrates an interesting case between two poles of agro-food-systems-thinking, namely, agro-industrial (conventional) and agro-ecological (organic). Somehow aquaponics needs to find its place in this continuum.

The aim of this chapter is to shed light on the current *status quo* regarding the barriers of certifying aquaponics as organic food production, and to discuss the underlying principles, contradictions and views upon its sustainability. It will also discuss possible future scenarios emerging out of the links between the rationales and implementations of the two production systems. We can consider both organic farming and aquaponics as food production systems, because both farmers and aquaponics producers are faced with complex decision-making situations involving the balancing of interconnected and interrelated inputs, external factors (environment, markets, value chains, etc.) and management procedures in order to produce food.

19.1.1 Aquaponic Production Systems and the Technology Applied

Present-day aquaponic production systems are generally categorized according to the type of technology applied to the plant production part, and whether the integration is coupled into one single loop between the plants and the fish or decoupled into separate loops. The most common technologies applied in the plant production are: (1) The Deep Water Culture (DWC) or in the literature often called UVI because originally developed at the University of Virgin Island, (2) NFT (Nutrient Fluid Technology) and (3) 'Flood and Ebb'. The DWC and NFT are the most common or 'classic' technologies applied to the plant production, and often the fish and plant production are connected into one dependent loop of water and nutrient flow. This singular connection and interdependency of the whole system is a factor that increases risks tremendously, and is a prime barrier to establishing large-scale commercial production.

The main differences between the first two systems are related to how the plants are grown.

In the DWC system, the plant bed is the floating system where plants are grown on RAFTs (usually polystyrene) floating in long tanks of variable width, acting both as an extensive biofilter and a water buffer, regulating temperature and pH fluctuations.

In the NFT system, plants are grown in hydroponic plastic pipes, well known from modern horticulture. A thin layer of nutrient water supplied to the pipes feeds the plants. In both cases of the NFT and DWC, the holes for the plants are fixed, which constrains the producer as to what kind of plants can be produced. In some aquaponics systems, both plant-growing technologies from the DWC and NFT are applied at the same time giving more flexibility and security while running a singular aquaponics loop (Kledal and Thorarinssdottir 2018).

In the third category, 'Flood and Ebb', plants are grown in pots placed on (often moveable) plant tables, and then fed two or three times a day by flooding the tables for 5–10 min. The plant tables provide the option of producer with flexibility in the choice of plants grown and the size of the pots, as well as the prospect of using soil and this opening up the possibility of organic certification.

In recent years, decoupled aquaponics is starting to emerge as the production system applicable to large-scale commercial aquaponics production (Fig. 19.1). In decoupled aquaponics the fish and plant production, each has their own loop of water supply, but is also connected to each other via a fertilizer tank supplying nutrient deficiencies to the plants. In this way, the dependency between the fish and plant production has been removed, but the symbiotic benefits are kept allowing for investment in large-scale commercial production. There is currently some debate about the advantages of circulating, or coupled vs. decoupled aquaponics (Goddek et al. 2016). However, there is not yet a consensus about the status of decoupled systems since they could be considered as just another plant nutrient supply method, as long as the water does not circulate back to the fish (Junge et al. 2017).

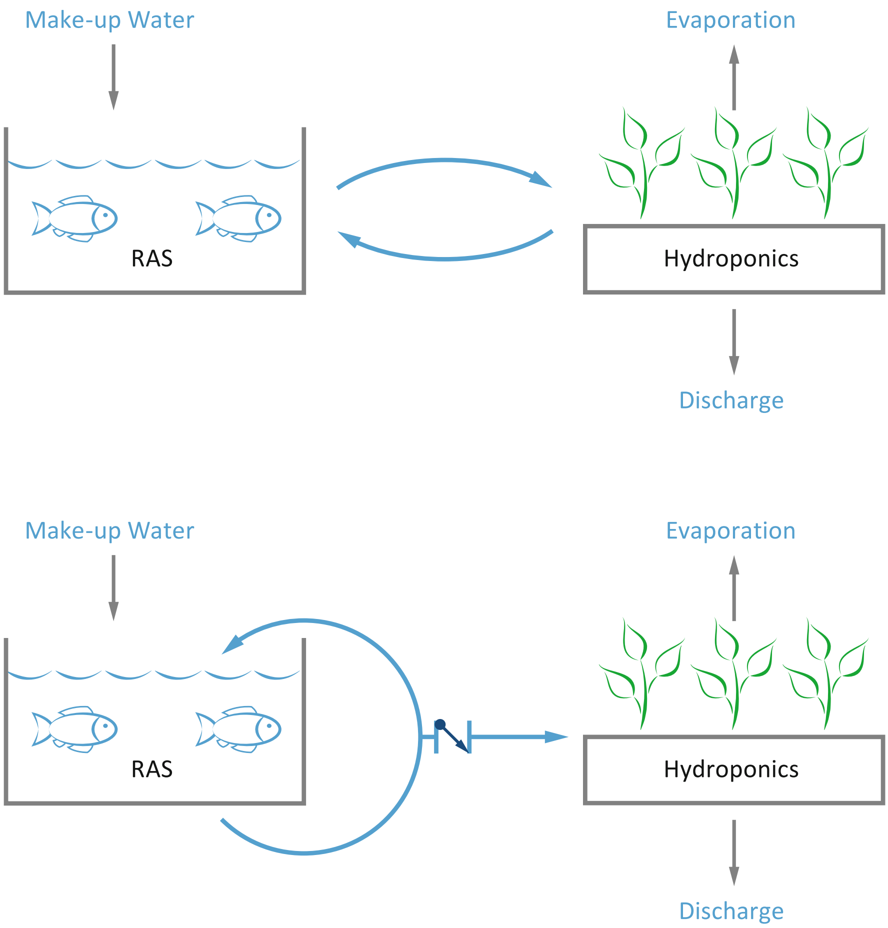

Fig. 19.1 (**a**) coupled (**b**) decoupled aquaponics system. (Adapted from Peterhans 2015)

Aquaponics is in general receiving increased interest globally as a sustainable food production method, and with the prospects of promoting aquaponics on a commercial scale, there is an equivalent interest in receiving organic certification with its related price premiums on the produce. According to Kledal and Thorarinssdottir (2018) and König et al. (2018), the commercially available systems of aquaponics are mainly based on the research carried out by Rakocy and his co-workers (Rakocy 1999a, b, 2002, 2009; Rakocy et al. 2001, 2004, 2006, 2009), as previously described (the classic production technologies 1 and 2 above) where plants and fish are connected in a singular dependent loop. Likewise, most production systems, whether they are based on DWC, NFT or moveable plant tables with ‘Flood and Ebb’, are not using an organic growth media, hence already excluding themselves from obtaining an organic certification for the horticultural part. Regarding aquaponics production, access to organic fish feed is in general only available for a few commercial freshwater fish species. So, aside from the various input factors, there are constraints to starting an organic aquaponics production on a commercial scale.

So we can see that despite the growing interest in marketing aquaponics as an environmental-friendly food production system the present organic legislation regime in the EU and USA prohibits aquaponics from being recognized as such (NOSB 2017). However, the discussion is not finalized, and while it is ongoing, some private certification agencies in the US allow for the certification of the vegetables as organic (Friendly Aquaponics 2018).

19.1.2 Aquaponics and the EU Organic Regulation Regime

In the EU, the present regulatory framework for organic fish and horticultural production is regulated by the Council Regulation (EC) No. 834/2007, whereas more detailed rules are regulated by the Commission Regulations (EC) No. 889/2008 and (EC) no. 710/2009. However, the EU organic regulatory regime does *not* have any standards or regulations for certifying aquaponics as organic. The organic regulation is based on the aims and principles of recognizing organic farming as a natural resource-based food production (Lockeretz 2007; Aeberhardt and Rist 2008). This is backed up in the implementing regulation annex by the exclusion of inputs not allowed for organic farming. Consequently, aquaponics farming systems using the RAS technology and soilless vegetable production (hydroponics) cannot be certified as organic under the present EU organic regulation.

However, among aquaponics practitioners, there is continuous discussion about aquaponics and organic certification. First of all, the rapid industrial developments within fish farming and the market diversification and demand for organic products make it economically desirable to qualify for the organic price premium as one way to reimburse the high capital investments required for commercial aquaponics. Second, it appears only natural to link an environmental-friendly food production such as aquaponics, to already well-established certification labels and consumer perceptions of a sustainable food production rather than engaging in the high transaction costs of creating a whole new food label.

In view of the current discussions on limited resources for food production, animal welfare, the increasing pressure on the sustainability of the aquatic environment, paralleled with the ongoing technological progress within aquaponics, this article asks why aquaponics cannot be certified organic.

In the following paragraph, the organic rules and regulations under the EU regime creating barriers to aquaponics will be examined.

19.2 Organic Regulations

19.2.1 Organic Rules in Horticulture

The hydroponic production technology in the absence of an organic growth media cannot be certified as organic, which has proven to be a long-time effective barrier for the conversion of existing greenhouse vegetable producers to organic farming schemes (König 2004). For horticultural products, the specific EU regulation preventing products produced under 'classical' aquaponics systems to obtain an organic certification are the following:

> *834/2007 Regulation (12): ....Plants should preferably be fed through the soil eco-system and not through soluble fertilizers added to the soil*

> *889/2008 Article. (4): Organic farming 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.*

Since aquaponics is based on using fish sludge as a source of fertilizing the plants, the absence of mineral fertilizers would at first seem like a step towards organic production. However, the 'classical' aquaponics production systems started using components from the soilless hydroponic technology, and therefore the plants produced under such a system *cannot* be certified as organic. In order to understand this prohibition in organic regulation, it is helpful to remember that hydroponics was developed and adopted by growers as a response to the challenges greenhouse growers met in intensive soil-based vegetable cultivation systems, e.g. enrichment of the soil with soil-borne pathogens. In contrast, the organic horticulture approach departs from the question of how greenhouse farming has to look like in order to avoid these challenges. Their starting point is instead to change the management of the soil rather than inventing a production technology without soil.

In addition to this general principle of soil-based production, organic horticulture can be considered a specialized niche within organic farming offering a considerable variety of crops. The legislation for fruit vegetables, such as tomato, cucumber, pepper, eggplant, etc. prescribes cultivation in natural soil. Plants sold with the soil, such as seedlings or potted herbs, can be certified as organic. The prerequisite is that the plant could continue growing at the customer's greenhouse or kitchen window. This means, that herb bunches, salads cut off from the roots need to be grown in soil in order to qualify for organic certification. Inputs allowed for organic production are regulated in the implementing regulation. For Germany, Switzerland and the Netherlands, the testing and approval of inputs for organic production is maintained by FiBL (Research Institute of Organic Agriculture), who are currently aiming at developing a European List on inputs certified as suitable for organic status.

The nutrient supply in organic greenhouse production is a challenge. Not only are mineral fertilizers common in hydroponic production systems not allowed but, in the special case of the German organic farmer associations (going beyond EU legislation), also hydroxylates that are of animal origin (interview with organic extension service). Greenhouse growers who have invested in infrastructure sealing the natural soil with permanent greenhouse flooring, have faced a long-time effective barrier for the conversion of existing greenhouse infrastructure to organic farming schemes, except for potted herbs (König 2004). New investments in greenhouse infrastructure have contributed to the increase of organic fruit and vegetable production in the last years, e.g. in Germany. However, for these modern organic growers, aquaponics does not yet provide any solution as they are looking for answers into the areas of suitable soils, improved crop rotation, effective microorganisms, compost and the like.

Horticulture is facing the general challenge that the organic EU regulation is not very detailed in this area. Theoretically, this leaves room for new production approaches such as aquaponics. However, at this stage of development within both commercial organic horticulture and aquaponics, the start-up costs for the producers are immensely high let alone the search for information on production management, prohibitions, potential yields, etc. In the end, the suitability of innovative production systems is left to the decision of the local certification authority on a project-by-project basis (König et al. 2018).

However, since the starting point in organic agriculture is about soil-based production and the fact that horticulture, aquaculture and aquaponics are small sub-sectors; the EU regulation regime on organic production may not be something that is expected to change in the near future.

19.2.2 Organic Rules in Aquaculture

For organic aquaculture, the production is regulated by Commission Regulations of 889/2008 and 710/2009. In parr. 11. Commission Regulation (2009), recirculating technologies are clearly prohibited in organic aquaculture, except for the specific production in hatcheries and nurseries making and selling fingerlings for further growth in open-air pond systems.

> *Parr*. 11.
>
> *Recent technical development has led to increasing use of closed recirculation systems for aquaculture production, such systems depend on external input and high energy but permit reduction of waste discharges and prevention of escapes. Due to the principle that organic production should be as close as possible to Nature, the use of such systems should not be allowed for organic production until further knowledge is available. Exceptional use should be possible only for the specific production situation of hatcheries and nurseries.*

Since recirculating technology is at the core of the aquaponics production system, it is at present not possible to get a complete organic certification of an aquaponics system, if all of the finishing produces is to be sold for the consumer market.

Likewise, the organic regulation on fish density in open ponds and marine cages are mainly made to secure a minimal discharge of fish manure to the aquatic environment. Questions on fish welfare are therefore an indirect matter related to their well-being based upon the level of freshwater exchange in the ponds. The stocking density in organic aquaculture systems is often 1/4 to 1/3 of that in modern RAS systems, and therefore from an economical aspect, not very cost-effective for this technology. At the same time, we need research and development on animal welfare indicators as well as on feasible and meaningful animal welfare monitoring tools as a prerequisite to discussing specific stocking densities. Only then will we be able to assess the potential economic viability of the aquaculture part of an organic aquaponics system (Ashley 2007; Martins et al. 2012).

19.2.3 Aquaponics and the USA Organic Regulation Regime

As in Europe, there is an ongoing discussion in the USA about how to handle soilless or soil replacement approaches for nutrient provision to plants as a mean of a resource-efficient food production and their inclusion or exclusion from the organic certification scheme. Despite these discussions, the state of the art is somewhat similar undecided to that in Europe, but practices differ: recently, the Crops Sub-committee of the National Organic Standards Board provided a suggestion to make aeroponics, aquaponics and hydroponics prohibited practices under Sect. 205.105 of the USDA Organic Regulations (NOSB 2017). This decision was rejected with 8:7 votes, yet not achieving 10 votes to make the decision a recommendation of the NOSB to USDA. Only the rejection of aeroponics found sufficient votes (14 out of 15, NOSB 2017). Therefore, the USDA Agricultural Marketing Service is only reviewing the recommendation to exclude aeroponics from organic certification (AMS 2018, p.2). This NOSB decision had been forced due to non-harmonized practices in the past among accredited organic certification agencies, whereby some of them certified hydroponics as organic under the National Organic Program (NOP) while others did not. These differing practices can be seen as a result of a long discussion process with no clear conclusions, ending with eight certifiers certifying hydroponic operations as organic in 2010 and a 33% increase of organic certified hydroponic producers (NOSB 2016: Hydroponic and aquaponics subcommittee report). Already back in 2010, the NOSB had received recommendation for a federal rule concerning greenhouse production systems, indicating basically that '*Growing media shall contain sufficient organic matter capable of supporting natural and diverse soil ecology. For this reason, hydroponic and aeroponic systems are prohibited.*', yet this explicit prohibition did not enter current law (NOSB 2010, 2016:122). Instead, the more open definition of organic production from 2002 was in place, where organic production is '*[a] production system that is managed in accordance with the Act and regulations in this part to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity*' (NOSB 2016, p. 7). The hydroponic and aquaponics subcommittee concludes that '*Under current law and clarification from NOP/USDA, hydroponic and aquaponic production methods are legally allowed for certification as USDA Organic as long as the producer can demonstrate compliance with the USDA organic regulations.*'

(NOSB 2016, p. 10–11). However, the difficulty is that organic production is about management of the soil, whereas hydroponics is a system managing fertilizers. By not addressing this difference could lead to some ambiguity and potential negative consequences for the support of organic certification by farmers and consumers (AMS 2016). In the (NOSB 2016, Alternative Labeling Subcommittee Report), other experts presented a range of ideas as to how labels within the USDA organic scheme or outside could appear. Because of a lack of standards and norms, which is a necessary basis for labels, the group did not arrive at a consensus. The opinion was that, if aquaponics were included, or an extra label added, among the already existing great diversity between the different organic productions systems, it would both challenge the certification process as well as being a source of confusion for consumers. Interestingly, the suggestions of label alternatives under the USDA organic umbrella, or in addition to it, highlight the anecdotal evidence that the principle of aquaponics farms seems to be appealing to consumers, and that they do not need to be certified organic to be viable (NOSB 2016, Alternative Labeling Subcommittee Report, p.5).

In summary, the NOSB (2016) provides a detailed process description from the early 1990s until today, which reflects also different opinions of stakeholders involved in this discussion. The Organic Foods Production Act of 1990 (OFPA) builds on this basis for the development of federal US organic certification for the NOSB, and since then the discussion about allowing greenhouse production systems for organic certification or not has been in place (NOSB 2016). By now, there is agreement in the discussion which recognizes that the roots of organic farming lie in the concern about soil fertility and soil quality. All organic farming practices and standards developed are based upon this premise, and any discussions about its further development have to start from this point of view.

In the discussion, there are more open questions involved as to whether hydroponics could be called organic or not. The comparison of conventional and organic farming, in the case of horticultural greenhouse crops, hinges on some poorly researched or still controversially discussed issues (NOSB 2017):

The type of farming practice may also explain the differences found in organic and conventional products, e.g. lower content of secondary plant metabolites of conventionally grown greenhouse vegetables compared to organic vegetables from field farming. Allowing hydroponics to be certified as organic, this currently communicated added value of organic products could not be communicated to consumers anymore as added value unambiguously.

An important source of nutrients in hydroponic systems is hydrolysed soybean meal, which US growers import from Europe in order to ensure GMO-free sourcing compatible with organic standards. This impinges negatively upon the overall sustainability.

One principle of organic farming is dealing with resilience, which is doubted for hydroponic and aquaponics farming systems as they are highly dependent on an external energy supply (anecdotal observations). Opponents state that organic farms are likewise not ‘resilient’ against severe natural disasters, yet both groups remain somewhat unclear about their resilience concept when applied to these production systems.

A comparison of processes at the root surface, i.e. the microbial environment in soil versus water and the nutrient uptake, is an open question and opponents argue that literature on this topic is perceived as not sufficient.

In contrast, all the arguments that can be found in Europe as to why hydroponics or aquaponics should be certified as organic are also brought into the discussion in the US. The most remarkable point is, however, the lack of data on the direct comparison of systems in order to be able to evaluate the mentioned impacts and advantages systematically. In summary, the NOSB rejected to label hydroponic or aquaponics systems as organic in general because (NOSB 2017, p. 70–71):

> *§ 6513 Organic Plan: "An organic plan shall contain provisions designed to foster soil fertility, primarily through the management of the organic content of the soil through proper tillage, crop rotation, and manuring...An organic plan shall not include any production or handling practices that are inconsistent with this chapter."*
>
> • *§ 205.200 General: " Production practices implemented in accordance with this subpart must maintain or improve the natural resources of the operation, including soil and water quality."*
>
> • *§ 205.203 Soil fertility and crop nutrient management practice standard: (a) "The producer must select and implement tillage and cultivation practices that maintain or improve the physical, chemical, and biological condition of soil and minimize soil erosion." (b) "The producer must manage crop nutrients and soil fertility through rotations, cover crops, and the application of plant and animal materials." (c) "The producer must manage plant and animal materials to maintain or improve soil organic matter content..."*

Later, in the year 2016, definitions were given for hydroponics, aquaponics and aeroponics, stating for aquaponics that (NOSB 2017, p. 82):

> *Aquaponic production is a form of hydroponics in which plants get some or all of their nutrients delivered in liquid form from fish waste. Aquaponics is defined here as a recirculating hydroponic system in which plants are grown in nutrients originating from aquatic animal waste water, which may include the use of bacteria to improve availability of these nutrients to the plants. The plants improve the water quality by using the nutrients, and the water is then recirculated back to the aquatic animals.*

The NOP has strict standards for handling animal manure in terrestrial organic production, but no such standards exist to ensure the safety of plant foods produced in the faecal waste of aquatic vertebrates. Also, the NOP has not yet issued standards for organic aquaculture production, upon which aquaponics plant production would be dependent. '*The Crops Subcommittee is opposed to allowing aquaponic production systems to be certified organic at this time. If aquaculture standards are issued in the future, and concerns about food safety are resolved, aquaponics could be reconsidered.*' (NOSB 2017, p. 82).

In there is the 'Naturally Grown' certification, a peer-review, grassroot certification, which explicitly includes aquaponics (https://www.cngfarming.org/aquaponics). This certification involves a catalogue with criteria from January 2016. Only the vegetable produce is certified, not the fish part because at the moment it (e.g. fish feed) does not meet the general criteria for livestock certification. The criteria regulate the following aspects: System Design and Components, Materials for Main System Components and Growing Media/Root Support, Water Sources, Monitoring, Inputs for pH Adjustment, Waste Use & Disposal, Crop Production and Management, Fish Management, Location and Buffers, Energy and Record Keeping. The scheme is based on peer inspection schemes and does not allow the usage of synthetic pesticides and fungicides, copper-based pesticides, petrochemical-based pesticides or fungicides. It does not regulate the components on the plant part, but assesses its functions: water regulation, aeration, degassing, biofiltrations and removal of fish waste solids.

In summary, there are individual organic certification bodies in the US certifying aquaponics (parts) as organic production, but there are also cases reported of farmers claiming organic production without being certified (Friendly Aquaponics 2018). After this chapter goes to press there may be new developments affecting the organic certification topic. In addition, the issue of urban farming being declared as farming, and hence being eligible for agricultural funds might get a clearer status with the pending new US Farm Bill.

19.3 Discussion and Conclusions

This chapter has attempted to clarify the regulatory aspects relevant to understanding why aquaponics presently is not eligible for organic certification in the EU and the USA. As in the EU, the main paradigm behind organic farming in the USA is briefly, to manage soils in a natural way. In the EU, organic certification decisions for organic aquaponics are not carried out by local authorities, whereas the USA has seen a growth in this type of action in the last few years as well as an increase in private peer-review certifications and decisions of individual organic certification agencies.

In principle, all EU organic regulations are open to adaptation as soon as there is new scientific evidence, as stated in paragraph 24.

> *Parr. 24*
>
> *Organic aquaculture is a relatively new field of organic production compared to organic agriculture, where long experience exists at the farm level. Given consumers' growing interest in organic aquaculture products further growth in the conversion of aquaculture units to organic production is likely. This will soon lead to increased experience and technical knowledge. Moreover, planned research is expected to result in new knowledge in particular on containment systems, the need of non- organic feed ingredients, or stocking densities for certain species. New knowledge and technical development, which would lead to an improvement in organic aquaculture, should be reflected in the production rules. Therefore provision should be made to review the present legislation with a view to modifying it where appropriate.*

So, the horticultural, aquacultural and organic sectors would need to organize themselves, integrating knowledge from different domains. Yet, there are difficulties in convening such knowledge-intensive discussions as the experts and the communities of practice are fragmented and dispersed. Moreover, it is a knowledge-intensive endeavour: the NOSB subcommittee on Hydroponic and aquaponics stated that an in-depth justification would need more time (NOSB 2017; Hydroponic & Aquaponic Subcommittee Report, p. 2). In the EU, the most important Organic Research Institute (FiBL) involved in regulation and input testing is based in Switzerland. However, with its new organizational umbrella now located in Brussels, circumstances are expected to improve in the coming years. Still, to review all the details of every component of hydroponic and aquaculture will raise new questions that only a very few organic greenhouse and aquaculture experts in Europe will be able to answer. Aquaponics actors might then be in a situation to discuss (a) the circular economy approach, e.g. from the point of view of Life Cycle Assessment and in terms of the construction and production components used to compare it with a soil-based production and (b) to consider the question of how does aquaponics improve the on-site (sustainability) situation of fish and plant production. Asking such questions may stimulate ideas for new system-designed aquaponics that might be perceived as interesting by the organic community. However, it may also raise new (or in fact old) barriers to the implementation of large-scale organic production, e.g. thinking of organic pots that do not pose a challenge to the potting machine for aquaponics salads and fish welfare indicators in order to develop knowledge-based species-specific stocking densities. In this way, system design changes may raise new research questions.

For the time being, more collaborative research and development into developing aquaponics systems for the organic sector might be an interesting pathway that would best be discussed and developed among open-minded experts and growers from aquaponics, organic greenhouse production and organic aquaculture. To conclude, there is a great need for a knowledge exchange and discussion among the aquaponics and organic niches to explore the potentials and limitations of their respective production models, and reach some kind of consensus as to whether there is a future role for recirculating aquaponics systems in the organic community and what organic aquaponics could actually look like. But with the diverse visions of aquaponics systems by entrepreneurs, farmers, researchers and communities already in place, what would certify them all as organic mean for communication to the consumer, for marketing and for achieving sustainability goals? In the USA as in Europe, the question is who would benefit from organic certification of aquaponics? At present, aquaponics seems somewhat to be an ugly duckling both within the conventional and the organic agriculture regimes, but in the future it may turn into a beautiful sustainable swan—and may be certified organic?!

References

Aeberhardt A, Rist S (2008) Koproduktion von Wissen in der Entwicklung des Biolandbaus – Einflüsse von Marginalisierung, Anerkennung und Markt. In: Mayer J, Alföldi T, Leiber F, Dubois D, Fried P, Heckendorn F, Hillmann E, Klocke P, Lüscher A, Riedel S, Stolze M, Strasser F, van der Heijden M, und Willer H (Hrsg.) 2009. Werte – Wege – Wirkungen: Biolandbau im Spannungsfeld zwischen Ernährungssicherung, Markt und Klimawandel. Beiträge zur 10. Wissenschaftstagung Ökologischer Landbau, ETH Zürich, 11.-13. Februar 2009. http://orgprints.org/14377/1/Aeberhard_14377.pdf

AMS (2016) Memorandum to the national organic standards board. Hydroponic and Aquaponic Task Force Report. Agricultural Marketing Service. https://www.ams.usda.gov/sites/default/files/media/2016%20Hydroponic%20Task%20Force%20Report.PDF. Accessed 2 Feb 2019

AMS (2018) Memorandum to the National Organic standards board. Response to National Organic Standards Board Recommendations (Fall 2017 Meeting). https://www.ams.usda.gov/sites/default/files/media/NOPResponsetoNOSBFall2017.pdf. Accessed 2 Feb 2019

Ashley PJ (2007) Fish welfare: current issues in aquaculture. Appl Anim Behav Sci 104(3–4):S. 199–S. 235

Commission Regulation (2008) (EC) no 889/2008 of 5 September 2008 laying down detailed rules for the implementation of council regulation (EC) no 834/2007 on organic production and labelling of organic products with regard to organic production, labelling and control. Off J Eur Union 2008(1):84

Commission Regulation (2009) (EC) No 710/2009 of 5 August 2009 amending Regulation (EC) No 889/2008 laying down detailed rules for the implementation of Council Regulation (EC) No 834/2007, as regards laying down detailed rules on organic aquaculture animal and seaweed production. Off J Eur Union L 204:15–34

Endut A, Jusoh A, Ali N, Nik WBW (2011) Nutrient removal from aquaculture wastewater by vegetable production in aquaponics recirculation system. Desalin Water Treat 32:422–430. https://doi.org/10.5004/dwt.2011.2761

Friendly Aquaponics (2018) USDA organic certification of aquaponic systems. https://www.friendlyaquaponics.com/organic-certification/. Accessed 21 Dec 2017

Goddek S, Delaide B, Mankasingh U, Ragnarsdottir K, Jijakli H, Thorarinsdottir R (2015) Challenges of sustainable and commercial aquaponics. Sustainability 7:4199–4224. https://doi.org/10.3390/su7044199

Goddek S, Espinal CA, Delaide B, Jijakli MH, Schmautz Z, Wuertz S, Keesman KJ (2016) Navigating towards decoupled aquaponic systems: a system dynamics design approach. Water 8:303

Graber A, Junge R (2009) Aquaponic systems: nutrient recycling from fish wastewater by vegetable production. Desalination 246:147–156

IFOAM (2005) Definition of organic farming. https://www.ifoam.bio/en/organic-landmarks/definition-organic-agriculture. Accessed 2 Feb 2019

Junge R, König B, Villarroel M, Komives T, Haïssam Jijakl M (2017) Strategic points in aquaponics. Water 9:182

Kledal PR, Thorarinssdottir R (2018) Aquaponics: a new niche for sustainable aquaculture, 173-190. In: Hai FI, Visvanathan C, Boopathy R (eds) Sustainable aquaculture. Springer, Cham. https://doi.org/10.1007/978-3-319-73257-2

König B (2004) Adoption of sustainable production techniques: structural and social determinants of the individual decision making process. In: Proceedings of the 15th international symposium on horticultural economics and management, Berlin, Aug 29–Sept 3 2004

König B, Janker J, Reinhardt T, Villarroel M, Junge R (2018) Analysis of aquaponics as an emerging technological innovation system. J Clean Prod 180:232–243. https://doi.org/10.1016/j.jclepro.2018.01.037

Lockeretz W (2007) Organic farming. An international history. CAB International, Wallingford, p 275

Martins CIM, Gakhardo L, Noble C, Damsgard B, Spedicato MT, Zupa W, Beauchaud M, Kulczykowska E, Massabuau J-C, Carter T, Planellas SR, Kristiansen T (2012) Behavioural indicators of welfare in farmed fish. Fish Physiol Biochem 38

NOSB (2010) Formal recommendation by the national Organic Standards Board (NOSB) to the National Organic Program (NOP). https://www.ams.usda.gov/sites/default/files/media/NOP%20Final%20Rec%20Production%20Standards%20for%20Terrestrial%20Plants.pdf. Accessed 2 Feb 2019

NOSB (2016) Hydroponic and aquaponic subcommittee report 2016. Hydroponic & Aquaponic Subcommittee Report. Preserving a philosophy while embracing a changing world, In: NOSB 2016: National Organic Standards Board (NOSB) Hydroponic and Aquaponic Task Force Report. https://www.ams.usda.gov/sites/default/files/media/2016%20Hydroponic%20Task%20Force%20Report.PDF. Accessed 21 Dec 2017

NOSB (2017) National organic standards board crops subcommittee proposal hydroponics and container – growing recommendations. August 29, 2017. https://www.ams.usda.gov/sites/default/files/media/CSHydroponicsContainersNOPFall2017.pdf. Accessed 21 Dec 2017

Peterhans H (2015) Aquaponic nutrient model. Thesis project. MS Thesis. Wageningen University. p 37

Rakocy J (1999a) Aquaculture engineering – the status of aquaponics part 1. Aquaculture Magazine, pp 83–88

Rakocy J (1999b) Aquaculture engineering – the status of aquaponics part 2. Aquaculture Magazine, pp 64–70

Rakocy J (2002) Hydroponic lettuce production in a recirculating fish culture system. Virgin Islands

Rakocy J (2009) Ten guidelines for aquaponic systems. US Virgin Islands

Rakocy J, Bailey D, Shultz K, Cole W (2001) Evaluation of a commercial-scale aquaponic unit for the production of Tilapia and lettuce. University of the Virgin Islands, St. Croix

Rakocy J, Bailey D, Shultz C, Thoman E (2004) Tilapia and vegetable production in the UVI aquaponic system. University of the Virgin Islands

Rakocy J, Masser M, Losordo T (2006) Recirculating aquaculture tank production systems: aquaponics–integrating fish and plant culture. Southern Regional Aquaculture Center

Rakocy J, Bailey D, Shultz C, Danaher J (2009) Fish and vegetable production in a commercial aquaponic system: 25 years of research at the University of the Virgin Islands. Kingshill, Virgin Islands, USA

Shafahi M, Woolston D (2014) Aquaponics: a sustainable food production system. ASME International Mechanical Engineering Congress and Exposition. Volume 3: Biomedical and Biotechnology Engineering. Montreal, Quebec, Canada, November 14–20, 2014