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Organic aquaponics in the European Union: towards sustainable farming practices in the framework of the new EU regulation

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Abstract

Under the new Commission Regulation (EU) 2018/848 which has entered into law in January 2021, aquaponic produce cannot be certified as organic in the European Union. Given the multiple components of an aquaponic system, which involve growing plants in hydroponic conditions, recycling of fish waste and raising fish in artificial conditions, the achievement of organic certification for aquaponic produce is a complex matter dictated by many parameters. Although in theory and in practice aquaponics fulfils nearly all organic farming principles, rules such as the need for crops to be cultivated in soil and the ban on using recirculating aquaculture systems currently prevent aquaponic produce from achieving organic certification. This review examines these rules in the new regulation on horticulture and aquaculture. The rules are evaluated, their foundations discussed, and suggestions are made on the type of system modifications that could potentially make it possible for aquaponic produce to be certified as organic. Suggested modifications include the use of soil in the hydroponic section and the implementation of environmental enrichment for improving the fish welfare in the aquaculture section. Several EU policies and strategies that support the development of aquaponics are also discussed, and potential policies for the development of organic aquaponics are formulated.

Key words: aquaculture, aquaponics, certification, horticulture, hydroponics, organic.

Introduction

Today, more than 820 million people do not have enough food, with more than one in every five children under the age of five being stunted (United Nations 2019). Our food systems are failing, and the COVID-19 pandemic is making things worse: UN Secretary-General António Guterres said on 9 June 2020 that the world is on the brink of its worst food crisis in 50 years (The Guardian 2020). Better social protection for poor people is urgently needed as the impending recession following the COVID-19 pandemic puts basic nutrition beyond their reach (United Nations 2020b). This is resulting in the global food industry searching for more sustainable and accessible systems for the production of healthy food, particularly fresh vegetables and fruit. Vertical farming techniques such as hydroponics and aquaponics that maximise output and minimise the use of resources (space, soil and water) emerge as the best candidates to address this problem. Aquaponics is an innovative food production method that involves the farming of fish and other aquatic animals and plants – mostly vegetables and herbs – together in either coupled (closed-loop) or decoupled[1] systems. In coupled aquaponic systems, the waste from the fish is converted by bacteria that occur naturally in the water into nutrients for the plants, which absorb them, thus cleaning the water for the fish and thereby forming a full recirculation cycle (Somerville *et al.* 2014:4). Due to its integrative character, aquaponics is a complex food production technology that can address the three pillars of sustainability: environmental, economic and social (König *et al.* 2016). In 2015, the European Parliament included aquaponics as one of the ten technologies that could change people's lives,

[1] Whereas coupled systems pass the water from the fish through filtration to the plants and then back to the fish, decoupled systems use the fish water to fertigate the plants, but the water is not subsequently returned to the fish.

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praising the innovative technology based on its waste recycling and circular economy principles (van Woensel *et al.* 2015). The European Parliament also pointed out that aquaponic systems can contribute to growing local food sustainably, given the reduction in resource consumption that is associated with coupled fish farming and vegetable cultivation (Sanders 2013). The reputation of aquaponics as a way to produce food sustainably has quickly spread in the past decade, with European Parliament resolution 2017/2118 (INI) calling on the Commission and the Member States to 'promote innovative and environmentally friendly technologies in aquaculture, such as aquaponics, in order to produce food in a sustainable and resource-efficient way and to avoid negative impacts on the environment'. Aquaponics is also mentioned as a research and funding priority in the 'Report on technological solutions for sustainable agriculture in the EU' (McIntyre 2016) and is considered as a new revolution in food production in the 2014 European Commission amended budget (European Commission 2014b). In spite of such recognition, research in aquaponics is still in its infancy, which is reflected by the significantly lower number of peer-reviewed publications on aquaponics compared with aquaculture, hydroponics and green roofs. By contrast, aquaponics maintains its popularity amongst the general public, boasting high number of results on Google – in this regard, aquaponics has been termed an emerging technology and science topic (Junge *et al.* 2017).

Although aquaponic technology is considered to be a sustainable way of producing plants and fish (Somerville *et al.* 2014), its position in the market is seen to be hindered by EU regulations. These regulations make it difficult for producers to market their products effectively and thus maximise profits, which would create a stable and sustainable future for aquaponics (Kledal *et al.* 2019). Given the steady growth and popularity of organic produce in the EU, it is speculated that organic certification of aquaponic produce could help with its marketability and commercialisation (Kledal *et al.* 2019). This would occur by using the organic price premium as one way to reimburse the high capital investments required for commercial aquaponics (Kledal *et al.* 2019). In fact, a 2015 consumer report notes that organic produce is 47% more expensive (Marks 2015). Whilst this additional cost does not necessarily equate to profit, as organically produced yields may be lower and production costs higher, there is the assumption that at least some of this 47% would be additional profit. Furthermore, the organic certification label seems like the natural choice for a market positioning, given the environmentally friendly and sustainable characteristics of aquaponics. This is also in light of what most people understand an organic label to mean: high standards of animal husbandry and free from pesticides and inorganic fertilisers (Denver *et al.* 2019; Lee *et al.* 2019; Thøgersen *et al.* 2019).

There are many advantages of using aquaponics from the perspective of sustainability, most notably: low water usage, little to no chemical usage, no use of synthetic fertilisers or pesticides and recycling of waste (Goddek *et al.* 2015), the latter presenting a potential solution to the environmental problems caused by the eutrophication of aquatic ecosystems (Kledal *et al.* 2019). Given these attributes, it would seem logical, at least from the point of view of the general public, for aquaponic produce to be certifiable as organic. However, two aspects of the technology currently prevent this. The first aspect is the integration of two distinct production methods, namely horticulture and aquaculture, both of which come with their respective regulations for organic production. This is exacerbated by the fact that crop production and aquaculture are administered by two separate Directorates-General of the European Commission, DG Agriculture and Rural Development (AGRI) and DG Maritime Affairs and Fisheries (MARE). The second aspect is the agro-industrial set-up aimed at using technological advances in order to increase production, as opposed to the organic agro-ecological one which aims to accommodate such advances for the progression of ecological principles (Kledal *et al.* 2019). Aquaponics is not included in the EU organic agriculture certification scheme, as it is considered a type of hydroponic technology, and hydroponics is not allowed in organic farming. Furthermore, from January 2021 a key prerequisite for organic agricultural production is for plants to be grown in soil that has a direct connection with the subsoil and bedrock. Additional rules that prevent aquaponic produce from being certified as organic include the exclusion of raw fish waste ('manure') used as fertiliser for crops and the use of recirculating aquaculture systems (RAS) which is a core component of coupled aquaponics. Laws that prevent organic certification of aquaponic products in the European Union are not shared by countries such as the USA and Canada, where hydroponic/aquaponic products can be certified as such.

This review explores the new rules implemented in Regulation (EU) 2018/848, their relationship with the underlying principles of organic production, the perceived reasoning behind each rule, the apparent inconsistencies in the rules and potential ways forward which could be taken in order to lobby for organic certification for aquaponic produce. We argue that aquaponics already possesses all the qualities and features needed to be included in organic certification and that the few obstacles that currently prevent this are either based on bad science or are unsupported by any solid scientific proof. Although further research is needed, amendments to conventional aquaponic systems could potentially solve most of these barriers.

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Modifications such as the addition of soil and the use of environmental enrichment practices in recirculating aquaculture systems could in fact bring aquaponics closer to organic certification, even with the current rules.

The organic movement and EU regulatory frameworks

Organic agriculture, whilst still occupying a niche sector within agricultural production, has gone through different stages in its evolution. Organic 1.0 has been defined by Rahmann *et al.* (2017) as the period during which the organic agriculture vision first developed. The organic movement began in the early 20th century in reaction to increasingly intensive farming methods and the growing use of synthetic fertilisers. As a holistic, ecologically balanced approach to farming, the pioneers of organic agriculture focused on finding natural ways to improve and maintain the health of the soil. The movement grew in the 1970s as more people became interested in their own health and that of their environment, and in the 1980s and 1990s, production and consumption increased, official standards defining organic produce were formulated, and grant aid for organic farming was introduced in the European Union. Organic 2.0 has developed in the last three decades, and during its fast growth, it has brought the establishment of organic research institutions, associations and regulations. Organic 3.0 refers to the current period, in which organic agriculture has diffused globally and contributes to solving global challenges of agri-food systems (Rahmann *et al.* 2017). In the EU, the organic sector is worth approximately €27 billion – an increase of 125% compared with 20 years ago – with a land expansion rate at around 400 000 hectares per annum (European Commission 2017); in 2018, organic farming covered 13.4 million hectares of agricultural land, which corresponds to 7.5% of the total utilised agricultural area of the European Union (eurostat 2020). The rapid diffusion of highly intensive organic production systems over the last decade has sparked discussion on the principles of organic farming amongst producers, consumer associations and policymakers of the organic sector (Tittarelli 2020).

Whist organic agriculture standards vary around the world, they are all based on several underlying principles, namely the health of the soil, conservation of biodiversity and minimisation of resource use, as defined by the International Federation of Organic Agriculture Movements (IFOAM 2014:13)[2]:

> 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.

In the EU, the current regulatory framework in place for organic fish and vegetable production is regulated by Council Regulation (EC) No. 834/2007, whereas more detailed regulation standards are addressed by Commission Regulation (EC) No 889/2008 and Commission Regulation (EC) No 710/2009. The newly published Council Regulation (EU) 848/2018 is a long-awaited update which has entered into force on 1 January 2021. These rules effectively repeal Council Regulation (EC) No 834/2007 and all the regulations based on it, including Commission Regulations (EC) No 889/2008 and (EC) No 710/2009. The European Commission maintains that the new rules reflect the major changes that have taken place in the EU organic sector in the last twenty years, offering a simpler and more harmonised approach (European Commission 2017).

The drafting of new rules is based on a process of consultation and before making any regulatory decision the European Commission must consult with all EU countries, which happens through regulatory committees. Such committees provide the European Commission with updated information on the opinions of citizens and experts in the sector. Regarding organic production and certification, the main regulatory committees are the Expert Group for Technical Advice on Organic Production (EGTOP), the Committee on Organic Production and the Civil Dialogue Group (CDG). EGTOP was established in 2008, taking the place of several temporary ad hoc expert groups as a permanent group advising European institutions on various aspects of organic production, thus making sure that EU rules are proportionate and effective, whilst simultaneously keeping up with the rapidly advancing sector. EGTOP also produces organic yield reports on a regular basis as well as assessments of EU countries' requests for technical annex amendments of EU regulations and assists the European Commission in preparing policy initiatives and legislative proposals. Additionally, EGTOP coordinates activities and exchanges views with the EU member states. The views of EU countries on current and upcoming organic legislation are represented by the Committee on Organic Production, which serves as a connection point between the EU and the individual countries that constitute it. The committee comprises of representatives from all EU countries and, like EGTOP, it meets regularly to discuss suggested changes regarding regulation. The CDG is made up of

[2]The International Federation of Organic Agriculture Movements (IFOAM) 'Founded in 1972, we are the only international umbrella organization for the organic world, uniting a diverse range of stakeholders contributing to the organic vision' (https://www.ifoam.bio/en/about-us).

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representatives from a variety of different groups, such as environmental charities, NGOs, producer and consumer cooperatives and trade unions. The CDG helps advise and monitor the organic policy developments of the EU Commission, whilst assisting the Commission in the formulation of legislative proposals and policy initiatives (European Commission, Co-operation and Expert Advice).

In 2013, EGTOP published a report titled 'Final Report on Greenhouse Production (Protected Cropping)', where the group reviewed Council Regulation (EC) No 834/2007 and proposed some specific production rules for organic greenhouses. Many of these recommendations have been included in the new Commission Regulation (EU) 2018/848. The ones most relevant to aquaponics include the recommendation that soil fertility be provided mainly though slow-release fertilisers, the preservation of soil health by preventive means, the encouragement of the use of natural enemies, the recommendation of efficient water and energy use including restriction of artificial light use and maximisation of renewable energy, the restriction of peat use and the prohibition of the use of containers for the cultivation of organic fruits and vegetables (EGTOP 2013; Schofield 2013). The influence that the report had on the amendments that followed and were implemented in the new Commission Regulation (EU) 2018/848 are indicative of the need to evaluate and discuss the rules in place for amendments to be made in the future and to bring change that could allow aquaponics to be recognised as an organic food production technology.

The 'organicness' of aquaponics

The rules in Commission Regulation (EU) 2018/848 are based on the underlying principles of organic production, where every rule is based on one or more principles. These principles can be subdivided into three categories: (i) Environment, (ii) Plants & Animals and (iii) People (Table 1). The environment category includes principles that deal with environmental protection, preservation of natural processes and sensible energy usage. The plants and animals category deals with the high standards required for animal welfare and the preservation of good plant and animal health. The people category deals with the effects of organic farming on human beings, such as the effects on rural development, food safety and product quality.

Overall, aquaponic produce is environmentally sustainable, respects natural cycles, employs high standards of health and welfare for the farmed organisms, is safe to eat and can support rural and social development; this means that aquaponics embodies the true spirit of the principles of the organic regulation.

Besides fulfilling all the organic principles laid out in Commission Regulation (EU) 2018/848, with the exception of the principle of the preservation of soil function and long-term fertility which can be fulfilled with the adoption of soil, aquaponics fulfils the majority of the production rules, with the exception of six rules layed out in section 4. In fact, aquaponics minimises environmental contamination (rule 1.6) through the recycling of waste, limits the use of fertilisers (rule 1.9.3), does not use mineral nitrogen fertiliser (rule 1.9.8) and encourages the use of natural enemies (rule 1.10.1) because of the impossibility of pesticide use that would harm the fish. Furthermore, the optimal use of RAS in aquaponics guarantees a variety of advantages over aquaculture systems such as cages, which remain certificable under Commission Regulation (EU) 2018/848. The escape of non-local species mentioned in rule 3.1.5.7 could have tremendous environmental consequences (Naylor *et al.* 2001; Thorstad *et al.* 2008), hence the rule for farming only locally present species (rule 3.1.2.1b). The chance of an escapee is, however, only an issue when open aquaculture systems such as ponds or sea cages are used. In RAS, the chance of an escapee is effectively zero (Jeffery *et al.* 2011), thereby making the local species rule irrelevant. Whilst there are ways that some species may escape, for example through cleaning operations, the risk can be avoided through appropriate management and maintenance systems. Besides the possible introduction of alien species, open aquaculture systems have other constraints, such as water resource use, localised reduction in benthic biodiversity, changes in water flow, pollution, significant dredging of water bodies and physical modification of land (European Commission 2016). In RAS, most of these issues are either absent or mitigated. Aquatic organisms grown in RAS are separated from the aquatic environment and cause no damage to wild populations. An aquaponic system that employs optimal farming practices, provides organisms with suitable and specifically tailored environmental parameters and poses little to no risk to wild populations is completely in line with organic principles. The use of RAS in coupled aquaponics guarantees the impossibility of escape incidents (Jeffery *et al.* 2011). Whilst we believe that there are no 100% guarantees, these small risks can be managed through appropriate management practices.

According to rule 3.1.4.1(a), disease prevention shall be based on keeping the animals in optimal conditions, and the closely related rule 3.1.5.4 states that aquaculture systems must provide flow rates and physiochemical parameters that safeguard the animals' health, welfare and behavioural needs; both these rules are based on the principle of high animal welfare and reproduction standards. Such a position recognises the importance for aquatic animals to express normal behaviour and is in line with the principles of the 'Five Freedoms' concept stated by the Farm Animal Welfare Council (FAWC 1979). In fact, there is substantial ethological, neuroanatomical and

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Table 1 Summary of the principles of organic production, extrapolated from Chapter I, Article 5 and Article 6 of Commission Regulation (EU) 2018/848, divided into environment, plants and animals and people categories; for each principle, the way that aquaponics fulfils it is annotated

Category	Principles (concepts)	Aquaponics accordance
Environment	Best environmental and climate practice	The sustainability advantages of aquaponics include low water usage, little to no chemical usage, no use of synthetic fertilisers or pesticides, and the recycling of waste (Goddek *et al*. 2015); its 90–95% water reuse significantly reduces its reliability on natural resources (Hoevenaars *et al*. 2018)
	Preservation of biodiversity	The optimal functioning of an aquaponic system is based on the diverse microbial communities in the biofilter section (Somerville *et al*. 2014:75)
	Preservation of natural resources	Aquaponics offers a reduced consumption of water compared with conventional agricultural systems (Goddek *et al*. 2015)
	Recycling of waste and by-products of plant and animal origin	Aquaponic technology is based on the recycling of fish waste, which is processed and transformed into nutrients for the plants
	Preservation of soil function and long-term fertility	Whilst conventional aquaponics is generally soil-less, the development of soil-based aquaponic systems would fulfil this principl
	Respect for natural systems and cycles	The nutrient recycling principle of aquaponics is based on natural cycles
	Maintenance of the state and balance of soil, water, and air	Aquaponics is largely not soil-based and does not impact on existing soil conditions
	Preservation of natural landscape elements	Given the relatively small amount of water necessary, aquaponic systems can be located in a variety of places, including deserts and areas with degraded soil, thus using space that is unsuitable for other food production systems, such as rooftops, abandoned industrial sites and generally non-arable or contaminated land (Hoevenaars *et al*. 2018), thereby aiding the preservation of natural landscape elements
	Responsible use of energy and natural resources	Energy for pumping is kept to a minimum, as aquaponic systems mainly work by gravity (Somerville *et al*. 2014:54), and energy can be generated by alternative sources. Additionally, as fertilisers are produced within the system, input of natural resources is minimised
	Use of production processes unharmful to the environment	The processes involved in aquaponics are not harmful to the environment; in fact most or all the waste that is produced is recycled (Somerville *et al*. 2014). Aquaponics allows for intensive production in small spaces, thus contributing to urban heat island mitigation (Zinzi & Agnoli 2012), and they can use harvested rain water (Junge *et al*. 2017)
	Preservation of the health of the aquatic environment and the quality of surrounding aquatic and terrestrial ecosystems	RAS are land-based systems that do not interfere with natural aquatic ecosystems
	Low-carbon footprint	Aquaponics is especially well suited for the production of food close to consumers, given its low dependence on natural water sources, and its effective use of space, thus lowering carbon emissions resulting from the transport of food from rural areas to cities
Plants & animals	High animal welfare and reproduction standards, including meeting animals' behavioural needs	RAS use in aquaponics allows the farmer to closely monitor water parameters for the well-being of the animals, guaranteeing optimal temperature, dissolved oxygen levels, pH and water flow, and adjusting them according to the behavioural needs of the animals
	Preservation of the health of the plants and animals	RAS use in aquaponics allows the farmer to closely monitor the health of the animals and plants by checking for signs of disease or injury
People	Rural development	Aquaponic systems can be set up and operated in a variety of locations, ranging from cities to rural areas, allowing for intensive production in small places, either in rural areas or in areas where land is scarce or polluted (Junge *et al*. 2017)
	Increased economic return to farmers	Organic certification of aquaponic produce could guarantee an increased economic return to farmers (Marks 2015)
	High food safety standards	Because of the recirculating water aspect of aquaponics, the technology is pesticide-free, and food is guaranteed to be grown in a way that is aligned to natural principles and safe to eat

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Table 1 (continued)

Category	Principles (concepts)	Aquaponics accordance
	Enhancement of social and territorial cohesion	The high versatility of aquaponic systems makes them relatively easy to set up and operate in diverse places and for different purposes. Aquaponics can enhance social and territorial cohesion by being placed near city centres, thus enhancing connectivity between people and the food they consume, or in schools and social centres, thus improving health, well-being and education
	Maintenance of high product quality	Aquaponic produce has been praised for its high quality and good flavour (Khandaker & Kotzen 2018)
	Use of processes that do not harm human health	Processes used in aquaponics, such as the conversion of fish waste into nutrients for the plants, are based on natural principles and do not harm human health

physiological evidence that fish are sentient creatures, although it remains controversial whether they experience feelings or emotions and are conscious of pain and fear (FAO 2019:2). RAS allow the farmer to closely monitor the fish for signs of diseases, as well as guaranteeing optimal water quality, flow and exchange rates. In a closed system, all the relevant parameters that ensure fish health are checked for, and cleaning and disinfection of the premises are paramount to the success of the operation whilst also preventing potential disease outbreaks. One of the advantages of using a RAS is the ability of guaranteeing that the farmed animals are kept in optimal conditions throughout the rearing process; this way, disease prevention is based on keeping the animals in good health. Whilst diseased fish grown in ponds, for example, can easily go unnoticed, thereby extending their suffering and increasing the risk of spreading the disease, fish grown in RAS can clearly be monitored for signs of disease, thus allowing for prompt response and treatment. The use of RAS in coupled aquaponics provides the possibility of frequent health checks, application of optimal husbandry principles and the complete control of welfare, feed delivery, and disease prevention (Nazar *et al.* 2013). Through RAS, good quality water, adequate temperature and light conditions can be ensured, as required by rule 3.1.5.3.

Despite fulfilling both the organic principles of Commission Regulation (EU) 2018/848, with the exception of preserving soil function and long-term fertility and the majority of the production rules, aquaponics remains unable to produce food that can be certified as organic in the EU. The situation is different in Canada, where produce from aquaponic systems is currently certifiable as organic under standard CAN/CGSB-32.312-2018, which defines an aquaponic cultivation method as a system that 'combines the cultivation of crops and livestock in a symbiotic relationship'. Such types of multitrophic cultivation methods based on the recycling of nutrients are encouraged under Canadian standards, as stated in paragraph 6.1.4: 'Nutrient cycling through practices such as Integrated Multi-Trophic Aquaculture is encouraged'. In the United States, the USDA National Organic Program (NOP) does not prohibit hydroponic and aquaponic crops from being labelled as organic and granted the USDA Organic Status (USDA National Organic Program). This does not apply to aquaculture products, which remain excluded from organic certification, although, as reported by the USDA National Agricultural Library, the NOP is in the process of developing organic practice standards for aquaculture products (USDA National Agricultural Library).

Rules preventing organic aquaponic production

Although aquaponics is a highly sustainable system for food production (Goddek *et al.* 2015), several rules from Commission Regulation (EU) 2018/848 make the organic certification of aquaponic produce challenging (Table 2). In this section, these rules will be reviewed, their scientific foundations discussed and their relationship with aquaponics outlined. Given the hybrid nature of aquaponic systems, rules concerning aquaponic production are found in both the standards on crop production and aquaculture.

Rules on crops

Crop-related rules are listed in Annex II of Commission Regulation (EU) 2018/848; major stipulations which impact on aquaponic produce are the use of living soil, the need for the soil in which the plants are grown to be in contact/association with the bedrock and subsoil and the maintenance and enhancement of soil fertility.

As stated in rule 1.1, the presence of a living soil connected with the subsoil and bedrock is a requirement for the organic certification of crops. This is the first time that a connection with the subsoil and bedrock is clearly stated in an EU regulation. Previous regulations, including Council Regulation (EC) No 834/2007 and Commission Regulation (EC) No 889/2008, do not mention such a connection. It is, however, stated in the 2013 report from EGTOP 'Final Report On Greenhouse Production (Protected Cropping)' that in both regulations soil means 'upper soil . . . in contact with the subsoil, so that roots can grow into the subsoil' (EGTOP 2013:30). Such definitions leave considerable

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room for interpretation and as a consequence, Commission Regulation (EU) 2018/848 clearly specifies the required connection, meaning that any soil-less production method or culturing technique in which soil is taken out of its natural origin and then used alone or mixed with something else cannot be used in organic farming. Thus, soil effectively went from being considered a compositional entity to a spatial one, where the soil location and connection is, in part, what matters, rather than only its composition. The organic argument for the use of soil is that the vast majority of plants evolved to grow in soil, and the presence of soil in agriculture is thus one of the foundations of organic farming, where plants grown in soil benefit from deep and complex biological processes that soil organisms provide through symbiosis and nutrient transformations (Magdoff & van Es 2009). Such definitions of soil based on its direct connection with the bedrock rather than its composition are seen to be in line with the principle of respecting natural systems and cycles. This is because the vast majority of plants found in nature grow in a soil that is in connection with the subsoil, although this does not offer any relevant farming advantages and is not based on any scientific principles. It is the topsoil section itself that stores the most organic matter and provides a highly fertilised environment for plants to grow in. The subsoil, on the other hand, generally has low organic matter content, low oxygen and can have high clay concentrations, although for perennial plants it can prove beneficial where the roots can reach deeper to absorb minerals over a longer period of time. This, however, is not the case in most standard farmed crops, which have short roots that are unable to reach the subsoil layer (Fan *et al*. 2016). The mandatory connection of soil with subsoil and bedrock also clearly excludes any method of production involving soil-less media from organic certification, as well as any soil taken out of the site where it naturally formed. Sanders (2013) criticised the 2007 EU Commission Regulation for allowing certain countries to produce crops in raised/demarcated beds. According to the study, crops produced with such systems should not have been allowed to be certified as organic, as they render intensive production of vegetables in greenhouses permissible, which is claimed to be a production method that fails to respect natural systems. The new Commission Regulation (EU) 2018/848 reflects this claim, forbidding the use of raised/demarcated beds in organic farming, as well as adding the connection with the subsoil and bedrock as a requirement for the organic certification of crops (rule 1.5). It appears that not only is the composition of the soil not taken into account as long as the required connection with the subsoil and bedrock is fulfilled, but that the regulation offers no specification on its living part either. In fact, whilst crop farming must take place in living soil to be organic (rule 1.1), a definition of living soil is not given in the whole regulation, and it could be argued that virtually all top soils on earth are living soils, since virtually all top soils host some organisms and exhibit some kind of biological activity. Whist in Annex II, part 1 of the regulation soil needs to be living, in Article 3 (70) soil can also be non-living, as long as it is fertilised with materials and products that are allowed in organic production and connected with the subsoil and bedrock. This can be a cause of a great deal of confusion, since without a clear definition of what living soil is and with differing points of view regarding the regulation, recreating a living soil that is allowed to be considered organic can be a difficult challenge. As coupled aquaponic systems do not use soil and have no complex soil ecosystem providing the plants with most of the nutrients they need, rule 1.1 excludes aquaponic produce from organic certification. Even if soil-based aquaponics were to be used, it would be *de facto* impossible to realise a coupled aquaponic system without containers detached from the soil where plants grow, except for growing herbs and ornamental plants (rule 1.4); this is assuming that fish waste were allowed to be used as nutrient for the plants, which it is not. This makes all produce from coupled aquaponic systems, where water from the plants is returned to the fish units and that do not grow herbs or ornamental plants, automatically excluded from organic certification. One of the obvious benefits of using soil detached from the subsoil and bedrock layers is the possibility of cultivating produce away from rural areas and closer to population centres where the technology offers a highly scalable means of food production which can take place close to or within city boundaries. Producing food near to or within cities greatly reduces the carbon and ecological footprints of food production, creates a city food identity and enhances the connection that people have with food and the way it is grown (Hui 2011; Ackerman *et al*. 2014). This rule thus hinders the development of food production systems away from rural areas, in line with the principle of rural development. Whilst the principle may be laudable in some cases, it contradicts current attitudes and policy, where agricultural land needs to be used not only to produce food but also to provide public goods and services and in some cases, this means rewilding the land and not producing food. On the other hand, food still needs to be produced and it does appear arbitrary that unproductive peri-urban and urban land cannot be used for organic production, because rural landscapes are prioritised.

An exception to rule 1.1 as noted previously is given to ornamental plants and herbs, which can be sold in pots to the end consumer, and for growing seedlings or transplants, which can be grown in containers for further transplanting, as specified in rule 1.4. This topic was addressed by EGTOP (2013) in their report years before the new mandatory connection with the subsoil and bedrock and its

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Table 2 Production rules from Commission Regulation (EU) 2018/848 that prevent the certification of aquaponic produce, principles that each rule is based upon and how each rule prevents certification

Production rules	Underlying principles	Obstacles
Crop production (Annex II)		
1.1: Organic crops, except those which are naturally grown in water, shall be produced in living soil, or in living soil mixed or fertilised with materials and products allowed in organic production, in connection with the subsoil and bedrock	• Preservation of soil function and long-term fertility • Respect for natural systems and cycles • Maintenance of the state and balance of soil, water, and air • Preservation of natural landscape elements • Rural development	• Conventional aquaponic systems function without soil • Fish waste is not allowed as a fertilisation material in organic production • The design of coupled aquaponic systems does not allow for plants to be in connection with the subsoil and bedrock
1.2: Hydroponic production, which is a method of growing plants which do not naturally grow in water with their roots in a nutrient solution only or in an inert medium to which a nutrient solution is added, is prohibited	• Respect for natural systems and cycles	• Coupled aquaponics is generally considered to be a type of hydroponics, which makes aquaponic produce automatically excluded from organic certification
1.9.2 The fertility and biological activity of the soil shall be maintained and increased: . . . (b): Soil fertility and biological activity shall be maintained and increased in greenhouse or perennial crops by the use of green manure crops, legumes, and plant diversity (c): Soil fertility and biological activity shall be maintained and increased in all cases by the application of preferably-composted livestock manure or organic matter from organic production	• Preservation of soil function and long-term fertility • Respect for natural systems and cycles • Maintenance of the state and balance of soil, water, and air	• Coupled aquaponics functions without soil, thus soil fertility and biological diversity cannot be maintained nor increased • Green manure crops, composted livestock manure or organic matter cannot be applied without the use of soil • Fish effluent is not allowed in organic production
Aquaculture production (Part III)		
3.1.5.1 Closed recirculation aquaculture animal production facilities shall be prohibited, except for nurseries and hatcheries for the production of species used for organic feed organisms	• Respect for natural systems and cycles • Responsible use of energy and natural resources	• Coupled aquaponic systems use closed recirculation aquaculture animal production systems
3.1.5.2. Artificial heating or cooling of water shall only be permitted in hatcheries and nurseries	• Responsible use of energy and natural resources • Low-carbon footprint	• RAS used in aquaponics generally require artificial heating and sometimes cooling of water
3.1.5.3 For freshwater fish, the bottom type shall be as close as possible to natural conditions	• Respect for natural systems and cycles • High animal welfare and reproduction standards, including meeting animals' behavioural needs	• Although environmental enrichment practices allow tank modifications to produce an environment close to nature for the fish, a fully natural bottom type only occurs in ponds

exceptions were introduced. In the report, the authors made the claim that growing plants in a 'horticultural substrate' should be authorised for ornamentals, herbs, seedlings and transplants. This claim was consequently added to the new Commission Regulation (EU) 2018/848. Based on the EGTOP report, the principle behind this exception is that the consumer cannot be misled about the production method of potted herbs and ornamentals, which can be bought in pots. This way, consumers are sure that the plant that they are buying was grown on a substrate. Another practical reason is that the consumer can grow such plants at home, keeping them in the pots that came with the plants on purchase. This is in contrast to produce that is harvested out of sight of consumers, in which case EGTOP adds that it 'should always come from plants grown in soil, and not from horticultural substrate cultures' (EGTOP 2013:30). Such practical reasons effectively seem to supersede the principle of respecting natural systems and cycles, which effectively goes from being a pillar of organic farming, as found in Article 5 of Commission Regulation (EU) 2018/848, to a statement that can be supplanted by any reason that can make the selling of produce more practical. The inclusion of seedlings or transplants in the exception is likely to be a way of facilitating the

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production of plants in systems that would maximise their production in their early stages. This is similar to the aquaculture rule that prohibits the use of RAS (Recirculating Aquaculture Systems) with the exception of hatcheries for the production of fingerlings that are then transferred to grow-out facilities (rule 3.1.5.1 – see below). Culturing seedlings in containers makes the process of transplanting them much easier, given the possibility of transplanting the root system encapsulated in the container to a grow-out system. An equivocal point is that the exception does not add any specifications on the type of culturing methods that can be used to grow herbs, ornamentals, seedlings and transplants. In the EGTOP report (EGTOP 2013) the term 'horticultural soil' is used, which leaves room for interpretation as there is no clear definition of horticultural soil given in the report. Furthermore, in Commission Regulation (EU) 2018/848 there is no mention of the type of culturing methods or substrates allowed for producing these horticultural varieties. Whilst it is uncommon to see aquaponic produce that has been grown in pots, coupled aquaponic technology does allow production of plants in pots filled with soil or other media, as shown by Palm *et al.* (2019), who successfully grew ornamental plants (*Hedera helix*) in soil in an aquaponic system. It is most likely that the effects that such systems would have on the growth and well-being of plants and fish will be benign, but this has yet to be investigated. This principle not only allows the organic certification of herbs and ornamental plants grown in pots, which constitutes an exception to the necessary connection with the bedrock and subsoil (rule 1.1), but it also allows these plant categories to be grown in inert media. In fact, following a request for clarification, the European Commission responded that 'ornamentals and herbs can be produced not only in living soils as laid down in point 1.1. but also in pots to be sold in pots to the consumer with or without soil' (Nathalie Sauze-Vandevyver, pers. comm., 2020). This would indeed mean that for such plant types soil would not be needed and that any type of substrate material that is allowed in organic farming could essentially grant herbs, ornamentals, seedlings and transplants organic status. Since the organic culture of these varieties can take place with or without soil, it would appear that hydroponic technology should be allowed for growing herbs and ornamental plants. Hydroponic technology is, however, clearly not allowed (rule 1.2), and herbs and ornamental herbs are only exempt from rule 1.1, but not 1.2. Further clarifications are needed on the type of substrates that are allowed for the culturing of such varieties, as well as whether a substrate is needed at all.

Conventional soil-less aquaponic systems are based on hydroponic farming, which is prohibited and not certifiable as organic (rule 1.2). Hydroponics is a highly controlled food production method (FAO 2020) that relies entirely on the continuous supplementation of artificially sourced inorganic nutrient solutions and on tightly controlled water parameters (Jensen 1999). As such, hydroponic technology goes against the organic principle of respecting natural systems and cycles, as plants that do not grow naturally in water are cultivated with their roots in/partially in water. The nutrients that are added to the solution are not present in that form in the farming environment. Whilst aquaponics is not directly mentioned in the regulation, conventional soil-less aquaponic systems are based on hydroponic technology, and their produce cannot therefore be granted organic status. Besides the link between the two technologies, they are, however, based on entirely different principles. In contradistinction to hydroponics, in aquaponics there is no need for any mineral nitrogen fertiliser, the use of which is not allowed in organic production, as reported in rule 1.9.8. In aquaponics, all the nitrogen needed by the plants is supplied through the fish waste, which is converted by the bacteria which form naturally in the system into forms readily absorbable by the plants (Somerville *et al.* 2014). According to the definition of Francis *et al.* (2003) on sustainable agricultural production being achieved through the design of systems that close nutrient cycles, aquaponics is a highly sustainable technology that not only respects natural systems and cycles but is based on, and works by, applying principles found in nature. Effectively, aquaponics mimics nature by making use of naturally occurring processes and the cycling of nutrients that occur in water ecosystems. Therefore, whilst aquaponics is based on hydroponic technology, the exclusion of aquaponics from organic certification is unjustifiable under the principle of respecting natural systems and cycles.

From the mandatory use of soil introduced in rule 1.1, further specifications on its management arise. As stated in rule 1.9.2, the fertility and biological activity of the soil must be maintained and increased in organic production in all cases by the application of livestock manure and organic matter from organic production and in the case of greenhouse crops, by the use of short-term green manure crops, legumes and plant diversity. This rule is based on the principle of respecting natural systems and cycles, thus relying on naturally occurring processes such as the use of legumes for the production of nitrogen (Shah *et al.* 2003) and the use of livestock manure to increase soil fertility. Organic greenhouse production is characterised by extreme nutrient demands within short growing periods (Zikelia *et al.* 2017). Through this rule, the nutritional needs of plants are intended to be fulfilled by substituting off-farm synthetic inputs, which are generally used in conventional agriculture, with off-farm organic inputs. This substitution of synthetic fertiliser with organic fertiliser has been considered as an imitation of conventional agricultural practices (Contreras *et al.* 2014). Zikelia *et al.* (2017) have criticised this

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input substitution approach, stating that all soil fertility approaches in organic greenhouse production lead to high element imbalances, especially the ones based on compost and farmyard manure. Observed imbalances, such as a high accumulation of phosphorus, and increased soil pH, salinity and organic matter concentration, all negatively affect the long-term sustainability of the system. Since solid livestock manures and composts exhibit an unbalanced nutrient composition, it is impossible to achieve a balanced system by their application. Suggested practices in organic regulations, such as soil tillage practices, crop rotations, organic amendments and agro-ecological services crops are only effective when applied to less intensive systems (Tittarelli 2020). Additionally, the use of any fertilisers – on the land, organic or inorganic, within and outside greenhouses – can threaten underground as well as surface water quality, where these nutrients end up in streams and rivers. Aquaponic technology is based on the use of fish waste ('manure') as a source of nutrition for the plants. In Commission Regulation (EU) 2018/848 some fertilisers can be used as an input in organic production, provided that they are authorised in accordance with Articles 9 and 24 and listed in an implementing act provided for by Article 24(9). The use of manure in Commission Regulation (EU) 2018/848 is restricted to livestock manure, as there is no mention of fish manure. In fact, following a request for clarification, the European Commission responded that 'fish raw manure is not mentioned in Annex I to Regulation (EC) No 889/2008 therefore its use is at present not allowed in organic production' (Nathalie Sauze-Vandevyver, pers. comm., 2020). However, as fresh fish manure is similar in its chemical composition to other livestock manures, it is suitable for use as a fertiliser (Naylor *et al.* 1999), and its use should be allowed in organic farming. The use of fish manure as nutrition for the plants is also in line with the principle in Commission Regulation (EU) 2018/848 (article 6c): 'the recycling of waste and by-products of plant and animal origin as input in plant and livestock production'.

Rules on aquaculture

Aquaculture-related rules are listed in Part III of Commission Regulation (EU) 2018/848. The main stipulations which impact on aquaponic produce are the prohibited use of recirculating aquaculture systems (RAS), the contained use of energy and the implementation of measures that render the culturing environment as close as possible to the natural environment of the cultured species.

Perhaps the biggest constraint to the certification of aquaponic produce as organic, at least from the point of view of aquaculture, is the prohibited use of recirculating aquaculture systems, or RAS, as stated in rule 3.1.5.1; the rule however contains the exception of the use of RAS in hatcheries and nurseries or facilities for the production of species used for organic feed organisms. This rule is based on two main principles: firstly, RAS are artificial systems that do not resemble natural environments, and secondly, these systems are highly energy dependent. Whilst this is often true, closed recirculation aquaculture facilities provide several advantages over traditional and extensive culturing methods. Complete environmental control and optimal parameters for the growth of many different species can be set and monitored for the well-being of the animals. Aeration, water current, temperature, pH, salinity for saltwater and brackish species and light can in fact all be tailored based on the biological needs of the farmed animals and with much more control than in pond and raceway farming systems. The principle of responsible use of energy and natural resources also underpins rule 3.1.5.2, which prohibits the artificial heating or cooling of water, except for hatchery and nursery facilities. Whilst RAS generally require a higher energy cost in order to ensure that the animals are grown at the highest standards possible, the rule fails to acknowledge that such cooling and heating can be produced using renewable sources. In fact, for small greenhouses solar energy can be readily harnessed in order to run climate control systems or to provide passive heating. In countries such as Iceland or Japan, near-surface geothermal energy can be used to sustainably heat or cool water (Goddek *et al.* 2015). In fact, in Iceland geothermal energy is used to grow many varieties of vegetables in greenhouses, which would otherwise be impossible to grow (Butrico & Kaplan 2018). A further option is to use waste water heat from combined heat and power units to heat up or cool down greenhouses. Such units are generally found in combination with agricultural biogas plants, where surplus heat is plentiful (Goddek *et al.* 2015). If renewable energy for the manipulation of water temperature is used, the principle of responsible use of energy is fulfilled, and there is indeed no reason why artificial heating or cooling of water for grow-out aquaculture operations should not be allowed. Especially given the permitted use of natural borehole water to heat or cool water for all stages of production, there is no logical reason why geothermal borehole water should not be allowed to be used for controlling the water temperature through the use of a heat transfer pump. By manipulating the water temperature artificially, optimal conditions for the growth of any species can be achieved, thereby minimising temperature fluctuations that are observed in extensive aquaculture systems that are currently allowed in the regulation, such as ponds and sea cages, thus contributing to the well-being of the farmed animals. In conclusion, artificial heating and cooling of water for the grow-out phase of aquatic organisms should be allowed, depending on the nature of the energy production method. A categorical exclusion of all kinds of artificial

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cooling or heating of water, regardless of the amount of energy consumed and the way that energy is produced, is based on general principles that fail to take account of the developments in sustainable energy provision in the modern world, including photovoltaics (solar power), solar water heating, wind power, ground source heat pumps, geothermal heating and CHP (Combined Heat and Power) plants. The use of RAS in coupled aquaponics provides the option of readily controlling water parameters, including water temperature (Nazar *et al.* 2013). In order to limit or avoid expensive cooling or heating of the system's water, aquaponic growers should consider culturing fish and plant species that are suited to the local climatic conditions. In fact, by farming species that better conform to the available parameters, energy consumption can be lowered. Forbidding the artificial heating and cooling of water for juvenile and adult aquatic organisms greatly limits the possibility of produce from aquaponic farms being certified as organic. In fact, a stable water temperature is essential in aquaponics, as fluctuations in temperature can harm not only the fish, but also the plants and nitrifying bacteria (Goddek *et al.* 2015). Whilst stable conditions are achievable in equatorial areas without additional technology, the artificial heating and cooling of water is vital for aquaponic farms in regions with seasonally changing climatic conditions, as well as in hot and arid areas (Goddek *et al.* 2015). Controlling the water temperature through artificial means can guarantee optimal welfare for the aquatic organisms and reduce stress in both aquaculture and plant species by limiting temperature fluctuations. If done sustainably, the artificial control of water temperature can result in a 'green' method of food production that respects the health of the farmed organisms.

Another rule that hinders the organic certification of aquaponics produce is rule 3.1.5.3, which states that for freshwater fish the bottom type must be as close as possible to natural conditions, and in the case of 'carp and similar species', the bottom must be natural earth. This rule also refers to the principle of respecting natural systems and cycles, as well as the principle of high welfare and reproduction standard. Although tanks used in RAS can be modified to increase the complexity of the environment through a practice known as environmental enrichment (see section 5.2), it is assumed that 'as close as possible to natural conditions' means that the bottom type must be part of a natural system, rather than an artificial one. The specification of natural earth bottom for 'carp and similar species' is rather ambiguous. In fact, most cultured fish species are incredibly distant phylogenetically from one another, and grouping all freshwater fish together and asserting that the bottom type should be similar to the bottom type observed in their natural environment is an unsubstantiated generalisation that is based on the idea that natural surroundings provide the fish with a perfect environment at all times. In the case of tilapia, a highly territorial and potentially aggressive species, enriching the farming environment and bottom type to resemble their natural conditions increases fighting amongst individuals, as it raises the value of their territory (Gonçalves-de-Freitas *et al.* 2019). Even if freshwater fish could indeed all be grouped together and assumptions could be made that bottom types that resemble natural conditions would improve their welfare, it is not clear as to why saltwater fish would be excluded from such a rule. In fact, many benthic and demersal saltwater fish species are cultured as well; these species, such as flat fish like halibut and sole, heavily rely on the bottom type. In the case of 'carp and similar species', the rule adds that the bottom must be natural earth. What 'similar species' the authors of the standards are referring to, and how a species is judged as being similar to carp, is unclear. The practice of modifying the bottom type and adapting it to the natural condition of the cultured aquatic organisms falls into the nature-based concept of environmental enrichment practices. This approach aims at increasing fish welfare by rendering the culturing environment as close as possible to the environment the organisms naturally live in (Näslund & Johnsson 2016). However, this approach is most useful when the fish are conditioned to be then released into the wild, and less so for organisms that were likely not adapted to natural conditions due to domestic selection (Newberry 1995). Furthermore, whilst this assumption makes logical sense, conclusions in science must be based on experimental results, which in this case are lacking. The assumption that freshwater fish enjoy better welfare when cultured in bottom types that resemble their natural environment is yet to be proven, especially because best welfare practices differ between species, and freshwater welfare indications should not all be placed together in the same group. This rule hinders the certification of aquaponic produce by posing a further limit to the use of RAS. Nevertheless, the high versatility of RAS can allow for tank modifications, including bottom type. In fact, the tank environment in RAS can be modified to include different kinds of substrates, tank covers, surface colours, natural lighting, objects and even 'toys' (items that the fish may be interested in), in order to improve the welfare of the cultured animals.

Discussion

This analysis of the new organic regulations reveals that several wrongful assumptions have been made, which result in illogical and biased legislation that hinders the development of science-based agricultural production. In all cases, such wrongful assumptions do not seem to be based in science, but rather on an unchecked extension of the organic principles to areas that are unproven, and for

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which a clear explanation is often not given. An example can be found in rule 1.1 on the required connection with the subsoil and bedrock, which is based on the concept that since such a connection reflects what is often found in nature, it must promote a sustainable and 'green' farming approach. Instead, this rule effectively prevents the growing of produce from truly sustainable technologies such as aquaponics, based on waste recycling and other sustainable principles, from being certifiable as organic. Sweeping generalisations are also often made throughout the regulations, which result in rules that fail to illustrate logical sense and result in unjust exclusions. With regard to organic certification and soils, it is apparent that these regulations have been made to protect the interests of the organic farming community. Whilst this protectionism does not apply to aquaculture, the effect is the same, as the regulations stop the advance of science and technology. Examples of rules which are unverified by science include rule 3.1.5.3, in which all freshwater fish are considered to share a characteristic for which a 'natural' bottom type would be beneficial, and all saltwater or brackish-water fish species are excluded. Finally, several exceptions to other rules seem to contradict the principles upon which these rules are based. Such is the case of rule 1.4, for which ornamentals, herbs, seedlings and transplants are excluded from rule 1.1 and its mandatory connection with the subsoil and bedrock, effectively bypassing the principle of respect for natural processes and cycles in order to benefit the consumer and, of course, the producer. Such assumptions cause confusion, misinterpretation and result in innovative technologies such as aquaponics being irrationally excluded. A revision of Commission Regulation (EU) 2018/848, taking into account the vast array of cultured species and science-based findings, and adopting clearer and further detailed rules, would result in a more accessible, science-based system of certification, which would stimulate meaningful collaboration amongst scientists, producers and consumers. Only if such a regulation were to be put in place would it then be possible for aquaponic produce to reach the organic status that it rightfully deserves.

Possible advances in aquaponic technology: an eye to the future

Soil-based aquaponics: a possible solution?

Developing soil-based aquaponic systems where plants are cultured in soil instead of inert media or water could provide a pathway to organic certification for aquaponic fruit and vegetables. To do this, the inclusion of soil in aquaponics needs to be tested in order to find the best design for this novel culturing method, taking into account the seemingly indissoluble link with soil that organic certification requires. Whilst the use of soil would not automatically guarantee organic certification for produce due to the lack of connection with the subsoil and bedrock and the forbidden use of fish waste as a fertiliser, it could fulfil the requirement for plant nutrition coming primarily from the soil ecosystem, as found in paragraph 28 of Commission Regulation (EU) 2018/848. Whilst a definition of nutrition through the soil ecosystem is not given in the regulation, the addition of nutrients by the use of materials listed in Annex I to Commission Regulation (EC) No 889/2008 is permitted and represents the type of substances that are allowed to increase the fertility of the soil. Given the statement by EGTOP (2013:15) that 'soil fertility and an active soil ecosystem are the basis for plant nutrition in organic systems', the addition of fertilisers allowed in organic production is aimed at providing soil with the nutrients that the plants need and is therefore considered to be part of the fertility generated by the soil ecosystem. Following the definition of aquaponics by Palm *et al.* (2018), for a culturing system to qualify as aquaponic the majority (>50%) of the nutrients sustaining plant growth should be derived from waste originating from feeding the aquatic organisms. Therefore, in order for aquaponic produce to be given organic status nutrients should come primarily from the soil ecosystem, which can only be achieved if fish waste is recognised as a viable source of fertiliser for the soil. On the production side, soil inclusion could play a role in solving the long-held problem in conventional aquaponics of the differing water parameters (most notably pH) between the plant and fish units, which has been argued to produce fish and plants in sub-optimal conditions (Palm *et al.* 2019). In fact, there is potential for soil to possibly act as a buffer, maintaining a relatively acidic environment in the plant unit, whilst maintaining a relatively alkaline environment in the fish and biofilter units. Experiments are needed in this field, especially in order to determine the influence of soil ingress into the water on fish health in coupled aquaponic systems. Furthermore, the inclusion of soil in aquaponics would make the addition of beneficial soil organisms possible, which could in turn improve the overall condition of the soil, keep the plant rhizome healthy, and benefit the plants by enhancing the availability of nutrients, a practice that is allowed by Commission Regulation (EU) 2018/848 (rule 1.9.6). Beneficial soil microorganisms include mycorrhizae (symbiotic associations between soil fungi and plant roots) and beneficial soil bacteria that are already naturally present in the soil and benefit most plants today (Adams *et al.* 1998). However, the impact that additions of microorganisms would have on soil-based aquaponic systems is yet to be investigated. An analysis of soil microbial community changes when exposed to fish water could reveal the role of such microorganisms in the production of nutrients available to the plants. The effects on the fish also need to be investigated based on the principle of high

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welfare standards, to ensure that fish well-being is not compromised in soil-based coupled aquaponic systems.

Environmental enrichment in RAS

A greenhouse aquaponic system can provide the farmed organisms with optimal growing parameters, high welfare standards and lower energy consumption through the adoption of renewable energy sources, thus allowing the farming of species adapted to local water parameters. In Canada, aquatic organisms grown in RAS can be certified as organic, as stated in paragraph 6.8.3 of standard CAN/CGSB-32.312-2018: 'Recirculation systems are permitted if the system supports the health, growth, and well-being of the species'. This is in contrast with the EU, where animals grown in RAS are not allowed to be certified as organic.

Commission Regulation (EC) No 710/2009 (paragraph 11) states that

> 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.

The European Commission was therefore already acknowledging the benefits of RAS in 2009, but is still reluctant to grant organic certification for RAS products.

As aquaculture production and its popularity as a farming method continue to grow, its standards are increasingly regulated. Organic standards for aquaculture products are now included in all of the world's major organic certification schemes, and many variations of certification schemes are provided by the aquaculture industry, as well as governments, NGOs and retailers (FAO 2010). Furthermore, best practice-type certifications are in place for RAS-produced seafood, such as the Best Aquaculture Practices certification (https://www.bapcertification.org/Standards), which ensures the sustainability and welfare aspects of certain operations, which must fulfil strict requirements in order to obtain the certification. However, standards for fish are generally less detailed than the ones for livestock, as the field of fish welfare is still in its infancy. Such is the view of the European Food Safety Authority (EFSA), which claims that

> the concept of welfare is the same for all farm animals, i.e. mammals, birds and fish, used for human food and given protection under the Treaty of Amsterdam. Fish welfare however has not been studied to the same extent as terrestrial farm mammals and birds, neither welfare concepts nor welfare needs have been clearly understood for the various species of farmed fish. (EFSA 2009:6)

Exploring fish welfare is a complex task, where numerous approaches can be taken in order to assess and improve the well-being of fish. Historically, there have been three concepts under which animal welfare has been defined: (i) nature-based, (ii) function-based and (iii) feelings-based. The definitions are not mutually exclusive, although each of them takes a different viewpoint, as follows:

(1) In the nature-based definition, good animal welfare is fulfilled if the animals can engage in natural behaviour.

(2) The function-based definition considers animal welfare to be in good order if the animals are in good health and show normal biological functioning and good growth. This concept is often criticised for being too reductionist; as claimed by Ashley (2007:2), 'physical health is the most universally accepted measure of welfare and is undoubtedly required for good welfare ... However, for many, good welfare goes beyond just physical health and also involves a lack of mental suffering'.

(3) This introduces the feelings-based welfare concept, which regards farmed animals as sentient beings that are able to experience feelings and that can suffer emotionally; such a position is still controversial for fish (FAO 2019).

A welfare practice that addresses all three welfare concepts, and for which recirculating aquaculture systems seem to be well equipped, is environmental enrichment. Environmental enrichment has been defined in many ways. Näslund & Johnsson (2016:3) define it as 'a deliberate increase in environmental complexity with the aim to reduce maladaptive and aberrant traits in fish reared in otherwise stimuli-deprived environments', whilst Shepherdson (1998:6) defines it as 'an animal husbandry principle that seeks to enhance the quality of captive animal care by identifying and providing the environmental stimuli necessary for optimal psychological and physiological well-being'. Such traits can be physiological, behavioural, psychological and morphological, as well as related to fitness, such as survival, health and reproduction. The interest in improving some of these traits has been generally channelled into improving the outcome of the release of cultured fish for restocking purposes, as well as in the use of fish as model organisms in laboratories. As research on fish progresses, and national and international legislation and guidelines for fish welfare become increasingly detailed, environmental enrichment is often recognised as a

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necessary approach for the establishment of sufficient welfare practices in fish (Näslund & Johnsson 2016). Commonly recognised categories of environmental enrichment (Young 2003) are:

- Physical enrichment, which includes additions or modification to the tanks, thus increasing structural complexity;
- Sensory enrichment, which deals with the brain and sensory organs;
- Dietary enrichment, which concerns the type and delivery of food;
- Social enrichment, which adds interactions and contacts amongst individuals; and
- Occupational enrichment, which relates to the increase in environmental variation in order to decrease physical and psychological monotony.

Environmental modification studies have been undertaken using several aquaculture species, mainly as a means for improving welfare by adapting tanks to the species-specific needs. Enriching the aquaculture environment can have several positive effects on fish physiology, health, and survival (Näslund & Johnsson 2016). However, since it requires increased labour and maintenance, tank enrichment techniques are rarely taken up by aquaculture producers (Gerber *et al.* 2015), and their use has been reserved for investigating whether they can improve survival and reproduction and, consequently, production. Examples include the use of artificial seaweed in Ballan wrasse aquaculture to be used as a substrate for laying eggs (Leclercq *et al.* 2018), and testing different tank bottom substrate materials in flat fish farming (Reif *et al.* 2010). Similar species-specific modifications will likely need to be implemented in order for RAS to be recognised as an organic means of producing fish. The possibility of obtaining organic certification and therefore increasing revenues could be a catalyst for making tank modifications aimed at improving fish welfare in RAS. Such tank enrichment modifications can, however, prove to be challenging to employ. In fact, relatively few operational welfare indicators (OWI) for cultured fish have been validated to date, given the limited amount of knowledge of and the diversity of farmed species (FAO 2019). With more than 600 species of aquatic organisms farmed worldwide (FAO 2020), environmental enrichment protocols will need to be species-specific, as there are large differences in the preferences of fish across taxa. For example, rainbow trout (*Oncorhynchus mykiss*) exhibit lower growth rates with increasing stocking density (Ellis *et al.* 2002), whilst the opposite is observed in Arctic char (*Salvelinus alpinus*) (Jørgensen *et al.* 1993).

In summary, RAS can guarantee optimal living conditions through optimal control of water parameters and frequent health checks. However, in order for RAS to be included in organic certification, greener energy methods and environmental enrichment could be implemented in order to achieve smaller energy consumption rates, lower energy dependence and high welfare standards for the cultured organisms. Such implementations are based on rule 3.1.3.2, which forbids artificial heating and cooling of water in aquaculture facilities, and on the principles of responsible use of energy and natural resources, and low-carbon footprint (Table 1). EU regulations are expected to take some time to change with regard to recirculating aquaculture systems, even though EU organic regulations are open to adaptation as soon as new scientific evidence arises, as stated in paragraph 48 of Commission Regulation (EU) 2018/848 as follows:

> Organic aquaculture is a relatively new field of organic production as compared to organic agriculture, where long experience exists at the farm level. Given consumers' growing interest in organic aquaculture products, further growth in the rate of conversions of aquaculture units to organic production is likely. This will lead to increased experience, technical knowledge and development, with improvements in organic aquaculture that should be reflected in the production rules.

The aquaculture industry in the EU is still in its infancy, and it could only be a matter of time before the EU Commission recognises organic standards for RAS under particular conditions, which could also include aquaponic production. Further research is, however, still needed to ascertain the benefits of environmental enrichment on commercial species in order to increase welfare, which could lead to species-specific environmental enrichment guidelines to be used for organic certification of RAS-grown aquatic animals in the future.

Organic aquaponic systems

Aquaponic technology is still in its infancy, and current systems are likely to go through significant changes in the near future. With the advancement of technology and research effort, some of the factors that currently decrease the productivity of an aquaponic system, such as the difference in pH needs between the cultured fish and plants, or the presence of small nutrient deficiencies in crops, could be solved. The high degree of versatility of aquaponic systems makes them highly adaptable in order to accommodate a vast array of production objectives and standards. The adoption of the suggestions given in this review, such as the use of soil in the hydroponic units and the use of environmental enrichment in the aquaculture units, could pave the way to the introduction of systems that will enable the produce to achieve organic certification (Fig. 1). Further advances could include the adoption of a sludge treatment system

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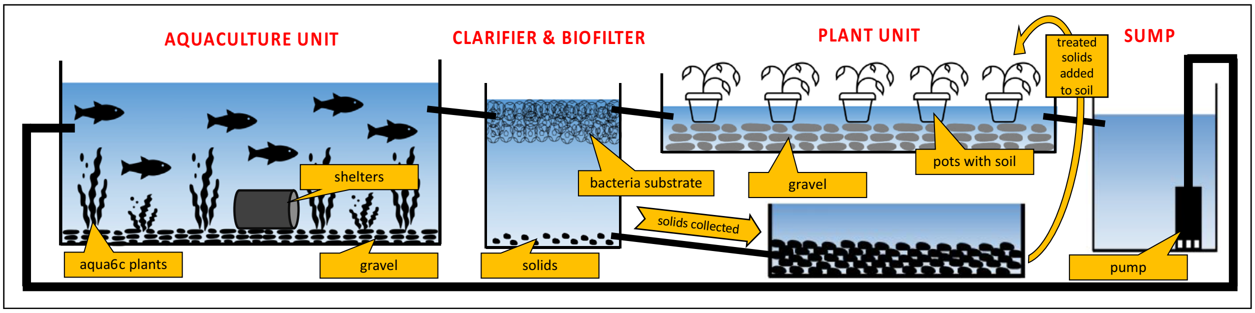

Figure 1 Representation of a system for organic aquaponic production, split into units (red) and item description (orange). Fish tanks can be enriched with aquatic plants (living or artificial), substrate-specific to the cultured species, with structures to be used as shelters, whilst the plant unit consists of pots filled with soil and periodically flooded with nutrient-rich water from the aquaculture unit.

for the reuse of waste solids from the aquaculture unit to be then mixed with soil, in order to provide the plants with the missing microelements that are generally removed with the solid part of the waste.

EU policies

Policies in support of organic aquaponics

Aquaponics is at the nexus of two different technologies – recirculating aquaculture and hydroponics – and of their different respective regulatory and policy fields; furthermore, its development is affected by different levels of governmental regulations, such as the facilitation of urban agriculture having to come from national or even sub-national level, as the EU has no jurisdiction in planning law. If aquaculture operations were to have the financial incentives or planning obligations to deal with waste water, the implementation of aquaponics could gain major traction, although this would require a significant change in the current regulatory approach (Reinhardt *et al.* 2019). According to König *et al.* (2018), only once the proponents of a new technology are sufficiently organised to contribute to the legitimation of their technology can an institutional alignment, and thus market formation and commercial viability, occur. The implementation of sustainable technologies can benefit greatly from the influence of regulatory frameworks. There are, however, no specific regulations or policies in place for aquaponics in the European Union, possibly because of the multidisciplinary nature of the technology, which combines intensive land-based aquaculture, industrial horticulture and waste water recycling, with producers being affected by conflicting and disparate regulations (Reinhardt *et al.* 2019). Under the Directorate-General for the Maritime Affairs and Fisheries (DG MARE) of the European Commission, aquaponics regulations were left up to the individual member states. Nonetheless, several aquaponics projects have been supported by the EU through research funding and innovation partnerships, such as the Seventh Framework Programme which funded aquaponics-related project INAPRO on integrated multi-trophic aquaculture and agriculture systems and the eight framework programme Horizon 2020 which funded aquaponics-related initiatives ECOFISH, EASY, and Cool-Farm (Gregg & Jürgens 2019). COST Action FA1305 'The EU Aquaponics Hub' was funded by COST (EU Cooperation in Science and Technology) and the EU Framework. However, whilst the EU is assisting the development of aquaponics through financial measures, these mostly target research projects, whilst the sector would also need assistance in commercial development through support for proof-of-concept projects (Hoevenaars *et al.* 2018). Although no policies or regulations are in place directly for aquaponics in the EU, some existing policies and strategies from related fields can provide opportunities and support. Since aquaponics involves both fish and plant production, relevant policies are the Common Agriculture Policy (CAP), the Common Fisheries Policy (CFP) which has established the Aquaculture Advisory Council (AAC), the EU Food Safety and Nutrition Policy and the EU Environmental Policy. The goals of these policies include promoting innovation, improving access to space and water, increasing sustainability and competitiveness, preventing the generation of waste, improving the welfare of animals including fish, developing a low-carbon economy, promoting the efficiency of resource use (thus directly relating to organic aquaponics and its low water and nutrient use), promoting the use of areas unfit for other food production systems and employing local food production approaches (Hoevenaars *et al.* 2018). The Common Agriculture Policy (CAP) is mainly relevant to the hydroponic part of aquaponics. In the document 'Overview of CAP Reform 2014–2020' several priorities are laid out, including modernising existing farms, reducing emissions, closing the cycles of organic waste, water and nutrients, improving animal welfare and minimising the use of inorganic fertilisers (DG Agriculture and Rural Development 2013), all

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measures that are in line with organic aquaponics. The Common Fisheries Policy (CFP) is relevant to the aquaculture part of aquaponics and includes the implementation of the Water Framework Directive in relation to sustainable aquaculture (European Commission 2013). The Commission staff working document 'On the application of the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) in relation to aquaculture' outlines the aim of Water Framework Directive (WTD) as being 'to improve and protect the chemical and ecological status of surface waters and the chemical and quantitative status of groundwater bodies throughout a river basin catchment' (European Commission 2016). The document also lists the main possible environmental effects of aquaculture that should be addressed and mitigated: the benthic impacts and nutrients discharge of aquaculture operations, the increase in diseases and parasites amongst wild and cultured fish, chemical discharges, escapees with a concentration on escapees of alien species and the physical impacts of aquaculture operations (European Commission 2016), all of which are either mitigated or absent in aquaponic production. The EU Food Safety and Nutrition Policy aims to ensure safe and nutritious food from healthy plants and animals, whilst supporting the food industry and covering all stages of food production; the policy supports aquaponics through its new food chain technologies approach, which aims to increase productivity using other primary production technologies (European Commission 2014c). The sustainable, waste recycling aspects of aquaponics are supported by the EU programme 'Living well, within the limits of our planet, 7th EAP-The new general Union Environment Action Programme to 2020', which aims to make cities more sustainable by establishing a resource-efficient, green and competitive low-carbon economy (European Commission 2014a), as well as by the Strategy on the prevention and recycling of waste, which is based on the prevention of waste followed by reuse, recycling, recovery and disposal (European Commission 2011). Finally, the welfare of farmed fish that is of pivotal importance in organic aquaponics is supported by the EU platform on animal welfare strategy for the protection and welfare of animals (European Commission 2012). None of these policies, however, mentions aquaponics, and it is the opinion of DG MARE that regulations on aquaponics should be resolved *within* each individual Member State (DG Mare Committee, pers. comm., 2017).

Potential policies for the development of organic aquaponics

When organic certification became part of statutory legislation, as is the case in the USA and the EU, it became not only legitimate but also necessary to review this legislation to ensure that it is fit for purpose. The BBC's Good Food web pages note that the UK's Department of Food and Rural Affairs (DEFRA) states that

> organic food is the product of a farming system which avoids the use of man-made fertilisers, pesticides; growth regulators and livestock feed additives. Irradiation and the use of genetically modified organisms (GMOs) or products produced from or by GMOs are generally prohibited by organic legislation. (BBC Good Food 2020)

It also says that

> organic agriculture is a systems approach to production that is working towards environmentally, socially and economically sustainable production. (BBC Good Food 2020)

Such statements highlight the fact that organic determination is an issue that is becoming more mainstream and that certification needs to be based on the production methods that benefit consumers but also the local and global environment as well as the economy. The key drivers of policies for organic production thus need to be environmental, social and economic production. On the contrary, it is clear to the authors that some of the current drivers behind the formulation of some of the rules for organic certification are not scientifically based and in some cases are indeed protectionist of an existing hierarchy. It is also clear that organic produce and production methods need to encompass technologies that in fact are better for the environment than existing organic standards. Thus, for example, using fish water in a controlled greenhouse is likely to be better for the environment than placing animal manure onto the ground which can have polluting consequences. The organic label should mean much more than certifying that the produce was grown in soil according to traditional methods or that the fish are wild caught. In order to raise the level of organic certification to a level which is based on science and remains true to its ideals of producing healthy food using natural methods, but taking account of technological advances, this next section identifies a set of policies and rules that could, in the future, be used as the basis for introducing aquaponics within the organic certification framework in the UK and the EU. The concept behind the policies and the rules is to maintain the tripartite goals of 'environmentally, socially and economically sustainable production', maintaining ethical and nature-based aspects of organic production that facilitate the organic certification of aquaponic produce, whilst leaving behind those aspects which are not scientifically based. In order to fulfil these goals, the following aquaponics-specific policies and rules are outlined for organic aquaponics. These suggestions do not include the obvious and clear rules that deal

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with water quality, organic fish feed, prohibition of antibiotics and pesticides and herbicides etc:

Rules on crops

(1) Plants can be grown using the three main hydroponic systems, namely NFT, raft (deep water culture and gravel) as well as in pots and troughs, including soil-based substrates.
(2) In the case of both coupled and decoupled aquaponic systems, most of the fertility of the soil shall be maintained by the addition of water from the aquaculture unit.
(3) Fish waste/sludge/solids collection and use is encouraged to maintain and improve the fertility of the soil: in the pots where plants are cultured in coupled aquaponic systems and in the topsoil in decoupled aquaponic systems.

Rules on aquaculture

(4) Fish and other aquatic organisms need to be farmed to approved welfare standards for each species which provide them with a habitat and conditions that promote the health and well-being of the species. This needs to take into account diurnal cycles and the need for environmental stimulation.
(5) Fish tanks shall be enriched with items that conform with the nature of the cultured species, and in particular:
   (a) In the case of tilapias, the use of structures and blue tank colouration for the reduction of aggression and stress is encouraged (Volpato & Barreto 2001; Barley & Coleman 2010; Kadry & Barreto 2010; Torrezani *et al*. 2013; Maia & Volpato 2013; Favero Neto & Giaquinto 2020).
   (b) In the case of catfishes, the use of structures such as shelters is encouraged (Hecht & Appelbaum 1988; Hossain *et al*. 1998; Barcellos *et al*. 2009; Rahmah *et al*. 2013).
   (c) In the case of flatfishes, the use of sandy substrates is encouraged (Ellis *et al*. 1997; Tuckey & Smith 2001; Näslund & Johnsson 2016).
(6) Species that best conform to the local water parameters, especially temperature, should be used in order to minimise the artificial heating or cooling of water.
(7) Fish should be checked regularly for visual signs of distress (i.e. gasping for air, unnatural behaviour, inactivity, increased or abnormal aggressive behaviour).

Rules on systems

(8) Organic aquaponic systems need to derive most of their nutrients from the fish water and fish waste. Any additions which may be required, such as seaweed extracts, should be organic and from sustainable resources.
(9) In coupled aquaponic systems, any substance that could have a negative impact on the health and welfare of the fish shall not be used.
(10) The use of alternative energy systems is encouraged.
(11) Water harvesting is encouraged in order to replenish water in systems. This is especially important in water deficient areas.

Conclusions

Aquaponics is a novel, highly sustainable means of food production and widely recognised as a technology that could change the way we produce and think about food. As a sustainable and scalable way of producing pesticide-free, fresh, locally grown fish, fruit and vegetables in both cities or rural areas, thus lowering CO_2 emissions and contributing to the conservation of wild fish stocks, aquaponics is a food production system that meets the United Nations Sustainable Development Goals, especially No Poverty, Zero Hunger, Good Health and Well-being, Quality Education, Sustainable Cities and Communities, Responsible Consumption and Production, Climate Action, and Life Below Water (United Nations 2020a). Based on the principles of organic farming found in the new Commission Regulation (EU) 2018/848, aquaponics should already be considered an organic farming method, given its highly sustainable production features based on nutrient recycling, nature-based processes and energy efficiency. In fact, organic aquaponics provides numerous benefits for both producers, consumers and the environment. By blending principles of organic horticulture and organic aquaculture, organic aquaponics brings positive change in the areas of environmental, economic and social sustainability, thus embedding the true spirit of sustainable food production (Fig. 2).

The new organic regulation entered into force in January 2021, introducing more stringent rules for organic certification, whilst posing further obstacles to the organic certification of aquaponic produce. In order to overcome some of these obstacles and positioning aquaponic produce as potentially organic, there is a need for a review of the regulations to ensure that they are based on science and on the principles of sustainable development. Regulations need to have the flexibility and ability to incorporate new techniques and technologies that support the goals of sustainable food production. Proposed system amendments that would fulfil some of the rules that hinder organic certification are the use of soil in the hydroponic section (although the benefits of this are yet to be proven) and the implementation of environmental enrichment devices for the improvement of fish welfare in the aquaculture section. As stated in Kledal *et al*. (2019), aquaponic farmers should

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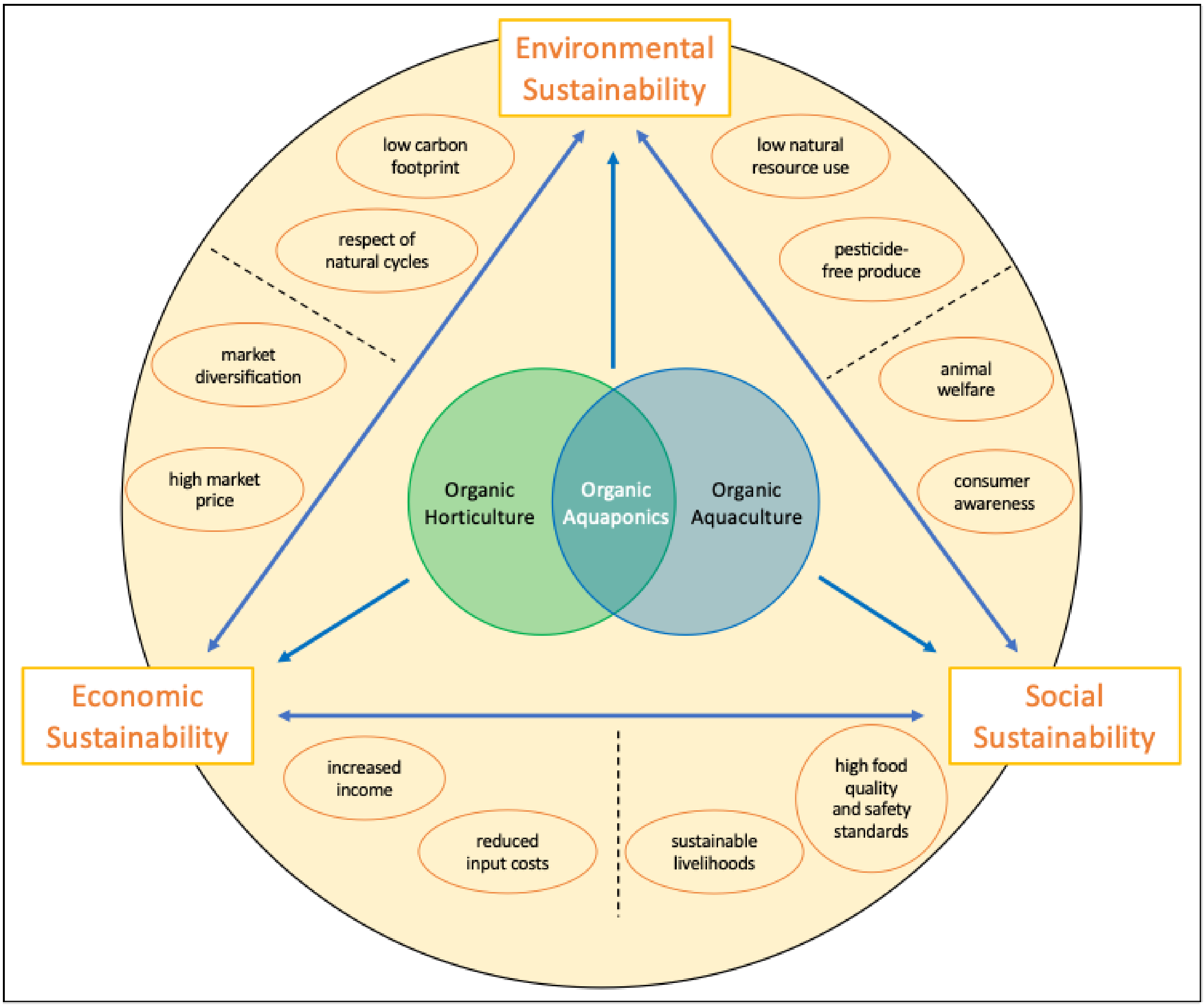

Figure 2 Aquaponics is at the centre of sustainable food production, combining aspects, principles and rules of organic horticulture and aquaculture production, providing numerous benefits in the areas of environmental, economic and social sustainabilities.

emphasise the benefits of the circular economy inherent in aquaponic production compared with conventional soil-based cultivation. This may result in changes in traditional aquaponic system designs, better adapted to the organic production of both plants and aquatic organisms. Novel aquaponic systems devoted to organic certification should explore the use of soil to grow crops and its effect on fish welfare and growth. In the case of decoupled aquaponic systems, the application of raw fish waste as fertiliser for crops is another area that requires research in order to see whether the current standards in the new regulation can be amended to include waste from aquaculture organisms. In fact, further research is needed to investigate the effect of fish waste on plant growth, thus determining its safety and allowing its use. In order for regulations concerning aquaponics to change, the domains of horticulture, aquaculture and organics need to organise, share and integrate knowledge, although such a task might prove to be quite difficult to achieve. Collaborative research to develop aquaponic systems for the organic sector is an intriguing path to follow with a huge potential that could open up new market opportunities for aquaponic produce. In time and with enough data, the EU could allow aquaponic produce to be certified as organic. Such a policy change could provide a huge increase in new businesses, skilled jobs and the production and consumption of local, healthy food, with fewer food miles and smaller carbon and ecological footprints. A question that is still unanswered is who would benefit from

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the organic certification of aquaponic produce. In fact, there is a need to assess the impact on aquaponic produce sales that organic certification would bring in the European market. Recent surveys indicate that in Europe commercial aquaponics has hit a level of disillusionment, possibly as a direct result of the numerous challenges faced by commercial producers (Turnsek *et al.* 2020). On the other hand, the publication of 'Aquaponics Food Production Systems' by Goddek *et al.* (2019), an open-access book covering the state of the art in aquaponics which has been downloaded over seven hundred thousand times (as of 2 October 2020), indicates the scale of interest in aquaponics. At present, the organic certification criteria that are used for some produce and production methods are not always set within a proven scientific framework, and in some instances the regulations appear protectionist. Whilst aquaponic production does not necessarily need organic certification in order to become a fully fledged food production industry, widely accepted by consumers as providing healthy and sustainable local food, it at least needs to be investigated. This research is being undertaken at the University of Greenwich in London, UK.

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Conflicts of interest

There are no conflicts of interest.

Ethical approval and patent consent

There are no ethical issues related to this paper; there are no patents relating to this paper; there are no images from external sources.

Clinical trial

No clinical trials were held.

Data availability statement

All data are available.

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