Original Research Article

Outlook on AGRICULTURE

Outlook on Agriculture
2022, Vol. 51(1) 39–45

DOI: 10.1177/00307270211070317
journals.sagepub.com/home/oag
SAGE

Regenerative agriculture as a biomimetic technology

Bart Gremmen

Abstract

As populations increase and economic affluence expand, conventional farmers will be unable to meet the demand for food. Two main scenarios offer different solutions. The first scenario aims to further intensify scientific- and technology-driven agriculture research. The second scenario aims to radically switch to nature-based solutions in agricultural systems. There seem to be two interpretations of the nature-based solutions scenario: on the one hand, the interpretation of the IUCN regards nature-based solutions, such as regenerative agriculture, as using nature and denies a link with biomimicry; and on the other hand, the interpretation of the EU regards regenerative agriculture as an example of biomimicry. This raises the question: is regenerative agriculture a prime example of biomimicry or is it only a very important way to use nature in agriculture? To answer this question, we take a step back and philosophically reflect on biomimicry. Based on two definitions of mimesis, we distinguish between two concepts of biomimicry, a 'strong' concept which emphasizes natural principles and copying natural models, and a 'weak' concept, which emphasizes inspiration by nature and creative invention. Secondly, we describe and analyze regenerative agriculture as part of the nature-based solutions scenario and interpret regenerative agriculture first as 'weak' and then as 'strong' biomimicry. Both interpretations have their problems. To address these, we propose a new concept of biomimicry based on a new definition of mimesis. This enable us to differentiate between biomimicry, strict imitation of nature, and nature-inspired invention. We argue that our conceptualization of biomimicry helps to operationalize regenerative agriculture as a biomimetic technology.

Keywords

Nature-based solutions, mimesis, biomimicry, natural systems agriculture, natural principles

Introduction

In recent decades global food system demands have increased exponentially. As populations increase and economic affluence expand, conventional farmers will be unable to meet the demand for food. This is mainly due to the fact that more than half of global agricultural lands are already degraded (Glover et al., 2010). As a result of efforts to increase food production, global agriculture has led to biodiversity loss, destruction of natural habitat, soil degradation and depletion of natural resources (Miralles-Wilhelm and Iseman, 2021). How can farmers meet future food demand while avoiding these destructive side-effects?

Two main scenarios offer different solutions. The first scenario aims to further intensify scientific- and technology-driven agriculture research. This amounts to a second Green Revolution, but now super-charged by high-technology. Its solutions involve new ways to reduce negative impacts on specific aspects of the food system. This is, for example, done by replacing phenotypic with genotypic breeding technologies, and mechanical with digital technologies. The focus is on technological interventions to support plant growth, and this scenario uses degraded land to increase food production while preventing further biodiversity loss and destruction of natural habitats.

The second scenario aims to radically switch to nature-based solutions. There are many kinds of nature-based agricultural systems: agroecology, organic farming, permaculture, natural systems agriculture, agroforestry, ecological agriculture, etc. The first nature-based agriculture, organic farming, has been studied and propagated since the early twentieth. In recent years the literature increasingly refers to the different nature-based agricultural systems as regenerative agriculture (Sumberg, 2022). Its focus is on soil fertility and not on plant growth. Its key methods, minimal tillage, no chemicals and intercropping, have become the core of the nature-based solutions scenario.

From a philosophical perspective, regenerative agriculture is a biomimetic technology, and an example of the '(re)turn to nature' (Sumberg, 2022). Proponents of biomimicry claim that it no longer exploits nature, but rather learns from nature. Nature provides models and can be used as a standard against which to evaluate agricultural

Philosophy Group, Wageningen University, Wageningen, Netherlands

Corresponding author:
Bart Gremmen, Philosophy Group, Wageningen University, Hollandseweg 1, 6700 EW Wageningen, Netherlands.
Email: bart.gremmen@wur.nl

practices and systems. As an example of biomimicry in agriculture, Benyus (1997), one of the founders of the biomimicry movement, refers to Jackson's book 'Nature as Measure: The Selected Essays of Jackson' (2011). Inspired by the prairie ecosystem, Jackson conceptualized Natural Systems Agriculture (NSA) around the use of perennial grains, perennial polycultures and intercropping to help address the problem of soil erosion.

If regenerative agriculture is considered to be a prime example of biomimicry, this could also lead to the conclusion that biomimicry is part and parcel of the nature-based solutions scenario. However, this is disputed by the IUCN which defines nature-based solutions as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016: 5). The IUCN states that this definition excludes "interventions that are merely inspired by nature, such as biomimicry" (Cohen-Shacham et al., 2016: 6). Thus, there appears to be two interpretations of the nature-based solutions scenario: on the one hand, the interpretation of the IUCN which regards nature-based solutions, such as regenerative agriculture, as using nature and denies a link with biomimicry; on the other hand, the interpretation of the proponents of biomimicry which regard regenerative agriculture as an example of biomimicry. This interpretational difference highlights the main question of this paper: is regenerative agriculture a prime example of biomimicry or is it only a way to use nature in agriculture?

In what follows, we address the conceptual side of nature-based solutions and biomimicry in particular, and focus on regenerative agriculture as a possible biomimetic technology. The next two sections set the scene. First, we take a step back and philosophically reflect on biomimicry as a new science that studies nature's models and then imitates or takes inspiration from them to solve human problems. We distinguish between two variants of biomimicry, a 'strong' variant which emphasizes natural principles and copying natural models, and a 'weak' variant, with emphasizes inspiration by nature and creative invention. Secondly, we describe and analyze regenerative agriculture as part of the nature-based solutions scenario. In the fourth section, we first interpret regenerative agriculture as 'weak' and then 'strong' biomimicry. Both interpretations have their problems. To solve these we propose a new concept of biomimicry based on a new definition of mimesis. This enables us to differentiate between biomimicry, strict imitation of nature, and nature-inspired invention. In the last section we argue that the new conceptualization of biomimicry helps us to operationalize regenerative agriculture as a biomimetic technology.

Biomimicry as an ecosystem-friendly approach to nature

Over the years, nature-inspired approaches to technology and innovation have increasingly received attention. They appear under a variety of names (e.g. biomimicry, bionics, biomimesis etc.) but in the following, we use the more common name 'biomimicry'. Biomimicry is "…a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems" (Benyus, 1997: 1). Nature is seen here as an inspiring source of knowledge – a solar cell inspired by a leaf for instance, or nature-based innovations such as recyclable and biodegradable materials.

According to the proponents of biomimicry, it introduces a new and ecosystem-friendly approach. Benyus (1997) for example argues that the first industrial revolution was characterized by the domination and exploitation of nature, whereas the contemporary – biomimetic – industrial revolution is characterized by learning from and exploring nature. By 'doing it the natural way', technological innovations can claim to be better embedded in, and in harmony with, the natural ecosystems of planet earth (Benyus, 1997). "The natural way is better because the evolution of nature is seen here as a process in which organisms were able to perfect themselves and learned to fly, swim, navigate, capture the sun's energy, etc. In short, living things have done everything we want to do, without guzzling fossil fuel, polluting the planet, or mortgaging their future. What better models could there be?" (Benyus, 1997: 2; cf. Todd, 2013) Nature functions here as a model – photosynthesis, self-assembly, self-sustaining eco-systems, but also eyes and ears for instance – which design and manufacturing processes imitate to solve technological problems. According to Benyus, the main lesson we can learn from nature is the "hand-in-glove harmony" of natural systems, in which "organisms are adapted to their places and each other", which should inspire future nature-based technological innovation.

According to the opponents of biomimicry, however, one might wonder whether it is only a slogan forged by chemists so they can play a role in the field of sustainability (cf. Bensaude-Vincent et al., 2002). The concept is so loose that one can argue that all technologies are built from natural resources and in this respect are natural in the strict sense of the word (cf. Forbes, 2005). They doubt that biomimicry is a real revolution, and wonder whether and under what conditions it can achieve its ambitions. The debates between proponents and opponents raise the question of what exactly explains the difference between the high ecological performances of biomimetic technologies in contrast with the low ecological performances of traditional technologies. We have shown that in the philosophical tradition there are two definitions of mimesis which could offer an explanation (Blok and Gremmen, 2016).

The first definition suggests that biomimetic technologies copy the models that nature provides. We have called this 'nature as model' view the 'strong' concept of biomimicry (Blok and Gremmen, 2016). This naturalistic definition of mimesis that we find in Aristotle's Physics can also be found in various biomimetic practices that imitate natural forms or processes (Hayes et al., 2020). The naturalism of this definition of mimesis consists in the imitation of the physical shape of natural phenomena in technological design, e.g. mimicking the kingfisher bird in the design of the nose cone of the Japanese bullet train to reduce air friction when trains enter and leave tunnels. Imitation can also concern natural processes, for instance imitating organic growth and healing processes in the development of self-healing and self-repairing concrete.

The second definition of mimesis suggests that biomimetic technologies progressively add to nature so that it is more complete or perfect (Aristotle, 1995). In this way they accomplish what nature is not capable of doing itself. What does mimetic perfection add to the original? According to Aristotle (1995), nature only provides access to the sensory phenomena that we encounter in the world. Mimetic perfection adds access to – and articulation of – general patterns or universals that constitute concepts like 'tree' and 'man'. These concepts are not inductively derived from natural phenomena, but are the product of a mimetic act that actively constitutes a type or category that subsumes individual sensory phenomena under a generic term. Is this mimetic act a free invention? No, because it articulates what is in a way already there in natural phenomena: general patterns, types, or categories.

The 'weak' concept of biomimicry depends on the second definition of mimesis (Blok and Gremmen, 2016). Here biomimicry is understood as a strategy "to mimic high-tech solutions that nature can give us, reformulate natural materials, natural strategies and to create new materials and devices that outperform anything that we have today" (Aizenberg, 2012). This 'weak' concept takes natural solutions as inspiration to create new materials and devices. It sees mimicry not as the duplication of natural solutions, but primarily as a creative solution inspired by nature (cf. Ball, 2001). The 'weak' concept acknowledges that "some form or procedure of interpretation or translation from biology to technology is required" (cf. Vincent et al., 2006), and therefore, both the complexity and temperamentality of natural phenomena are acknowledged.

Natural systems agriculture as regenerative agriculture

In common biomimetic practice, nature is translated into a variety of technologies, ranging from the built environment to artifacts like gecko-tape and sharkskin swimsuits. However, the current discussions about the potential of biomimicry also show that relatively little research has been done in terms of translating nature into agriculture (Stojanovic, 2019). Biomimicry seems to resonate quite well with some of the main issues around recent agricultural technologies (cf. Blok and Gremmen, 2018). Benyus (1997) uses Jackson's work on NSA as an example of biomimicry in farming practices: "In a biomimetic world, we would manufacture the way animals and plants do… Our farms, modeled on prairies, would be self-fertilizing and pest resistant. To find new drugs or crops, we would consult animals and insects that have used plants for millions of years to keep themselves healthy and nourished. … In each case, nature would provide the models: solar cells copied from leaves, steely fibers woven spider-style… perennial grains inspired by tallgrass…" (Benyus, 1997: 2–3)

NSA is considered to be part of regenerative agriculture (RA). RA seeks to improve the resources it uses, rather than destroying or depleting them. It is a holistic systems approach to farming that encourages continual innovation for environmental-, social-, economic-, and spiritual well-being (Rodale Institute, 2014). The term RA was coined about thirty years and has its origin in organic agriculture. According to the USDA "organic producers use natural processes and materials when developing farming systems—these contribute to soil, crop and livestock nutrition, pest and weed management, attainment of production goals, and conservation of biological diversity" (USDA, 2015: 1). Overall system health and the interaction of management practices are the primary concerns of organic producers, and they implement a wide range of strategies to develop and maintain biological diversity and replenish soil fertility (USDA, 2015). Robert Rodale developed regenerative agriculture to distinguish a kind of farming that relies on natural principles and goes beyond simply being 'sustainable' (Rodale Institute, 2014).

After a rapid onset, RA developed slowly over a period of two decades. In the past few years, however, there has been an explosion of interest, and many successes are now being claimed for regenerative agriculture. For example, proponents claim that a diversity of production methods may improve and even restore soil health and biodiversity, but also have the potential to offset greenhouse gas emissions by sequestering carbon stored in soils, trees, and plants. However, these claims are not yet substantiated. For example, as a study on cocoa agroforestry shows that "…evidence for the hypothesis of 'internal restoration' in agroforestry is patchy and the effectiveness may depend on local context. … Compared to other agricultural systems, complex agroforestry improves soil structure of degraded soil resulting from forest conversion. However, a considerable gap remains with forest soil conditions." (Saputra et al., 2020: 2261) Also, Giller et al. (2021) have written a critical review of RA's claims from an agronomic perspective. The main conclusions are that the claims about soil health and biodiversity are unfounded. Some reviews also dispute the claim that RA has the potential to address climate change. For example, Ranganathan et al. (2020) analyzes climate change mitigation options in the food and land sector and concludes that the practical potential of RA is at best modest We conclude that RA has serious empirical problems, and in addition there is a conceptual problem with RA.

There are many different definitions of RA. For example, the very broad definition of Dougherty: "Regenerative agriculture is an emerging concept for managing agricultural land. It seeks to combine the best conventional, organic, and biological farming practices into a system that improves productivity while enhancing ecosystem services. It primarily focuses on improving the health of soils by following basic soil health principles. These include maximizing soil cover, maintaining a system of continuous living roots, and encouraging genetic diversity, while minimizing soil disturbance" (Dougherty, 2019: ii). In this definition, RA is essentially a combination of best soil practices. An even broader definition is provided by Durkin and McCue: "Regenerative farming is a system of producing food and biomass that focuses on building functional biodiversity and soil health to produce consistent yields without relying on synthetic inputs (herbicides, pesticides, and chemical fertilizers)" (Durkin and McCue, 2021: 1). They explain the absence of a centralized "official" definition by pointing at the dynamic state of RA and consider it a journey and a shift in mindset (ibid). According to Dougherty "…the distinction between what makes a farmer 'regenerative' vs. 'conventional' is admittedly hard to define" (Dougherty, 2019: 5). We conclude that the conceptual basis of RA is weak: will reinterpreting RA as biomimetic technology help to solve this conceptual problem?

Nature based solutions as biomimetic solutions

Regenerative agriculture, as a common denominator of nature-based agricultural systems, is part of the umbrella concept of 'nature-based solutions' (NbS). This concept is used to cover a range of ecosystem-related approaches including ecosystem-based adaptation, natural climate solutions, and green infrastructure. There is little agreement as to the precise meanings of these, and this is also the case for NbS, the most widely used term (Sumberg, 2022). In the NbS literature there are two main perspectives. From the first, NbS is seen as rooted in the theoretical underpinnings of ecosystem service research, with a focus on systemic economic solutions (Maes and Jacobs, 2015). This perspective has a focus on technological artifacts outside agriculture. Therefore, we will concentrate on the second perspective, in which NbS id rooted in nature conservation, with a focus on ecosystems (Cohen-Shacham et al., 2016).

International Union for Conservation of Nature (IUCN) formulated what is now a widely used definition of NbS: "Nature-based Solutions are defined as actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016: 2). The actions of NbS occur along a gradient, from natural at one end to engineered at the other, from protecting a fully intact ecosystem (e.g. a wetland) to restoring degraded ecosystems (e.g. re-establishing traditional agroforestry) to creating new ecosystems (e.g. using permeable pavement) (Cohen-Shacham et al., 2016). Nature-based solutions are first and foremost actions focused on ecosystems. While societal challenges are secondary, the assumption is that they can only be addressed through solutions based on natural processes. From this perspective, to be nature-based means to use nature and not interventions that are merely inspired by nature, such as biomimicry (Cohen-Shacham et al., 2016: 6). This interpretation of biomimicry as inspired by nature can be identified in the 'weak' concept discussed earlier, because mimicry is defined here as a creative solution inspired by nature (cf. Ball, 2001).

The second definition of mimesis indicates the biomimetic articulation of natural principles that govern ecosystems. Therefore, the 'weak' concept of biomimicry can be found in biomimetic practices at the system level that mimic general patterns and principles observed in ecosystems (Marshall and Loveza, 2009). More general examples of these principles are the nine 'natural principles' of Benyus (1997) including 'nature demands local expertise' and 'nature uses only the energy it needs.' These principles are not inductively derived from natural phenomena, but rather are the product of a mimetic act that constitutes life principles like 'nature runs on sunlight'. This seems to fit very well with the eco-systems approach of RA, because what are portrayed as natural principles, like intercropping and perennial crops, play a central role.

However, all hope for a biomimetic agriculture that no longer dominates, and exploits nature will be gone if we accept the 'weak' concept of biomimicry as the theoretical basis of RA. If nature is understood only in mechanical terms, there will no longer be a difference between traditional technology, characterized by the exploitation of nature, and biomimetic technology, like RA. The 'weak' concept focuses on the re-creation of nature for human ends and does not take natural principles as a normative standard. Nature is considered purely as a "storehouse of readymade designs available for us to mix and match to our consumer purposes" (Mathews, 2011: 373), i.e. as a resource for useful ends and purposes (cf. Schyfter, 2012).

The specific advantages RA, derived from its focus on learning from nature, over technology that 'exploits' nature, disappear if we accept a 'weak' concept of biomimicry. One can only claim a more eco-system-friendly type of agriculture, like RA, if it not only mimics or incorporates natural principles but also is embedded in nature. This contrasts with using technology to exploit nature to satisfy human needs, like the second Green Revolution scenario (Blok and Gremmen, 2016). In other words: creative invention (the 'weak' concept of biomimicry) is too weak: a stronger concept of biomimicry is needed to help to define RA.

While the 'strong' concept of biomimicry seems logical, a closer inspection reveals difficulties (Blok and Gremmen, 2016). The idea that nature is a measure against which to judge the ethical rightness of technological innovations (Benyus, 1997) is at the core of the 'strong' concept of biomimicry. Biomimetic technology and innovation can claim to be ethical because natural principles are assumed to be conducive to ecological health and ecosystem integrity. Therefore Benyus (1997) refers to Jackson's Natural Systems Agriculture which also uses natural principles as a measure in technological design. Only as a copy or reproduction of natural processes can biomimicry in the strong sense claim to be bio-inclusive and ethical.

Strict application of nature as a measure for biomimetic practices is problematic for two reasons. First, it is impossible to meet the requirements of Benyus' bio-inclusive ethics because of the need to translate and interpret natural problem-solving so that it is useful for human problem-solving (Blok and Gremmen, 2016). Second, to take nature as a measure against which to judge the ethical rightness of our technological innovations is to commit the so-called naturalistic fallacy (Moore, 1903). This fallacy consists in arguing that something is good because it is natural. Because the 'strong' concept of biomimicry claims that technological innovations are good because they are based on nature, it commits the naturalistic fallacy. The question can be raised as to what extent, if at all, nature can be claimed to be ethically good.

It is possible to argue that the evolutionary measure of survival is a good measure of ethical behavior. However, we cannot claim that the fittest are automatically the ethically good (Blok and Gremmen, 2016). Also, Benyus' (1997) argument that natural R&D can be characterized as 3.8 billion years of trial and error that resulted in beautiful natural designs is wrong, because it also resulted in natural design with enormous amounts of waste. Here the example of leaf photosynthesis, which is inefficient and wasteful because of photorespiration, is highly relevant. Human problem solving cannot afford this bad design and needs management practices that prevent the loss of generations and enhance ethical behavior. Our ethical standards always limit the transfer of natural R&D to the context of human problem solving, and are not primarily derived from nature (mimicry) but imposed on nature (Blok and Gremmen, 2016). Therefore, the fact that biomimetic ethics is itself not ecological or natural leads to a paradox, and this is a formidable problem for the 'strong 'concept of biomimicry.

There also are difficulties concerning three presuppositions relating to the core of the 'strong' concept of biomimicry. The first is in distinguishing between 'discovery of natural principles' and 'invention of newly created artifacts.' The concept of 'invention' can be used both for finding and for making, and we must admit that every discovery, just like every invention, already involves a construction (Blok and Gremmen, 2016). The second presupposition concerns our ability to 'know' the designs of nature; to 'echo the ideas of nature'; or to 'borrow designs from the larger life system'. These require full access to nature, to be able to understand and know the natural processes itself (Blok and Gremmen, 2016). We wonder whether natural processes are fully accessible and understandable. The complexity and temperamentality of natural phenomena limit the possibility of our discovering and then echoing nature's models to solve technological problems (cf. Bensaude-Vincent et al., 2002). The third presupposition is a strict distinction between the technological intervention in nature and the pure receptivity of nature. To explore the applicability of natural phenomena in the context of technological problems, the complexity and temperamentality of nature make it necessary to translate and interpret the natural phenomena. As a result, the ethical advantage of biomimetic design becomes questionable because a strict distinction between reproduction and invention can no longer be made (Blok and Gremmen, 2016). We conclude that the difficulties of these three presuppositions of the 'strong' concept of biomimicry limit its value as a possible theoretical background of RA. We need a new concept of biomimicry.

This new concept must go beyond the two definitions of mimesis as either simple imitation or mere inspiration. The first definition of mimesis (A = A) – A as original and A as copy – entails a static relation of embeddedness. However, mimesis always involves an original (A) and something added to the original (A1) that cannot be lifted by any mimesis. Why? This addition (A1) cannot be identical to the original (A), because there would be no differentiation between them. This would be neither possible nor necessary (Blok, 2022). Therefore, mimesis always involves change (A → A1) and is thus better understood as a variant of the original. This explains why practitioners find that direct imitation of a biological prototype in technological design is rarely successful: interpretation, translation, and management are inevitably required (Blok, 2022).

Because the mimesis of the natural original (A) always involves change into a technological variant (A1) we can go beyond the first definition of mimesis as strict imitation (A = A). But how can we distinguish between change as a variant of the natural original (A1) and change as a nature-inspired invention of something completely new (B)? According to Blok, this is possible because a variant of the natural original (A1) differentiates a general pattern (principle, type, or category) from the original – natural phenomena – but remains embedded, and participates, in this original, which it perfects (Blok, 2022). We can distinguish mimesis from invention, because the invention of something completely new consists of a differentiation without remaining embedded whereas a mimetic variant, by adding something to the original, differentiates from the original but remains embedded, and participates, in this original.

Our new definition of mimesis as a variant of the natural original (A1) enables us to abandon Aristotle's definitions. We replace his two separate operationalisations of mimesis (imitation and invention) with two boundary conditions (differentiation and participation) (Blok, 2022). This also enables us to differentiate between biomimicry (A → A1), the 'strong' concept of biomimicry as a strict imitation of nature (A = A), and the 'weak' concept of biomimicry as nature-inspired invention (A → B). Mimesis as a variant of the natural original (A1) helps us to interpret RA as a biomimetic solution.

Regenerative agriculture: A biomimetic solution

If we apply the concept of biomimicry to agriculture, the problem is that we deal with natural systems in duplicate (Stojanovic, 2019). They are both the natural sources for mimicking (A), and at the same time the material (A1), when natural species and their relationships are incorporated in agricultural designs. "Nature being both the source and the material for design complicates differentiating nature from technology (a polarity necessary for biomimicry). What is actually mimicked … are functional relationships between wild species, and transferred to a slightly different group of species which suits human purposes better – for example the functional structure of temperate zone forest is mimicked by including cultivated fruit trees and domesticated animals into design, instead of wild fruit trees and game" (Stojanovic, 2019: 10). The technological import that is added (A1) to the natural original (A) is a functional assembly of species (cf. Mollison, 1988).

Our definition of mimesis as a variant of the natural original enables us to conceptualize RA as biomimetic technology. We propose the following definition of biomimetic RA: *differentiation* of agricultural design beyond existing ecosystems that at the same time remains *embedded*, and *participates*, in these ecosystems. This leads us to our first conclusion: because RA takes ecosystems as their point of departure in the development of new agricultural design, and is at the same time responsive to the wider ecological context on which agriculture depends, it is biomimetic agriculture. This enables us to answer the question of whether RA is a prime example of biomimicry positively and also leads to the second conclusion that biomimicry is part and parcel of the nature-based solutions scenario.

Our third conclusion is that the ecosystem services approach, with its focus on nature as inspiration and imitation of nature, is only biomimetic in either a sense that is too weak or too strong. Our fourth conclusion is that NSA, as part of RA, is indeed biomimetic, but in a different manner than Benyus (1997) intended it. NSA is biomimetic because of its focus on the use of natural principles in ecosystems.

As a fifth conclusion, we provide a criterion to distinguish between biomimetic agricultural technologies and agricultural technologies that mimic natural forms or processes to provide opportunities to reduce waste, improve efficiency in resource use, and so on. Biomimetic designs not only require us to mimic natural forms and processes but should also be embedded in-, and participate in ecosystems (Hayes et al., 2020).

Our main conclusion is that our definition of mimesis, as differentiation of a technological design beyond ecosystems, which at the same time remains embedded and participates in these ecosystems, helps to operationalizes RA as biomimetic technology. Although the fact remains that there are many empirically unfounded claims associated with RA, this outcome helps to provide RA with a stronger conceptual basis. At the same time, this conceptualization of biomimicry helps us to critique efforts both to imitate particular features or mechanisms of organisms and to invent features or mechanisms that are inspired by nature but are not embedded in ecosystems.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship and/or publication of this article.

ORCID iD

Bart Gremmen https://orcid.org/0000-0002-9652-6407

References

Aizenberg J (2012) *Extreme Biomimetics*. TED talk, You Tube, last accessed 20-10-2021

Aristotle (1980) *The Physics*. Trans P.H. Wicksteed and F.M. Cornford. Cambridge/London: Loeb Classical Library/ Harvard UP.

Aristotle (1995) *Poetics*. Trans W.H. Fyfe. Cambridge/London: Loeb Classical Library/Harvard UP.

Ball P (2001) Life's lessons in design. *Nature* 409: 413–416.

Bensaude-Vincent B, Arribart H, Bouligand Y, et al. (2002) Chemists and the school of nature. *New Journal of Chemistry* 26: 1–5.

Benyus JM (1997) *Biomimicry. Innovation Inspired by Nature*. New York: Harper Collins.

Blok V (2022) Technology as mimesis: Biomimicry as regenerative sustainable design, engineering, and technology. *Techné: Research in Philosophy and Technology*. In press.

Blok V and Gremmen B (2016) Ecological innovation: Biomimicry as a new way of thinking and acting ecologically. *Journal of Agricultural and Environmental Ethics* 29: 203–217.

Blok V and Gremmen B (2018) Agricultural technologies as living machines: Toward a biomimetic conceptualization of smart farming technologies. *Ethics, Policy & Environment* 21: 246–263.

Cohen-Shacham E, Walters G, Janzen C, et al. (2016) *Nature-based Solutions to Address Global Societal Challenges*. Gland, Switzerland: IUCN.

Cole RJ (2012) Transitioning from green to regenerative design. *Building Research and Information* 40: 39–53.

Dicks H (2017) The poetics of biomimicry: The contribution of poetic concepts to philosophical inquiry into the biomimetic principle of nature as model. *Environmental Philosophy* 14: 191–219.

Dougherty B (2019) Regenerative agriculture: The path to healing agroecosystems and feeding the world in the 21st century. *Nuffield International*, Nuffieldscholar.org.

Durkin L and McCue A (2021) Regenerative agriculture: Farming in nature's form. Available at: https://www.Metabolic., last accessed 19-10-2021

Forbes P (2005) *The Gecko's Foot: Bio-Inspiration Engineered from Nature*. London: Fourth Estate.

Giller K, Hijbeep R, Andersson J, et al. (2021) Regenerative agriculture: An agronomic perspective. *Outlook on Agriculture* 50: 13–26.

Glover JD, Reganold JP, Bell LW, et al. (2010) Increased food and ecosystem security via perennial grains. *Science (New York, N.Y.)* 328: 1638–1639.

Hayes S, Desha C and Baumeister D (2020) Learning from nature – Biomimicry innovation to support infrastructure sustainability and resilience. *Technological Forecasting & Social Change* 161. doi10.1016/j.techfore.2020.120287.

Jackson W (2011) *Nature as Measure: The Selected Essays of Wes Jackson*. Berkeley: Counterpoint.

Maes J and Jacobs S (2015) Nature-based solutions for Europe's sustainable development. *Conservation Letters* 10(1): 121–124.

Marshall A and Loveza S (2009) Questioning the theory and practice of biomimetics. *International Journal of Design & Nature and Ecodynamics* 1: 1–10.

Mathews F (2011) Towards a deeper philosophy of biomimicry. *Organization and Environment* 24(4): 364–387.

Miralles-Wilhelm F and Iseman T (2021) *Nature-based Solutions in Agriculture: The Case and Pathway for Adoption*. Virginia: FAO and The Nature Conservatoiry.

Mollison B (1988) *Permaculture A Designer' Manual*. Tyalgum: Tagari Publications.

Moore GE (1903) *Principia Ethica*. Cambridge: Cambridge University Press.

Ranganathan J, Waite R, Searchinger T, et al. (2020) Regenerative agriculture: good for soil health, but limited potential to mitigate climate change. Available at: https://www.wri.org

Rodale Institute (2014) *Regenerative Organic Agriculture and Climate Change: A Down-to-Earth Solution to Global Warming*. Kutztown, PA: Rodale Institute.

Saputra DD, Sari RR, Hairiah K, et al. (2020) Can cocoa agroforestry restore degraded soil structure following conversion from forest to agricultural use? *Agroforestry Systems* 94: 2261–2276.

Schyfter P (2012) Standing reserves of function: A heideggerian reading of synthetic biology. *Philosophy & Technology* 25: 199–219.

Stojanovic M (2019) Biomimicry in agriculture: Is the ecological system-design model the future agricultural paradigm? *Journal of Agricultural and Environmental Ethics* 32: 789–804.

Sumberg J (2022) Introduction to the OOA special issue Future agricultures: the promise and pitfalls of a turn to nature.

Todd J (2013) Living machines lecture. Available at: https://www.youtube.com/watch?v=wojrOpH5O7M (accessed 24 April 2016).

USDA (2015) Organic Practices Factsheet. Available at: https://www.ams.usda.gov/publications/content/introduction-organic-practices

Vincent J, Bogatyreva O, Bogatyreva N, et al. (2006) Biomimetics: Its practice and history. *Journal of the Royal Society Interface* 3: 471–482.