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REVIEW

REVIEWS IN Aquaculture

Aquaponics nomenclature matters: It is about principles and technologies and not as much about coupling

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Abstract

The food production system '*aquaponics*' has moved a long way from its inceptions in the 1970s and 1980s. This paper suggests that it is the principle of aquaponics that should define what aquaponics is and then the rest follows according to systems and technologies. This paper supports the Palm et al. (*Aquac Int*. 2018;26(3):813–42) position of having a nutrient supply threshold (>50%) from the feed via the aquatic organisms to the plants. We test the most recent alternative definitions (e.g. Baganz et al. *Rev Aquac*. 2021;14:252–64) that overcomplicate existing definitions and nomenclature. Any new definition needs to be referential to existing terms and properly tested. This paper does exactly that, concluding that several recent changes by Baganz et al. (*Rev Aquac*. 2021;14:252–64) are not needed. We also debate that the key principle behind aquaponics is '*all about coupling*'. Whilst coupling is an important aspect, existing technologies and those that will emerge are far more complex. Finally, this paper highlights the idiosyncrasies in the term aquaponics and we suggest an alternative term '*aquaorganoponics*', which in essence better describes the principles of aquaponics (*s.s.*) which transfers natural organic compounds combined with microbes in water from the aquaculture unit to the plants.

KEYWORDS
Agri-Aquaculture Systems, aquaorganoponics, aquaponics farming, nomenclature, nutrient supply, terminology

1 | INTRODUCTION

What's in a name? Over the years there have been many attempts in publications,[1–6] manuals[7] and forums, for example, COST FA1305, The EU Aquaponics Hub[8,9] to define what aquaponics is, and also by default what it is not. This situation is not unusual where new or emerging industries are trying to define themselves, set goals and standards, and where academics and researchers are similarly trying to understand and set parameters within which everyone understands what everyone is talking about. The refinement in definition, for the sake of clarity is extremely important with regards to research. Defining the term 'circular economy', which is central to the principal of aquaponics and which is similar in that it is also a relatively new area of research, Figge et al. noted that '*good definitions focus on only what is essential whilst distinguishing the term from other related concepts*'.[10] In Aquaponics, it is even more important when it comes to how this discipline sits and portrays itself within the marketplace. The definition is exceptionally crucial for producers who need to ensure that

The asterisk (*) highlights terms used in taxonomical approaches.

their produce is identified correctly, reaching the market it wants to reach, providing a 'level playing field' for producers and achieving prices that respond to the production principles and methods. Clear definitions that enable producers, consumers, authorities, and all other stakeholders to distinguish between the various systems are therefore a necessity for aquaponics to be recognised in its own right, where food is produced in a distinctive way.

Aquaponic technologies have been described as a subset of broader agricultural approaches that integrate aquaculture and agriculture, known as Integrated Agri-Aquaculture Systems (IAAS). '*The broad rationale for IAAS application in Australia is based on the need to achieve more economically viable and environmentally sustainable primary industries, and specifically to enhance farm productivity and water use efficiency through multiple water use for integrated production of both terrestrial and aquatic crops*'.[11] With rising interests in sustainable agricultural production systems and a circular economy that reduces or even eliminates waste products, aquaponics research as well as production systems have increased in recent years.[12–16] Love et al.[17] surveyed and counted 198 (81%) aquaponic relevant companies in the United States, 12 (5%) in Australia, 10 (4%) in Canada, and 3 (1%) were from the UK. In a survey on aquaponics in Europe by Villarroel et al.,[18] there were 68 respondents, 19% (13) were aquaponic companies. A recent, as yet unpublished survey undertaken by the University of Greenwich indicates that there are now 43 'aquaponic producers' in the EU and UK. There is an undeniable trend in interest in aquaponics as shown in Google's Ngram data and as shown extracted from Google Ngram Viewer using the term aquaponics.[6] This interest is also indicated by 1.5 million downloads of the Springer Nature open access publication 'Aquaponics Food Production Systems—Combined Aquaculture and Hydroponic Production Technologies for the Future', by Goddek et al.[19]

Since the first operational aquaponic systems by Naegel,[20] Lewis et al.,[21] and Rennert and Drews,[22] many different systems and designs have been introduced. (For a historical development see Palm et al.[5]) What all of them have in common is that they combine fish production and plant production with the help of nutrient converting bacteria. Rakocy et al.[2,3] formally defined aquaponics as the '*combined culture of fish and plants in closed recirculating systems*' and later as '*encompassing recirculating aquaculture systems (RAS) that incorporate the production of plants without soil*'.[23] Lennard[4] comprehensively defined aquaponics as '*a system of integrated, tank-based, aquatic-animal (fish) culture and hydroponic plant culture wherein the majority of nutrients required for plant growth arise from wastes derived from feeding fish.*' The organisms involved were designated as the initial user (i.e. the fish that consume the initial nutrient source, the feed), the intermediate converter (the bacteria) and the tertiary user (the plants). As a result of the COST Action FA 1305—'EU Aquaponics Hub',[9] which at the time 2014–2018 brought together most of the active researchers and industry partners in the EU, Palm et al.[5] presented a new definition of aquaponics as follows: '*Aquaponics is a production system of aquatic organisms and plants where the majority (>50%) of nutrients sustaining the optimal plant growth derives from waste originating from feeding the aquatic organisms*'.

In 2021, Baganz et al.[6] suggested that the standing definition of aquaponics as defined by the EU Aquaponics Hub and described in Palm et al.[5] was not suitable in definition and in the thinking behind it. Following this they defined their own version of what aquaponics is, as well as attempting to provide additional insights into different aspects of aquaponics which are covered by the name. However, instead of adding clarity, they have created a certain complexity that is likely to be detrimental to the field in its endeavours to find its place in the market. Whilst it is clear that the definitions of what aquaponics is and is not should be contested, and it is desirable that the nomenclature takes account of innovation in the field, this paper analyses the definitions proposed by Baganz et al.[6] in the context of the already existing literature in order to facilitate this debate. It is important for the industry and the aquaponic market that careful definitions are developed by the scientists that will be referred to by present and future policy and decision makers.

Apart from trying to create a new nomenclature for aquaponic systems, Baganz et al.[6] also proposed that aquaponics is '*all about coupling*'. For them this is the most crucial aspect of aquaponics as the phrase is included in the title of the paper.[6(p1)] As aquaponic technologies advanced, various degrees of decoupling emerged from fully coupled (single-loop) systems in order to make aquaponics more commercially viable. Whilst the issue of coupling in aquaponic production is an important one, we understand that aquaponics is not just '*all about coupling*' but also most importantly about principles, the different technologies in use and outreach to the various potential stakeholders.

This new process of investigation of the definition and nomenclature of aquaponics has had a profound outcome. We have always known that aquaponics is an unfortunate misnomer as the term does not adequately describe what it is. It is well cited that the terms ***aqua***culture and hydro***ponics*** have been joined together to make up the word aquaponics, but the link to hydroponics is very unfortunate. Whereas the aquaponics principle is based on natural processes, hydroponics, in the main, uses artificial fertilisers. We herewith introduce an alternative term '***aquaorganoponics***' for a better scientific designation of the main principle which is based on using the natural fertiliser produced by the aquatic organisms.

2 | DEFINING AQUAPONICS FROM RAKOCY VIA LENNARD TO PALM ET AL.

The term aquaponics first appeared in the literature in 1981 in a business magazine in the United States when describing the functions of the new Disney EPCOT (Experimental Prototype Community of Tomorrow) theme park. EPCOT had planned '*The Land*', where '*the organizers plan to grow everything from bananas to shrimps through **aquaponics**, hydroponics, multicropping, sand culture, aquacell modes and whatever else today's farmer has never dreamed of*'.[24] Later, Angiboust[25] used this term for a hydroponic technology in greenhouses that utilised water retention materials. In 1994, Rakocy[1] described a new University of the Virgin Islands (UVI) Agricultural Experiment Station approach to growing more food by integrating vegetable hydroponics with fish culture in recirculating systems, '*a technology that is being called aquaponics*'.[1] Since then, the origin of the term aquaponics is said to be a combination of ***aqua***culture and hydro***ponics***, however, with no confirmed evidence of its first use and meaning.

Rakocy et al.[2,3] and Rakocy[23] subsequently defined aquaponics as follows: '*Aquaponic systems are recirculating aquaculture systems that incorporate the production of plants without soil*.' This definition considered that the aquaculture unit is not restricted to tank based systems and that the plant production is without soil. Resh,[26,27] however, already distinguished between the two forms of hydroponics, soilless culture with substrates but no soil, and water culture or true hydroponics ('water working'), where the plant roots are suspended in a liquid medium (nutrient solution).

Malison and Hartleb[28] defined aquaponics as '*aquaponic (hydroponic) soil-less greenhouse culture of vegetable, herb, and fruit crops*'.

The aquaponic gardening community's[29] definition was '*aquaponics is the cultivation of fish and plants together in a constructed, recirculating ecosystem utilizing natural bacterial cycles to convert fish waste to plant nutrients. This is an environmentally friendly, natural food-growing method that harnesses the best attributes of aquaculture and hydroponics without the need to discard any water or filtrate or add chemical fertilizers*'.

In consideration of the further developments in aquaponics, including decoupled systems, Lennard[4(p21)] analysed all of the leading, scientifically configured, field tested aquaponic methods developed at the time, and recognised that a majority of '*at least 80% by weight* (and often more) *of the nutrients required for optimal plant growth are derived from the fish waste alone*'. Lennard[4] considered it therefore important to provide a more complete definition that was more reflective of the process and principle. He therefore defined aquaponics as follows: '*A system of integrated, tank-based, aquatic-animal (fish) culture and hydroponic plant culture wherein the majority of nutrients required for plant growth arise from wastes derived from feeding fish*.' Lennard's[4] extension of the Rakocy et al.'s[2,3] definition, however, fell short, creating limitations since he reduced the aquaculture systems to tank based, thereby excluding, for example, pond based systems.

In 2017, Lennard[30] noted when considering the evolution of aquaponics into many other system designs '*beyond its fully recirculating pedigree*' (p. 13), an aquaponics definition should concentrate more on its nutrient resource sharing capacities, rather than the integration of two technologies or the hardware involved. Based on the experiences with the UVI system, he argued that '*at least 80% of the total nutrients the plants require to grow well*' can be used '*as a set point for determining whether a particular integrated fish and plant production technology may be defined as aquaponics*' and not hydroponics.[30(p15)] He therefore adjusted his earlier definition to say that '*Aquaponics is*: '*A system of integrated tank-based fish culture and hydroponic plant culture whereby 80% or more of the nutrients required to grow the plants arise from the fish waste*'.[30(p15)] This definition once more maintained that the aquaculture part was limited to being tank based, limiting the aquatic animal production to being solely fish culture, and specified that the required nutrients from an aquaculture source to be >80%.

Also in 2017, by referring to the main two parts of an aquaponics system, Southern and King[31] defined aquaponics as follows: '*Aquaculture is the cultivation of aquatic animals and plants in natural or controlled environments. Hydroponics is the growing of plants without soil, using water to carry the nutrients. The term* '*aquaponics*' *was created to designate the raising of fish and plants in one interconnected soilless system*'.

Pantanella[32] stated that '*aquaponics is a plant production system that integrates soilless cultivation and recirculating aquaculture*'. Recognising that aquaponics is a means of producing food and that the aquaculture systems are not only tank based, he did not consider that soilless cultivation does not include true hydroponics according to Resh,[26,27] see above, as earlier also overlooked by Malison and Hartleb[28] and Southern and King.[31]

It was the opinion of the members of COST FA1305 that until then, the definition by Lennard[4,30] was the most appropriate so far but should be improved to become more comprehensive. Using the framework of all the previous definitions but especially of Lennard[4,30] and incorporating all the then known systems, and based on the principle of aquaponics, the EU Aquaponics Hub[5(p818)] deliberately and carefully defined aquaponics as follows: '*Aquaponics is a production system of aquatic organisms and plants where the majority (>50%) of nutrients sustaining the optimal plant growth derives from waste originating from feeding the aquatic organisms*'.

This definition thus extended the Lennard[4,30] definitions to include also (1) non-tank aquaculture systems, (2) all aquatic organisms, (3) non-hydroponic produced plants in surface waters (e.g. ponds), peat, soil, or in the open field, and (4) reduced the amount of aquaculture originating nutrients for optimal plant growth to >50%, similar to the early Rakocy et al.'s[2,3] definitions, and allowing also for the aquaponic production of, for example, delicate plants that require the addition of a specific set of nutrients. This new definition kept Lennard's suggestion that solids or their by-products can serve as another nutrient source beyond solely process waters. Whilst all the previous definitions of aquaponics were looked at by the EU Aquaponics Hub, it was Lennard's definitions[4,30] that then provided the most appropriate description of aquaponics that could be found. This evolution of definition is illustrated in Table 1, where Palm et al.[5] changed the definition in four main areas to be inclusive of the rapid development in aquaponic systems and research.

In 2019, a definition by Lennard and Goddek[33] in Goddek et al.[19(chapter5,p118)] described aquaponics as '*an integrated multi-trophic, aquatic food production approach comprising at least a recirculating aquaculture system (RAS) and a connected hydroponic unit, whereby the water for culture is shared in some configuration between the two units. Not less than 50% of the nutrients provided to the plants should be fish waste derived*.' There are positive and negative aspects in this new definition. The use of the term '*integrated multi-trophic*' is questionable. This term might be mistaken with '*integrated multi-trophic aquaculture (IMTA)*', an aquaculture (polyculture) production system that combines multiple '*aquatic*' species attributed to different trophic levels. Aquaponic systems are not per se multitrophic *sensu* IMTA (terrestrial plants?) and the definition of what integrated multi-trophic aquaculture really is, is also still under debate (e.g. '*The farming, in proximity, of aquaculture species from different trophic levels*,

TABLE 1 A comparison of aquaponic definitions: EU Aquaponics Hub[5] versus Rakocy[2,3,23] and Lennard[4,30]—table indicates the differences in word choice with a concise explanation.

Rakocy[2,3,23]	Lennard[4,30]	EU Aquaponics Hub[5]	Comments
Systems	*System*	*Production system*	The addition of the word production ensures that aquaponics is recognised as a means of producing food which is integral to its existence as an aquaponic system.
Recirculating	-	-	The term recirculating is deliberately omitted as Rakocy's definition came before the creation of decoupled systems which are not recirculating.
-	*Integrating*	-	The term '*integrating*' is deliberately omitted in order to accommodate a growing range of aquaponic scenarios, which is important for marketing.
-	*Tank based*	-	The term 'tank based' is deliberately omitted so that the term aquaponics could, for example, include pond-based aquaculture.
Aquaculture systems	*Fish culture*	*Aquatic organisms*	The broader definition by Palm et al.[5] includes all aquaculture systems as noted by Rakocy but also unlike Lennard allows for systems that produce invertebrates such as prawns, crayfish and others.
Production of plants without soil	*Hydroponic plant culture*	*Plants*	The use of the term plants uses a broader definition as plant growing is not restricted to hydroponic systems and thus, for example, plants could be grown using aquaculture waters in pots or in fields, indeed with soil.
-	*Majority of nutrients (80% or more), >50% in,*[33] *in Goddek* et al.[19]	*>50% of nutrients*	The choice of the majority (referring to 80%) by Lennard is arbitrary. It is logical to stipulate that >50% is the requirement as this denotes more than half (also see Rakocy et al.,[2,3]). The >50% rule is understood to mean the majority.
-	*Required to grow the plants*	*Sustaining the optimal plant growth*	Required and sustaining are similarly used, but the term optimal is introduced as the plants not only need to grow, but they need to grow to meet the standards of the industry and/or the market.
-	*(nutrients) arise from the fish waste*	*(nutrients) derives from waste originating from feeding the aquatic organisms*	The difference is that the waste can come not only from fish but other aquatic organisms and it is important to note that the waste is produced by feeding the aquatic organisms. This is important, because what is fed to the organic organisms determines the constituents of the waste and thus the amount of nutrients available for plant nutrition.

Note: Rakocy[2,3,23]: '*Aquaponic systems are recirculating aquaculture systems that incorporate the production of plants without soil.*' Lennard[4,30]: '*Aquaponics… is a… system of integrated tank-based fish culture and hydroponic plant culture whereby 80% or more of the nutrients required to grow the plants arise from the fish waste*.' Palm et al.[5]: '*Aquaponics is a production system of aquatic organisms and plants where the majority (>50%) of nutrients sustaining the optimal plant growth derives from waste originating from feeding the aquatic organisms.*'

and with complementary ecosystem functions, in a way that allows one species' uneaten feed and wastes, nutrients, and by-products to be recaptured and converted into fertiliser, feed, and energy for the other crops, and to take advantage of synergistic interactions between species. Farmers combine fed aquaculture (e.g., finfish or shrimps) with extractive aquaculture, which utilises the inorganic (e.g., seaweeds or other aquatic vegetation) and organic (e.g., suspension and deposit-feeders) excess nutrients from fed aquaculture for their growth', Christou et al.[34]). The use of the term '*aquatic food production approach*' is also vague and does not help to establish meaning (terrestrial plant production?). It excludes aquaponics (*s.l.*) farming *sensu* Palm et al.[5] where only the aquaculture unit is aquatic and terrestrial plants are cultivated in soil. However, the authors returned to the earlier Lennard[4,30] definitions to RAS systems (not only tank based systems), that include fish waste, and recognised the 50% threshold as first suggested by Rakocy et al.[2,3] and established in Palm et al.[5]

The next iteration regarding the terminology was by Baganz et al.[6]

3 | EXPLORING THE BAGANZ ET AL.[6] PROPOSITION

In reference to the hierarchy of nomenclature of aquaponics, at the start of their discussions, Baganz et al.[6] differentiated between integrated multi trophic aquaculture (IMTA) and aquaponics. This is in accordance with Palm et al.[5] where aquaponics and IMTA were both considered as part of an Integrated (Agri-Aquaculture) Production System. When integrated into aquaponics, the aquaculture entity is restricted to heterotrophic aquatic animals because only heterotrophic animal metabolism can create emissions that can be used as a nutrient base for the autotrophic plant entity.[6] Following this, Baganz et al.[6(p3)] provided a new definition of aquaponics:

> Aquaponics is a technology that couples tank-based animal aquaculture with hydroponics—involving microbiological processes—using water from aquaculture for plant nutrition and irrigation.

There are numerous issues that arise with this definition, some relating to over complicating what aquaponics is, not being inclusive enough and not being specific enough as discussed in Table 2. In essence this definition does not fulfil Figge et al's[10] criteria in his work on defining the term 'circular economy', that definitions must not be too broad or too narrow '*where narrow means when it does not accommodate all instances of the definiendum*', that is the term that is being defined.

The following discussion expands the comments made in Table 2.

3.1 | Production system Palm et al.[5] versus technology Baganz et al.[6]

The use of the term production system by Palm et al.[5] implies more than a technology. Whilst aquaponics has been recognised by the European Parliament as one of the 10 most promising food production technologies that could change our lives,[35] in the aquaponic

TABLE 2 Comparison of the EU Aquaponics Hub[5] definition and Baganz et al.[6]

Point	EU Aquaponics Hub[5]	Baganz et al.[6]	Comments
1.	production system	*Technology*	Baganz et al.[6] reduced the concept to the technological rather than a food production principle—the issue is that aquaponics is a principle that combines a number of technologies.
2.	-	*Couples*	Numerous types of aquaponic system have developed where they include coupled and decoupled elements.
3.	-	*Tank-based*	This term excludes many other systems including pond-based aquaponics, and unnecessarily reduces the definitions by Rakocy et al.[2,3] and Palm et al.[5]
4.	aquatic organisms	*Animal aquaculture*	The use of animal is non-specific and a term too broad to be scientifically useful. In essence the term needs to be heterotrophic aquaculture organism. However, Palm et al.[5] have not used this term because it is over complicated and they have differentiated the aquatic organisms from the plants in their definition.
5.	plants	*Hydroponics*	Baganz's terms are based on hydroponics as a technology. This is problematic, and not inclusive of for example pond-based aquaponics where for example plants may be grown on the surface of a pond. It unnecessarily reduces the definitions by Rakocy et al.[2,3] and Palm et al.[5]
6.	-	*Involving microbiological processes*	This does not in any way clarify the process because any biological system involves micro-biological processes and it is not distinctive to aquaponics at all.
7.	-	*Using water from aquaculture*	This phrase is redundant as it is clear that the water is coming from aquaculture.
8.	*>50% of nutrients*	-	The issue with omitting the principle of >50% nutrients being supplied from the aquaculture system means any percentage (0.00001%) is sufficient for a system to be termed aquaponic.
9.	sustaining the optimal plant growth	*For plant nutrition and irrigation*	Baganz et al.[6] did not consider the term optimal, which means that any plant (of any plant quality—poor or good) is adequate. This is not the case if aquaponics is to be commercially successful. That plants must '*grow well*' was already recognised by Lennard[30]
	(nutrients) derives from waste originating from feeding the aquatic organisms		This ignores the fact that aquaculture produces nutrients through process water and solid wastes (also see Lennard[4,30]). It is important to include both in the definition. Additionally, this is particularly important, because aquaponics needs to be partly marketed emphasising that it is part of the circular economy.
			Plant nutrition is an adequate term. However, adding the term irrigation does not account for aquaponic systems that use only the solid wastes, for example, using solid fish manure instead of animal manures on agricultural fields.

Note: Palm et al.[5]: '*Aquaponics is a production system of aquatic organisms and plants where the majority (>50%) of nutrients sustaining the optimal plant growth derives from waste originating from feeding the aquatic organisms.*' Baganz et al.[6]: '*Aquaponics is a technology that couples tank-based animal aquaculture with hydroponics—involving microbiological processes—using water from aquaculture for plant nutrition and irrigation.*'

section, the generic over riding term technology is replaced with the more specific term ‘food production’ system. This recognises that many different technologies are used in aquaponic systems, a notion that we prefer to follow. The truncation of production system from food production systems in Palm et al.[5] enable the inclusion of all aquatic organisms (including ornamental fish) and non-food plants such as ornamental and medicinal plants. This criticism by Baganz et al.[6(p3)], point (4) does, however, consider Palm et al.[5] where all types of aquatic organism and plants are included.

3.2 | The use of the word ‘couples’

The use of the word couples in the definition to refer to the interconnection of aquaculture and plant production is unfortunate and confusing as the term coupled and decoupled are ubiquitously used to describe different installations of single-loop and multi-loop aquaponic systems (see the discussion below). However, it is generally accepted that the aquaponics principle requires ‘coupling’ or connecting of the aquaculture and the aquatic or terrestrial plant units in order to generate the wanted benefits, as suggested by Baganz et al.[6]

3.3 | Tank based

Aquaponic systems are not restricted to tank-based aquaculture, for example, pond-based aquaculture[36,37] and through flow systems or raceways.[38,39] Baganz et al.[6] suggested that because Junge et al.[40] stated that fish tanks are part of aquaponic systems that this is the general consensus, but this is not in any way scientific and does not respect the situation on the ground.

Lennard[4,30] reduced the aquaculture systems to tank based, and increased it to recirculating aquaculture system (RAS) in Lennard and Goddek[33] in Goddek et al.[19] In 2017 Lennard discussed whether aquaponics could be practiced in earthen ponds.[30(p24)] According to Lennard, aquaculture in earthen ponds results in naturally balanced nutrient conditions that limit the availability of the nutrients to the plants. Thus, for Lennard, aquaponics should therefore be restricted to tank based fish culture that allow adequate and controlled nutrient accumulation. However, Jones[41] already described the construction of ornamental pond aquaponics for koi and water loving plants, for example, water cress. He stated that ‘*even though your aquaponic pond is outside, the basic rules of aquaponics still apply*’. Lennard's position also does not consider open pond aquaponics that can utilise additional fertilisers to enhance plant growth,[5] and that aquaculture of for example, shrimps, pangasius and African catfish in earthen ponds can have enormous stocking densities, feed input and thus adequate nutrient loads, allowing the process water to be directly used for aquaponic plant production. Furthermore, contemporary trout farms with partly recirculating water systems produce process waters with high nutrient loads.

It also must be considered that the EU and the UK have distinctly noted that RAS systems cannot be considered to be organic and that only systems that have natural bottom surfaces such as ponds would qualify for eco-certification.[42] Therefore, we argue that the exclusion of other means of producing fish and the reduction of aquaponics to tank based systems is not justified.

3.4 | Animal culture versus aquatic organisms

The use of the term ‘animal culture’ is not specific enough, it is too broad as it also includes water based higher vertebrates such as duck-bill platypus or sea otters and could readily be misconstrued.

3.5 | Hydroponics versus plant

The use of hydroponics refers to a single technology and not to what and how the plants are being produced. Based on the technological and biological processes involved, the choice of the term hydroponics is unfortunate. Aquaponics centres on connecting organically derived (natural) nutrient enriched water to the plant units and back to the aquaculture units. Hydroponics therefore does not account for the general difference between the aquaculture process water and the artificial nutrient solution in hydroponics (see Section 2), and also detrimentally diminishes the scope of aquaponics by, for example, neglecting ‘soil/substrate-based’ aquaponics. Additionally, with only soil-grown crops considered organic in the EU, advocating for the inclusion of soil-based substrates in aquaponics would make sense. And this should also be recognisable in the aquaponic definitions.

3.6 | Involving microbiological processes and using water from aquaculture

Microbiological processes occur everywhere, in any living system, and thus the term is too generic for it to be useful in a precise definition. In this context, Bernstein[29] already provided a much more detailed description of the involvement of microbiological processes (‘*utilizing natural bacterial cycles to convert fish waste to plant nutrients*’). The inclusion of the term ‘*using water from aquaculture*’ is redundant as the initial part of the definition already includes aquaculture. It also restricts the connection between the aquaculture and the plant units to process water and does not include other aquatic organism wastes as a potential nutrient source for the plants.

3.7 | No threshold versus >50% of nutrients

Baganz et al.[6] do not include any nutrient supply threshold to the plants. However, the inclusion of a threshold is essential in a definition of aquaponics. This was extensively discussed by Lennard[30] and determined by the EU Aquaponics Hub at >50%.[5] Baganz et al.[6] opposed the minimum share of nutrients that plant cultivation should receive from aquaculture. According to Palm et al.,[5] by definition, all systems under this 50% threshold cannot be considered to be true aquaponics, but potentially can still be seen to (partly) follow the aquaponic principle. Why is this distinction so important? It is essential for consumers and stakeholders to know if the plants mainly grow from the nutrients originating from the aquatic organisms or if the aquaculture process water is only added to a hydroponic plant production system. In other words, a threshold prevents the misuse of the term aquaponics where for example the combination of a small scale aquaculture system could be combined with large scale hydroponic plant production, mainly based on artificial fertilisers and according to Baganz et al.[6] this could be called aquaponics and marketed as being aquaponic. This may be done by companies for better marketing purposes, for example, to imply that the produce is being produced in an aquaponic system and is thus sustainable. The >50% threshold is fundamentally logical as it numerically differentiates between two different states. This threshold of >50% is used and accepted in every aspect of life to describe the majority; in politics, in economics, in maths, population demographics etc. Lennard and Goddek[33] recognised that '*a system containing one fish and several hectares of hydroponic plant cultivation, for example, should not be considered as aquaponics, simply because that one fish effectively contributes nothing to the nutrient requirements of the plants*'. Therefore, a reliable definition of aquaponics should contain, as a minimum, the requirement for a majority of aquaculture-derived nutrients for the plants, as correctly stated first by Lennard[4,30] and Lennard and Goddek[33] in Chapter 5 in Goddek et al.[19] Baganz et al.[6] state that it is not necessary to have a threshold as this should be specified through '*legal classifications*' or further specifications of '*quality labels*'. They say: '*We, therefore, prefer to omit the nutrient threshold as an element of definition and leave it to the processes of legal classifications or the specifications of quality labels*'.[6(p3)] This relegation is not helpful as it 'kicks the ball down the road' and 'passes the buck' to lawyers and politicians who have nothing at stake. In the end these bureaucrats 'who have no skin in the game', are going to be advised, in any event by academics and scientists.

3.8 | Sustaining the optimal plant growth versus for plant nutrition and irrigation

The term '*optimal plant growth*' (see '*nutrients that the plants require to grow well*' by Lennard[30(p15)]) has been used very specifically by Palm et al.[5] based on the principal of relative agronomic efficiency by Brod et al.[43] Palm et al.[5] stated that the authors '*applied dried fish sludge on agricultural land and achieved a relative agronomic efficiency compared with mineral fertilizer of 50-80%*'. Optimal plant growth was only possible with mineral fertiliser grown crops, reaching 100%. The term relative agronomic efficiency could not be used in the definition of aquaponics (1) because it would require its own definition and (2) it would be far too complicated. Thus, the term '*optimal plant growth*' was used to be associated with a threshold of >50%.

Baganz et al.[6] argued that a single threshold of >50% does not make sense because some plants require different proportions of nutrients for optimal growth. However, an overall threshold is necessary in order to produce more demanding plants such as tomatoes that are otherwise not competitive when only using aquaculture water and when compared with hydroponic competitors.[44] In such systems, direct water reuse is restricted to a minimum, and depends on other technologies that reuse evaporation water through cool traps. Such thresholds are not meant to apply to single nutrient optima (e.g. N, P, K) but to the entire suite of nutrients (by EC value) provided from the aquaculture to the plants. Optimal plants to be used in aquaponics are either less demanding in terms of nutrient composition inside the process water or can cope with different and varying proportions of macro- and micronutrients. In a series of experiments, for example, spearmint (*Mentha spicata*) grew better with intensive process waters from African catfish (*Clarias gariepinus*) in a semi-continuous (on-demand) coupled (see tab. 3) aquaponics system compared with extensive ones,[45] and basil (*Ocimum basilicum*) showed better growth performance with high density fish culture combined with nutrient accumulation in a decoupled gravel ebb and flood hydroponic subsystem.[46] Therefore, high nutrient loads especially of nitrogen, phosphorus and potassium support plant performance and quality in aquaponics production.

On the other hand, Palm et al.[47] demonstrated that under commercial conditions, the high stocking densities of African catfish (*Clarias gariepinus*) and regular aquaculture maintenance activities resulted in an extensive variation of main nutrient proportions inside the RAS water, varying from day to day. The resulting process waters arriving at the plant units changed drastically, preventing a constant and foreseeable macro-nutrient composition. Likewise, the bacterial community of the RAS process water changes with stocking density.[48] This will make process modelling of single nutrient fluxes under real commercial conditions truly challenging. Consequently, any threshold must apply to the total plant growth independent of the deficient nutrients and/or their proportions that are responsible for the reduced growth compared with the possible optimum under regular farming conditions.[5] This is unlike traditional or soilless hydroponics where the amount of nutrients and their composition can be fixed (through EC) and is not disturbed by fish process waters, the main reason for possible growth deficits in some aquaponics compared to hydroponic plant production.

4 | AQUAPONICS NOMENCLATURE

Aquaponics is relatively new to science compared with aquaculture and agriculture and even hydroponics. It started off in parallel by US and German researchers,[20–22] combining aquaculture with highly intensive monocultures in the 1970s–1980s.[49,50] The technology of growing plants without soil already dates back to 1600 in experiments by the Belgian Jean Baptiste Van Helmont and described in the book *Sylva Sylvarum* by Francis Bacon in 1627,[51–53] and further investigated in 1699 by the English scientist John Woodward and the French scientists De Saussure and Boussingault, who found that plants require carbon, hydrogen, oxygen, and nitrogen for good growth,[53] and later in the 1860s in Germany by Sachs[54] and Knop who developed nutrient solutions and named the technology '*nutriculture*'.[27,55] In 1929, Gericke (University of California) proposed the term '*aquiculture*' for '*water culture*'.[55–57] Only a short time later, Setchell (University of California) recommended the term '*hydroponics*'[57] to differentiate '*plant water culture based on nutrient solutions*' more precisely from the already established term '*aquaculture*'. It is natural that researchers want to use their own terminology that differentiates from an agriculture or fishery science terms. A contemporary definition of hydroponics by Resh states that hydroponics is ….' *the science of growing plants without the use of soil, but by the use of an inert medium* …', and if only water is used it is '*true hydroponics*',[27(p2)] or it was differentiated between '*liquid-culture hydroponics*' with nutrient solution alone and '*substrate-based hydroponics*' by Raviv et al.[58] Finally, aquaponics has unfortunately reunited the deliberate distinction between the terms '*aquaculture*' and '*hydroponics*' in the early 1980th (see Section 2).

After presenting a new definition of aquaponics, Baganz et al.[6] also changed the overarching nomenclature of Palm et al.[5] with an alternative. Somerville et al.[7(p4,19)] in a technical FAO handbook defined aquaponics as the '*integration of recirculating aquaculture and hydroponics in one production system*' and as '*a production system that combines fish farming with soil-less vegetable production in one recirculating system*', which is similar to other authors for coupled aquaponic systems (see Section 2). The authors (p. 6) placed aquaponics into the context of '*sustainable intensive agriculture*'. This was followed by Baganz et al.[6]

One criticism by Baganz et al.[6] regarding the nomenclature was based on an apparent misunderstanding of fig. 1 in Palm et al.[5] Palm et al.[5] similarly placed aquaponics including the two categories of aquaponics (*sensu stricto* [*s.s.*]*, *sensu lato* [*s.l.*]*) under Integrated ('Agri-/Aquaculture') Production Systems. If integration is the driver for more sustainable production systems, as waste is reduced, then both groups of authors had the same intention. However, Palm et al.[5] also included Integrated Multi Trophic Aquaculture (IMTA) alongside aquaponics into their scheme, therefore not following the exact terminology by Somerville et al.[7] To clarify this issue, we therefore expand the original figures in Palm et al.[5] in Figure 1 below which better explains the overarching principles all of which are combined within Integrated Agri-/Aquaculture Production Systems. Aquaponics, as defined by Palm et al.[5] is one of the principles, and true hydroponic, soilless (with substrates/media-beds), and soil based (pure soil or mixture with other substrates) aquaponics are categorised as technologies of the two categories aquaponics (*s.s.**) and aquaponics (*s.l.**) farming.

Baganz et al.[6] also raised the issue of definitions around the discussion of whether aquaponics can be eco-certified as being 'organic'. So far, '*aquaponics is not included in the EU organic agriculture certification scheme because it exploits hydroponics*'. In this paper we do not discuss the eco-certification but clearly acknowledge problems arising from the so far improper nomenclature and definitions. Aquaponics is a regrettable misnomer as the term does not adequately describe what it is. The link of aquaculture to hydroponics is unfortunate, because the term hydroponics was coined to differentiate 'plant water culture' from aquaculture (see above). Hydroponics mainly sterilises the water and directly provides inorganic, ionic nutrients to the plants. In contrast, aquaponics supplies the plants with many organic nutrients originating in the aquaculture units that must be processed and altered through a vast array of associated microorganisms.[30] The use of the term '*ponics*' in this context is wrong as it derives from the Greek to labour, work or toil. The word '*aqua*' is derived from Latin for water, so the word aquaponics is really 'a dog's breakfast' of mixing Latin and Greek together, and the meaning of 'working with water' is not helpful at all.

The premise and principle of hydroponics is that plants are grown without soil, but this is not always the case. Another premise is that the nutrients for the plants do not come from the soil, but are artificially added to the plant water. In reality, the nutrients could quite easily be extracted from terrestrial manures which are dissolved and filtered to become nutrient rich which can then been provided in an appropriate water solution to the plants. This type of hydroponics could be called '*organic hydroponics*' or '*organoponics*'. The latter term, however, is preoccupied and it is used to describe intensified urban agriculture particularly in raised beds founded in Cuba. Here the use of '*ponics*' is used correctly as it refers to work or labour and the term means work associated with natural organic compounds, and is satisfactorily descriptive of the urban farming method using organic fertilisers and other organic treatments.[59] The former term has been used by Lennard[30(p71)] in that '*aquaponics could be considered a form or sub-group of standard organic hydroponics, where the supplements required to meet plant nutrient requirements may also be sourced from organically certified inputs*'. Continuing the scrutiny of the terminology and what are the principles involved, as aquaponics is the transfer of organic compounds through water from aquatic organisms to the plants, it would better be described as '***aquaorganoponics***'. Although the introduction of an alternative name besides an already long established name might be distracting, this term is well suited because it describes exactly what the principles are which is the transfer/working ('***ponics***') of natural organic compounds ('***organo***') from the aquatic organism process water ('***aqua***') to the plants.

Baganz et al.[6(fig. 2, p4)] presented their own nomenclature (not definition) for the different aquaponic systems currently in use, placing all aquaponic activities under '*aquaponics farming*', including the two categories '*aquaponics*' (restricted to the combination of aquaculture in tanks with soilless/hydroponic plant cultivation) and '*trans-aquaponics*' for all other systems. According to Baganz et al.,[6] '*aquaponic farming*' was used inter alia by FAO (cited as Somerville et al.[7(p110)]) as an umbrella term for all technologies exploiting the aquaponic principle, independent of facility size. This seems to be incorrect. Somerville et al.[7] in a technical FAO handbook on the specific case of small scale aquaponic systems only twice used the term aquaponic farming in Chapter 7 on 'Fish in aquaponics' under 'Fish selection' (p. 110) in the main text, and in Appendix 1 (p. 169) on vegetable production guidelines. The term however, was used in a general sense and in essence Somerville never used the term 'aquaponics farming' in the

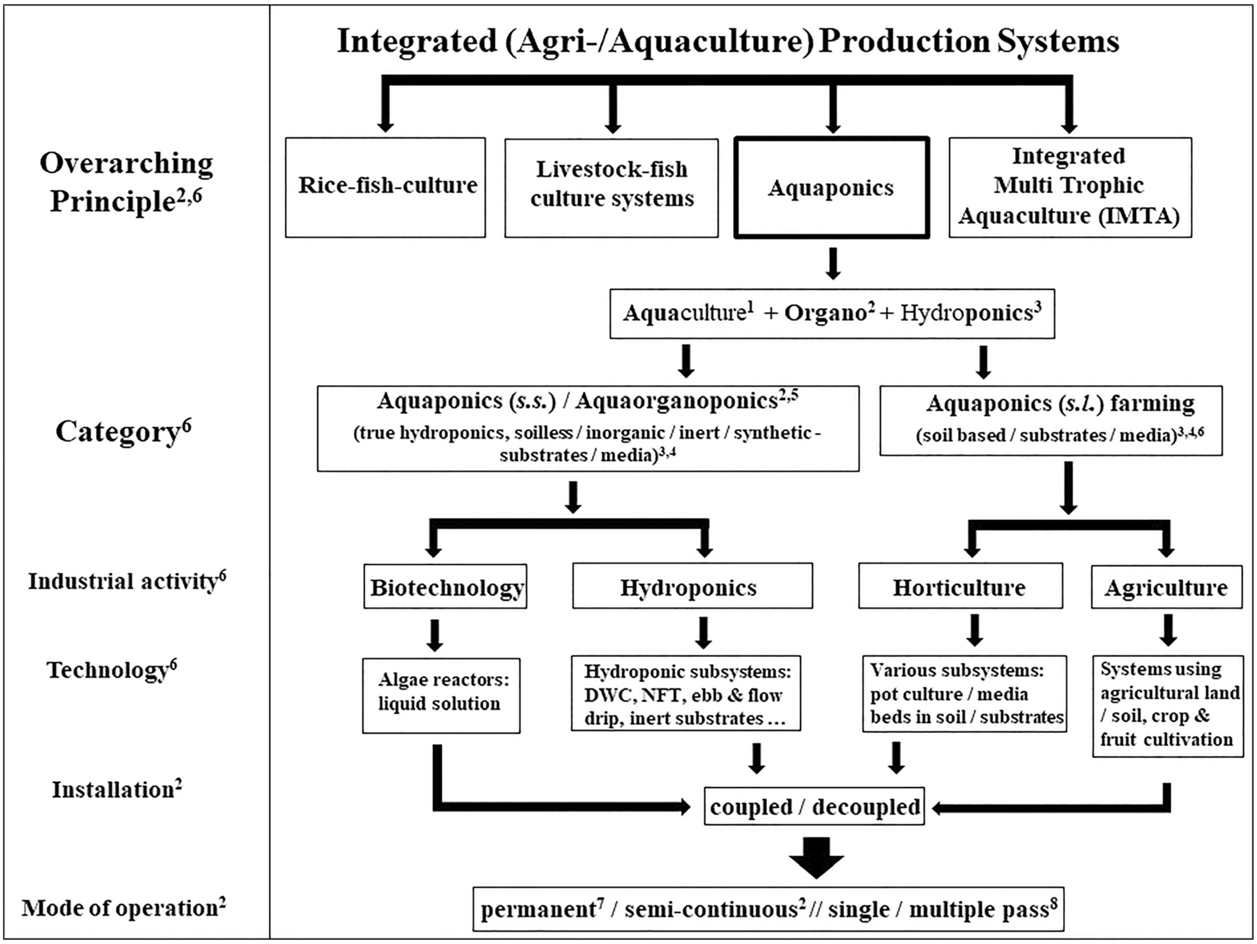

FIGURE 1 Integrated Agri-/Aquaculture Production Systems including aquaponics and its two categories (*sensu stricto* [*s.s.*]*, *sensu lato* [*s.l.*]*], industrial activities, main technologies, typical installations and modes of operation, altered from Palm et al.[5]). 1: After Welcomme and Barg[60]; 2: present study; 3: after Resh[26,27]; 4: after Maucieri et al.[61]; 5: new term; 6: after Palm et al.[5]; 7: after Baganz et al.[6]; 8: after Lennard.[30]

way of Baganz et al.[6] suggests he does. Baganz et al.[6] also argued that the aquaponic definition by Palm et al.[5] was not '*backwards compatible*' since its meaning of 'aquaponics' (functioning as an overarching term or overarching principles of Integrated Production Systems) comprises '*aquaponics s.l. (= aquaponics farming)*', which was intentionally excluded from the original definitions. This is a misinterpretation, because the 'FAO definition' ('*Bio-integrated system that links recirculating aquaculture with hydroponic vegetable, flower, and/or herb production*',[62]) as all other definitions before, did not encompass other systems such as aqua/algae culture as well as soil/substrate systems in the plant units, necessitating amending the old nomenclature to become more inclusive. Lennard[30] correctly stated that '*any definition should evolve and develop with the technology itself, rather than trying to restrict it*' (p. 16), a notion also followed by the present authors. Consequently, the use of the term 'aquaponics farming' (using soil based substrates and media) by Palm et al.[5] is appropriate and correct, as (1) it has priority, and (2) for the first time it categorised all aquaponic systems that included plant cultivation in soil/soil like media (horticulture and agriculture ≈ farming).

According to Baganz et al.,[6] '*aquaponics*' as one of the two categories of aquaponics farming is restricted to tank based aquaculture connected to soilless plant cultivation. This is in contrast to Rakocy et al.,[2,3] Somerville et al.,[7] Palm et al.[5] and Lennard and Goddek[33] in Goddek et al.[19] who did not have tanks in their definition. This makes categorisation of for example, a specialised tank based RAS systems connected to a plant cultivation in soil (as trans-aquaponics?) in comparison to for example, pond aquaculture combined with soilless hydroponics in a greenhouse with an entirely different setting and function difficult. As a combination of ***aqua***culture and hydro***ponics*** in its original sense, aquaponics (*s.s.**) combines two forms of hydroponics, soilless plant culture and true hydroponics[27] with any other aquaculture system, not only tank based, and was only in part developed from tank based RAS systems since the first experiments in tank based systems by Naegel[20] (discussion see Sections 2 and 3).

The chosen alterative term of '*trans-aquaponics*' is also problematic. Trans-aquaponics, according to Baganz et al.,[6] includes integrated aqua-agriculture systems exploiting the aquaponic principle without the restrictions of aquaponics systems (tank-based animal aquaculture with hydroponics). This categorisation is inadequate as why should a system which for example, grows algae in combination with intensive pond aquaculture should be considered trans and similarly why should raceway aquaculture connected to hydroponics be considered trans?

The prefix *trans* is of Latin origin with the meaning over/across. The purpose of a definition is an unequivocal determination of the meaning of an expression. In essence the term '*trans-aquaponics*' chosen by Baganz et al.[6] is also used to include the Palm et al.[5] term '*aquaponics farming*'. However, all systems behind this term have been properly defined by Palm et al.[5] for aquaculture systems (with or without tanks) connected to soil or soil like substrates/media-based plant cultivation, and therefore trans-aquaponics also conflicts with the existing definitions by EU Aquaponics Hub.[5] Consequently, the term '*trans-aquaponics*' by Baganz et al.[6] fails in stability and consistency, because it lumps together different, already clearly distinguishable systems according to Palm et al.[5] The term '*trans-aquaponics*' is also confusing, because for example, commercial pond aquaponics can include a hydroponic plant unit and principally function as a regular aquaponic system, and likewise plant pot (substrate/media) cultivation can be connected to any fish cultivation in tanks, a system often described as aquaponics with hydroponic substrate cultivation. It also includes '*open aquaponics*' as described already by Palm et al.[5(p820)]

It is not clear why the authors suggest a new but 'old' definition of aquaponics and seek to replace a thoroughly developed fully functional nomenclature. We therefore strongly suggest not to follow the terminology *sensu* of Baganz et al.[6] and we state that the nomenclature remains as illustrated by Palm et al.,[5(tab. 3, p833)] and updated in Figure 1. We therefore reject the alternative nomenclature as described by Baganz et al.[6] and note that in future, authors should in the first instance apply the already available names and their meanings from other already available disciplines, if possible, before creating new terms. Finally, it is important to note that besides an internet based FAO Aquaculture Term Portal[62], there is no official document with an accepted aquaponics definition by the EU or the FAO as noted by Baganz et al.[6] To move this forward was the intention by Palm et al.[5] in association with the EU Aquaponics Hub[8,9] that brought together most of the aquaponic researchers and entrepreneurs at the time (2014 and 2018) and carefully analysed the definitions of aquaponics and arrived at a consensus. The Hub, otherwise known as COST FA1305 represented members from 28 European countries and 4 other international countries, which made it the largest informed group of aquaponic researchers and industrial partners in the EU and the world.

5 | THE ISSUE OF COUPLING

Following Gooley and Gavine[11] and as noted above, aquaponic systems comprise one of the four Integrated Agri-/Aquaculture Principles[5(figs. 1 and 2)] and comprise of at least two units, an aquaculture (with or without tanks) unit and a plant unit (with organically derived water and hydroponic technologies). Under ideal conditions both systems are optimised in terms of nutrient exchange and water transfer, enabling profitable production at both ends. The connection with both systems is the constant water exchange, transporting the organically derived nutrient enriched water to the plant units and back to the fish. '*Coupled aquaponic installations*' have been seen as the archetype form of aquaponics.[19,44] This is also evident from the formal definition of aquaponics by Rakocy et al.[2,3] where '*aquaponics is the combined culture of fish and plants in closed recirculating systems*'. Recirculation of the water is the underlying principle for coupled aquaponics, referring to the continuous water and nutrient flow between the fish and the plants (fully recirculating systems according to Lennard[30]). The main task of coupled aquaponics is the purification of aquaculture process water through integration of plants, comparable with a constructed wetland,[44] which adds economic benefits when selecting suitable species like herbs, vegetables, medicinal plants or ornamentals, and which can be competitive in the local markets. Thus, coupled aquaponics with closed water recirculation systems, connecting both fish and plant (sub)units, has a particular role to fulfil. However, it is a compromise if the plants have certain physico-chemical requirements that the process water originating from the aquaculture cannot fulfil. In these cases, the plant production loses efficiency compared with the focus on plant production only, for example, in hydroponics, that is more comparable to decoupled aquaponic systems through the addition of commercial fertilisers.[19]

'*Decoupled aquaponic installations*' have been created in order to fine tune process water in each of the respective units.[19] They have been developed as decoupled (or multi-loop) systems that aim at providing additional fertilisers to the plants in order to expose them to optimal nutrient concentrations[63] and are now in common practice. Goddek and Keesman[64] stated that the relative additional requirements for external hydroponic-derived nutrients of three European systems were 40%–60% (NerBreen), 60% (Tilamur) and 38.1% (IGB, Berlin). Whilst the NerBreen and IGB Berlin systems meet the >50% threshold requirements to be called and marketed as being aquaponics.[5] According to Palm et al.,[5] Tilamur would need to increase their aquaponic process water use if they intend to market their products as aquaponics produce. Thus, the two different aquaponic installations must be strictly separated according to different underlying principles of use and are not directly comparable. Whilst coupled aquaponics tries to adapt the water quality from aquaculture by alteration system maintenance procedures, feed quality and integrating less demanding but more valuable plants, the goal of decoupled aquaponics is to establish commercial plant production by only partially using fish process water as the main source of nutrients. This partially prevents the original idea of aquaponics which was the uptake of nutrients by the plants and thus cleansing the water that is returned to the fish. In decoupled aquaponic installations, as the water is not cleansed and returned to the fish, more freshwater is used in the aquaculture unit. Additionally, there are nowadays numerous papers which suggest that there are allelopathic benefits of having plants inside the aquaculture systems which improves fish wellbeing and health.

Baganz et al.[6] newly introduced the term '*on demand*' to replace the already broadly used term decoupled aquaponic systems. This is inappropriate, as decoupled installations can also receive their process water as a continuous process without pumping it back to the aquaculture unit, for example, the first system by Rennert and Drews[22] lacking a one-way valve had a continuous water exchange from the aquaculture units to the plant units and then to the drains. Baganz et al.[6] named the accepted '*coupled*' installations as '*permanent*'. The issue, however, with using the term '*on demand*' is that it is possible to have water flowing '*on demand*' in both coupled and decoupled installations. Coupled aquaponics can be built as a continuous throughflow of the RAS water as process water for the plants (permanently) or discontinuously ('*quasi-closed loop*' or '*semi-coupled*' according to Schmautz et al.[65], Nozzy et al.[66], Knaus et al.[45]), where the water is pumped on-demand to the plants, utilised in for example, ebb and flood table systems for some time for plant usage and water cleaning (multiple pass), and then pumped back (discontinuous) to the aquaculture unit.[45,67] This technically requires a water transfer point as a reservoir (e.g. in the FishGlassHouse, Rostock[14]) or as seen in the IGB system a one-way valve.[68] Recent studies have demonstrated that with a semi-continuous (on-demand) coupled system (or even decoupled), adequate P, K and Fe fertilisers in the plant units have had no negative effects on African catfish RAS[69–71] thus allowing the water to be reused from the plant unit as a (semi)continuous water addition to the RAS. Consequently, the terms permanently coupled or on-demand decoupled cannot replace coupled and decoupled to describe aquaponic installations but can only serve as a subcategory for the continuous or non-continuous water exchange (mode of operation) between the minimum two units of both systems (Table 3, Figure 1).

Baganz et al.[6] suggested that (de)coupling of aquaponic systems can be extended also to other interconnections between the aquaculture and the plant units. Whilst coupled and decoupled systems describe the RAS water flow and its usage as process water and nutrient supply to the plants, several other parameters such as energy (e.g. heat), coupling time, nutrients from aquaculture sediments can describe the degree of interconnectivity between both systems in more detail, increasing the effectiveness and sustainability of the entire setup. It is generally agreed upon that aquaponic systems should be as resource efficient as possible and calculations on the coupling degree of different parameters might be possible in smaller scale systems. However, under commercial conditions, the size of the aquaculture units of for example, African catfish in northern Germany are above 300 tons annual production to achieve profitability on the aquaculture side,[72] and the enormous growth rate and low FCR between 0.75 and 0.83 under semi- to super intensive conditions (200–400 kg m^{3}) through the entire production cycle[73] results in different nutrient availabilities and proportions inside the process water throughout the entire production cycle.[47] Catfish together with various tilapia and carp species are the most common species of choice in aquaponics because they can be kept under high stocking densities and can cope with lower water quality. They can all receive a high amount of feed, resulting in good growth rates and cope well with rapidly changing nutrient compositions and proportions. It must be demonstrated that a model-based calculation of all in-and output parameters (single nutrient calculations as suggested by Baganz et al.[6]) under commercial aquaculture conditions, that often depend on daily management decisions and market conditions with resulting drastic changes in nutrient, water and energy flows, is viable and can become accepted.

6 | AQUAPONIC TERMINOLOGY

Baganz et al.[6] also raised the issue of aquaponics terminology and it is apparent that the driver behind their approach was to adjust the terms to better facilitate modelling approaches. We herewith suggest the most appropriate way of determining terminology is (1) based on the principles of first use and (2) broad acceptance in the industry. It is time that aquaponics research also matures by recognising its already developed terminology and only where necessary introduces new terms that are arrived at through consensus or are borrowed from other established scientific disciplines with a long history (see above), for example, aquaculture, biotechnology, hydroponics, horticulture, and agriculture (see tab. 3 in Palm et al.[5(p833)]). It is established best practice that already accepted, valid and/or long established terms should be incorporated and used. As an example, the preamble of the International Code of Zoological Nomenclature[74]*, an established agreement on the introduction of new names in zoology, states basic principles in order to promote stability and universality in scientific names. Precision* and consistency* in the use of terms are essential to a code of nomenclature, and most importantly priority of publication* is a basic principle. This is also required in the relatively new field of aquaponics.

Baganz et al.[6] suggested that the use of the word plant(s) (machine/factory) should not be used as a term to describe an aquaponic facility because there were other meanings of the word plant, meaning machinery or factories. We understand that very few people would ever refer to an aquaponics facility as a 'plant' and according to their own nomenclature all aquaponic systems are 'farms'.

Baganz et al.[6] discussed biofilters versus bioreactors and preferred the latter term. Espinal and Matulić[75] in Goddek et al.[19] described in the context of aquaponics as a general component of RAS the presence of nitrifying biofilters to oxidise ammonia excreted by the fish to nitrate, and referred to Gutierrez-Wing and Malone.[76] Because most aquaponic systems utilise RAS for fish or aquatic animal production, biofilter is the term of choice which is also the case in aquaponics. The term biofilter was used since the development of aquaculture RAS systems in order to describe the ongoing biological degradation of organic wastes inside these systems through microorganisms (e.g. see Krüner and Rosenthal[77]). This is exactly what happens in aquaponic systems, and is also referred to by Lennard[30] who used the terms biofilter and biofiltration.

Following Malone and Pfeiffer[78(fig. 1, p390)], a '*moving bed reactor*' is a type of RAS—fixed film/submerged and expanded biofilters, which were developed in Norway in the 1990s (European Patent: 0,575,314[79]; US Patent: 5,458,779[80]) for biological treatment of drinking water and aquaculture.[81] The so called 'Kaldnes'—'*moving bed biofilm reactor*' (MBBR) was developed '[…] *to adopt the best features of the activated sludge process as well as those of the biofilter processes*'.[81] In the US Patent it was written '*since the biofilter medium is not stationary, but moves with the streams in the bioreactor*',[80] including both terms 'biofilter' and 'bioreactor' in the same sentence. However,

TABLE 3 Selected aquaponic terms as taken from aquaculture and hydroculture technology, based on its first or widely accepted use.

Aeroponics	Aeroponics is the growing of plants in an opaque trough or supporting container in which their roots are suspended and bathed in a nutrient mist rather than a nutrient solution.	Resh,[27] Went[91]
Aquaponic nutrient water	Process water from the aquaculture unit that is upgraded with fertiliser/ additions to provide adjusted nutrient compositions to the plants.	Southern and King,[31] Palm et al.,[5] present study
Aquaponics farming	Aquaponic farming combines aquaculture with the farming of plants and crops in substrate or soil.	Palm et al.[5]
Aquaponics gardening	Is '[…] media-based aquaponics for growing vegetables and fish at home in a variety of climates.'	Bernstein[29]
Biofilter	The component of the treatment units of a culture system in which the removal of organic matter takes place and dissolved metabolic by-products are converted (mainly oxidized) as a result of micro-biological activity. The most important processes are the degradation of organics by heterotrophic bacteria and the oxidation of ammonia via nitrite to nitrate.	FAO[62]
Closed aquaponic system	This term was earlier used for coupled aquaponic systems: 'Aquaponics is an evolving closed-system food production technology that integrates recirculating aquaculture with hydroponics.'	König et al.[92]
Condensed water	Water from cold traps of air-conditioning that originated from plant transpiration and water surface evaporation.	Kloas et al.[15]
Coupled aquaponic system	A 'Coupled systems' consist of one connected water layer […]' (p. 2) and '[…] has the hydroponic part integrated in the circuit […]' (p. 4).	Peterhans[93]
Coupling time	Sum of non-continuous parallel run of aquaculture and plant units through for example, discontinuities in fish and plant production.	Baganz et al.[6]
Cupboard aquaponics	Systems for fresh food in urban homes/food service.	Wilson,[94] Palm et al.[5]
Decoupled aquaponic system	A system: '[…] in which the water flow is divided into two independent systems that can occasionally communicate whenever plants need a boost in nutrients or fish require reclaimed water from plants to dilute the wastes accumulating in the fish sub-unit.' (p. 10).	Thorarinsdottir et al.[95]
Discrete media beds	Growing a single plant in one container filled with media (e.g. gravel, expanded clay balls, vermiculite, perlite).	Lennard[30]
DWC	'Deep Water Culture' (Deep Flow) hydroponic subsystem. A liquid '[…] culture system […]' with '[…] a relatively large vessel filled with nutrient solution with the roots dispersed freely in this liquid'. 'Deep Water Culture (DWC): water flows down long troughs of water, typically about 12″ deep, like a slow-moving stream.'	Raviv et al.,[58] Southern and King[31]
Ebb-And-Flow (Flood) Systems (E&F)	'[…] Nutrient solution is pumped into a shallow bed to a depth of about 1 in. (2–3 cm) for about 20 min and then allowed to drain back to the nutrient tank once the pumps are shut off.'	Resh[27]
Facility product water use	Average water volume needed to produce 1 kg of fresh product within 1 year.	Baganz et al.[6]
Grow pipes	Sloping round tubes with a low water level and recesses at the top for plant stocking, conducted by NFT-like systems.	Anantharaja et al.,[96] Knaus et al.[46]
Growing media	Material which '[…] is needed for anchoring of the roots to support the plants and to increase the surface area on which the beneficial bacteria cling to and live.'	Dudley[97]
Hydroponic subsystem	Kind of hydroponic system or device for plant cultivation such as gravel, sand, perlite beds, NFT or floating raft.	Rakocy,[1] Lennard and Leonard,[90] Rakocy[23]
Intercropping crop production	Growing more than one crop at the same time.	Horwith,[98] Brooker et al.,[99] Maucieri et al.[100]
Liquid-culture hydroponics	Culture of plants only with nutrient solution '[…] without the use of any solid substrates […]'.	Raviv et al.[58]
Multiple pass Decoupled system	The process water is circulated inside the plant unit more than one times and then discarded.	Lennard[30]
NFT	Nutrient film technique (NFT) uses an approach whereby roots are suspended in a trough whereby a thin layer of nutrient solution is continually recirculated.	Raviv et al.[58]

TABLE 3 (Continued)

On-demand system	Decoupled system with water transfer point enabling on-demand process water transfer.	Baganz et al.[6]
One pass decoupled system	The process water is applied to the plants once and then discarded.	Lennard[30]
Organic hydroponics	The supplements required for aquaponics to meet plant nutrient requirements may also be sourced from organically certified inputs and therefore, aquaponics could also be considered a form or sub-group of organic hydroponics.	Lennard[30(p71)]
Polyponics	Polyculture (of aquatic organisms) + aquaponics; the use of several fish species together in one coupled aquaponic system.	Knaus and Palm,[101] Knaus et al.,[102] Palm et al.[44]
Process water	Process water is the liquid medium in which the aquatic organisms live and which carries the organic waste products (e.g. nutrients) that come into contact with the plant roots. Sometimes also used for condensed water which is moved back into the aquaculture unit by plant evapotranspiration and water surface evaporation via cold traps.	Kloas et al.,[15] Goddek et al.[88]
RAS (aquaculture) water	Medium in which the aquatic organisms are kept alive.	Multiple authors
Replaced water	In Aquaponic systems, water is replaced (not exchanged) …; … to replace water lost due to evaporation, evapotranspiration, spillage, leaks, and water exchanges.	Lennard and Leonard,[90] p. 549, Love et al.[13]
Sedimenter/separator	Separation of two phases, solid and liquid, from a suspension in a separator (solid–liquid separation).	Svarovsky[103]
Semi-continuous coupled	Systems with irregular water transfer from aquaculture to the plant unit.	Present study
Soil	Soil is made up of mineral particles, organic substances, air, water and living organisms; AND/OR; Soil is a mixture of mineral and organic matter that contains air, water, and micro-organisms. It provides a medium in which plants grow, a habitat for animals, and storage for water.	For example, Wallander,[104] Hartemink,[105] https://cosmos.ceh.ac.uk/soil[106]
Substrate	Material in or on which an organism grows or to which it is attached.	For example, Baker and Chandler[107]
Substrate aquaponics	Hydroponic subsystem with multiple plant media beds/pots/bags filled with substrates or growing media (e.g. coconut fibre, perlite, vermiculite, light expanded clay aggregate—LECA) as root holdfasts and water reservoir	For example, Petrea et al.[108], Pantanella[32]
Substrate-based hydroponics	Culture of plants with nutrient solution and substrate that is inert and has little ion-exchange capacity.	Raviv et al.[58]
System water	Recirculating water that is pumped from sump to tanks and which then flows back through filtration and troughs to the sump.	Southern and King[31]
Unit	Aquaculture or plant/hydroponic part of an aquaponics system	Present study

the association with aquaculture is clearly given and the term 'biofilter' must be used. In conclusion, the main task of biofilters, and thus also of the 'moving bed biofilm reactor', is the purification of water. In contrast, a bioreactor per definition is '[…] *the designed space where biological reactions take place* […]' and it '[…] *should create a biosphere* […] *for the biological reaction*'.[82] The historical development of bioreactors began with the production of wine and beer, that is, food production, as biotechnological processes. Later, industrial biotechnology developed scientifically with the fermentation of Louis Pasteur (1822–1895), further for example, in the bacteriology with Robert Koch (1843–1910), and by Alexander Fleming's *Penicillium* culture (1929) which was later implemented in large-scale production.[82] The mission of a bioreactor is thus the mass production of cell cultures or, in modern times, of, for example, enzymes, hormones or vitamins through biological reactions by definite microorganisms, which is in contrast to the function of the 'moving bed biofilm reactor' (MBBR) with its role of water cleaning. On a side note, the term 'moving bed biofilm reactor' is a misnomer and should be better referred to as '*biofilm slurry reactor*' as it is a stirred tank bioreactor with submerged particle biofilm aggregates that has no relation to a traditional bioreactor.[83,84]

Baganz et al.[6] also summarised the different terms that have been used to describe the water transfer between the aquaculture and the plant cultivation units. The terms *aquaculture* or *RAS water*, as the main nutrient source in aquaponics, describe the medium in which the aquatic organisms (not only fish) are kept alive and that is circulated inside the units. This is transferred as '*process water*' (an industrial term that has also been used in aquaculture terminology by Viadero and Noblet[85]; and Tango and Gagnon[86]) into the plant units or subsystems. The term process water has been frequently used in many publications on aquaponics[15,87–89] so it is unnecessary to re-create the terminology. We therefore refrain from using the simplified term '*fish water*' as done by Kloas et al.[15] Baganz et al.[6] preferred to circumnavigate this terminology by using the term '*nutrient water*'. This might be mistaken with aquaculture process water containing also liquid (ionic) fertiliser for the plants and should probably be called '*aquaponic nutrient water*', for fertilised process water particularly in decoupled systems. With regard to other water types, Lennard and Leonard[90] for the first time used '*replaced* water' as water added to the aquaponic system to account for the water lost through evapotranspiration (='*condensed*' water from cold traps of air-conditioning that originated from plant transpiration and water surface evaporation by Kloas et al.[15]). Love et al.[13] more comprehensively considered '*replaced* water' to compensate for water loss from evaporation, evapotranspiration, spillage, leakage, and water exchange. Different kind of waters to be used in aquaponics and their valid terms and meaning are provided in Table 3 as are a number of other selected terms already in use with references to their origin (Table 3).

7 | CONCLUSIONS

It is apparent that Baganz et al.'s[6] paper attempted two things: (1) to redefine aquaponics and (2) to rationalise and support aquaponic modelling through changes in terminology. The publication by Baganz et al.[6] has necessitated a response as their paper implies better clarification of the rationale and origins of earlier aquaponic definitions and the underlying principles, including the careful choice of words by Palm et al.[5] Their definition of aquaponics was an outcome of a deliberate and comprehensive discussions and processes within the EU Aquaponics Hub (with 32+ countries involved).

First, the newly provided definition of aquaponics by Baganz et al.'s[6] principally reformulated earlier definitions, which were based before most recent technological developments. The authors removed several key elements that had developed from Gericke,[57] (hydroponics), FAO: Welcomme and Barg,[60] (aquaculture), Resh,[26,27] (hydroponics), and in aquaponics mainly from Rakocy et al.[2,3] via Lennard[4,30] to Palm et al.[5] (Ref. 33 in part). The evolution of the definition via the above authors provided the most applicable definition of aquaponics, which should, as a minimum, contain the requirement for a majority of the aquaculture derived nutrients (from waste and process water) for the plants. Without this prerequisite, there would be no foundation for aquaponic determination. We therefore maintain the definition of aquaponics as provided by Palm et al.[5] that

> Aquaponics is a production system of aquatic organisms and plants where the majority (> 50%) of nutrients sustaining the optimal plant growth derives from waste originating from feeding the aquatic organisms.

Second, the issue of arranging aquaponics around a subset of terms devised for modelling is not conducive to understanding amongst aquaponic stakeholders. Restricting the term aquaponics to be solely the combination of tank based RAS combined with hydroponic plant cultivation as a main principle is a setback, and also disassociates the 'original meaning' which combined the terms ***aqua***culture (independent of systems) and hydro***ponics*** (independent of systems, see above). This restriction limits further terminology developments, as with most emerging technologies there will of course be the need for innovation and emerging terminologies also in the future. As noted above, the term aquaponics is very unfortunate because it reunites the terms aquaculture and hydroponics (the latter was coined to differentiate plant water culture based on nutrient solutions from aquaculture) and also does not properly describe the underlying processes. Continuing the scrutiny of the terminology and what are the principles involved, as aquaponics is the transfer of organic compounds through water from aquatic organisms to the plants by using hydroponic technologies, it would better be described as '***aquaorganoponics***'. This alternative term is suitable because it describes exactly what the principles are which is the transfer/working ('***ponics***') of natural organic compounds ('***organo***') from the aquatic organism process water ('***aqua***') to the plants. This would also allow the addition of chemically formulated fertiliser or growth stimulants (here *aquaponic nutrient water*), especially in decoupled systems. Aquaponic systems therefore can be clearly distinguished from hydroponic systems, underlying entirely different biological processes, and therefore require their own technological adaptations. We realise however, that the term aquaorganoponics is unlikely to catch on, apart from possibly, in the scientific world and the term aquaponics will most commonly be used, but this small step is important in describing what it really is.

In the third instance, as noted, the definition of aquaponics relates to the *principle* of aquaponics and not technologies, with the two categories aquaponics *sensu strictu** (for true hydroponics and soilless, here *aquaorganoponics*) and *sensu lato** (farming and gardening with soil). Defining the circular economy, which is central to the principal of aquaponics and which is similar in that it is a relatively new area of research like aquaponics, Figge et al. noted that '*good definitions focus on only what is essential whilst distinguishing the term from other related concepts*'.[10] Because new technologies and methods will always emerge this may further compromise and complicate the nomenclature in future. In all instances, whether the definition derives from the principle or technology, we hold to the philosophy of KISS (Keep It Simple, Stupid; Interaction Design Foundation[109]). This principle is based on the engineering principle of keeping all aspects of engineering simple in order, facilitating understanding and better and efficient management of systems (Interaction Design Foundation). This principle is furthermore essential in order for other stakeholders than scientists to understand aquaponics and its benefits.

Finally, we suggest that future aquaponic terms, before getting published and added to the literature must follow standard scientific procedures already in place, in that (1) existing terms from other or related disciplines, if transferable, must have priority (priority of publication* is a basic principle), (2) meanings of already published terms must be changed with propriety, and (3) that the terms must be tested for precision and consistency. This is essential in order to lift aquaponics research from a home based 'play ground' into a serious scientific discipline and assisting in its market recognition and commercial viability in the future.

AUTHOR CONTRIBUTIONS

Harry W. Palm: Conceptualization; writing – review and editing; methodology; writing – original draft; visualization; investigation; validation. **Ulrich Knaus:** Validation; visualization; writing – original draft; writing – review and editing. **Benz Kotzen:** Conceptualization; writing – original draft; writing – review and editing; visualization; methodology.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are all cited in the reference list.

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