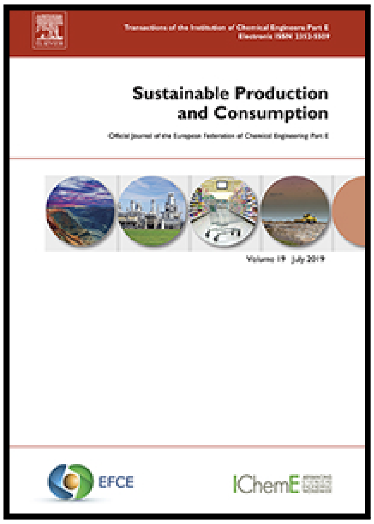
Editor: Adisa Azapagic

Journal Pre-proof



How to legally overcome the distinction between organic and conventional farming Governance approaches for sustainable farming on 100% of the land

Jessica Stubenrauch , Felix Ekardt , Katharine Heyl ,
Beatrice Garske , Valentina Louise Schott , Susanne Ober

PII: S2352-5509(21)00172-X
DOI: https://doi.org/10.1016/j.spc.2021.06.006
Reference: SPC 673

To appear in: *Sustainable Production and Consumption*

Received date: 29 March 2021
Revised date: 20 May 2021
Accepted date: 7 June 2021

Please cite this article as: Jessica Stubenrauch , Felix Ekardt , Katharine Heyl , Beatrice Garske , Valentina Louise Schott , Susanne Ober , How to legally overcome the distinction between organic and conventional farming Governance approaches for sustainable farming on 100% of the land, *Sustainable Production and Consumption* (2021), doi: https://doi.org/10.1016/j.spc.2021.06.006

Jessica Stubenrauch, Felix Ekardt, Katharine Heyl, Beatrice Garske, Valentina Louise Schott, Susanne Ober

How to legally overcome the distinction between organic and conventional farming

Governance approaches for sustainable farming on 100% of the land

How to legally overcome the distinction between organic and conventional farming

Governance approaches for sustainable farming on 100% of the land

Jessica Stubenrauch (corresponding author)
Research Unit Sustainability and Climate Policy,
Könneritzstr. 41, 04229 Leipzig, Germany
and
Helmholtz-Centre for Environmental Research,
Department Environmental and Planning Law
Permoserstr. 15, 04318 Leipzig, Germany
Email: jessica.stubenrauch@ufz.de

Felix Ekardt
Research Unit Sustainability and Climate Policy,
Könneritzstr. 41, 04229 Leipzig, Germany
and
University of Rostock
Faculty of Law, Interdisciplinary Faculty
Ulmenstraße 69, 18057 Rostock, Germany
Email: felix.ekardt@uni-rostock.de

Katharine Heyl
Research Unit Sustainability and Climate Policy,
Könneritzstr. 41, 04229 Leipzig, Germany
and
University of Rostock
Faculty of Agricultural and Environmental Sciences
Justus-von-Liebig-Weg 6, 18059 Rostock, Germany
Email: katharine.heyl@uni-rostock.de

Beatrice Garske
Research Unit Sustainability and Climate Policy,
Könneritzstr. 41, 04229 Leipzig, Germany
and
University of Rostock

Faculty of Agricultural and Environmental Sciences
Justus-von-Liebig-Weg 6, 18059 Rostock, Germany
Email: beatrice.garske@uni-rostock.de

Valentina Louise Schott
Research Unit Sustainability and Climate Policy,
Könneritzstr. 41, 04229 Leipzig, Germany
Email: valentina.schott@uni-erfurt.de

Susanne Ober
Research Unit Sustainability and Climate Policy,
Könneritzstr. 41, 04229 Leipzig, Germany
Email: susanne.ober@gmx.de

Abstract

Agricultural practices require a comprehensive transformation to preserve natural resources and secure high-quality food supply. Conventional and organic farming practices offer different pathways to further develop the sector. In particular, blending organic and conventional practices appears to be a promising pathway. However, proposals for implementing the latter are widely missing. This article addresses this research gap. The article applies a qualitative governance analysis and develops a legal framework to enable the transformation of the agricultural sector. The European Union serves as example. The analysis finds that existing provisions for organic farming provide important benchmarks but require amendments. Precisely, the restriction of external inputs, including permitted fertiliser application and pest control, needs to be slightly softened to achieve long-term yield stability. In contrast, organic provisions on livestock densities require tightening in order to meet international environmental targets set by the Paris Agreement and the Convention on Biological Diversity. In doing so, the article not only proposes a forward-looking governance approach to organic farming, but develops a legally binding regulatory framework valid to all farmers in the EU. As a consequence, the distinction between organic and conventional farming could be finally overcome, and the agricultural sector could be transformed to be truly sustainable.

Keywords

organic farming; Paris Agreement; Convention on Biological Diversity; agricultural policy, sustainability, governance

1. Introduction

Climate change and global biodiversity loss require sustainable food production. Simultaneously, sustainable food production needs to feed a growing population. In fact, conventional agricultural food production in the second half of the last century sharply increased crop production through increasing yields, and improved access to food for many (Evenson & Gollin, 2003; Pingali, 2012). However, sustainable food production must also comply with global environmental goals. Precisely, the Paris Agreement (PA) requires cutting down greenhouse gas (GHG) emissions in all economic sectors (UNFCCC, 2015) and the Convention on Biological Diversity (CBD) to stop global biodiversity loss (UN, 1992). Yet, by emitting 17% of global GHGs, the agricultural sector contributes significantly to climate change (FAO, 2020a). The whole food sector, including fertiliser production and contribution of food, accounts for even more than 30% (Crippa et al., 2021). Within the sector, two-thirds of the GHG emissions stem from livestock production (FAO, 2020b). Moreover, intensive (livestock) farming systems cause indirect land-use changes at the expense of biodiversity rich ecosystems which result in highly degraded terrestrial and aquatic ecosystems (Garrett et al., 2018; Leip et al., 2015; Prăvălie et al., 2021).

Conventional agricultural systems appear to affect ecosystems negatively (Agovino et al., 2019; Clark et al., 2020; Hedenus et al., 2014). At the same time, pressure on conventional farming systems, based on the use of mineral/synthetic fertilisers and pesticides, increases. Pressure arises not only due to water scarcity, extreme weather events or growing pesticide resistance, but also due to globally rising scarcity of resources and, in many cases, already degraded agricultural land (Houser and Stuart, 2020; Prăvălie et al., 2021; Techen and Helming, 2017). Here, organic farming practices offer an alternative approach. Precisely, organic farming can contribute to environmental protection and resource conservation. The advantages of organic farming include the preservation of natural soil fertility, better protection of adjacent aquatic ecosystems and lower ecotoxicology as well as positive effects on the soil's carbon sequestration potential, and higher on-farm diversity (Clark and Tilman, 2017; Eyhorn et al., 2019; Seufert and Ramankutty, 2017). Besides, organic farming is frequently less energy-intensive due to the restriction of external inputs to a potential minimum (Liu and Gu, 2016).

However, organic farming practices have shortcomings too. Depending on the organic farming system, the long-term supply of nutrient to the plants is limited. This applies in particular to phosphorus (P), but also potassium (K) and nitrogen (N) (Badgley et al., 2007; Jarosch et al., 2017; Ohm et al., 2017). As a consequence, yields can vary depending on the crop and site-specific characteristics, and a yield gap compared to conventional farming can be observed (de Ponti et al., 2012; Röös et al., 2018; Schrama et al., 2018). In fact, when adopting a yield-scaled approach, the GHG emissions as well as the eutrophication and acidification potential of organic farming perform frequently worse than conventional practices (L. G. Smith et al., 2019; Tuomisto et al., 2012). At the same time, research shows that yield-scaled cumulated N_2O emissions appear to be similar between organic and conventional systems due to other major influence factors such as soil pH, soil organic carbon content and microbial soil activity (Skinner et al., 2019).

However, as long as a yield gap exists, demand for scarce agricultural land will increase when increasing the share of organic farming. Yet, this development assumes that demand patterns, especially for animal derived products, remain unchanged. Currently, 70-85% of the world's agricultural land is used for animal food production (Poore and Nemecek, 2018). However, the PA and CBD require a reduction in global meat production by probably far more than half (Hedenus et al., 2014; Springmann et al., 2018; Weishaupt et al., 2020; Willett et al., 2019). Thus, reducing the consumption of animal-derived products by pursuing sufficiency approaches is expected to limit total global land use. A parallel increase in land use for the conversion to organic farming therefore most likely appears to be uncritical. Besides, the conflict over increased land use could be further defused if the yield gap was overcome.

Therefore, one aim of this paper is to elaborate the potential to further develop the organic farming approach of the European Union (EU). Although the sector is overall growing, organic farming still maintains a niche existence with a share of only 1% of agricultural land globally and 8.5% in the European Union (EU) -(EUROSTAT, 2021; Meemken and Qaim, 2018; Willer et al., 2020). According to the EU's Farm to Fork Strategy, the share of agricultural area under organic farming should reach 25% by 2030 (EU Commission, 2020a). To this end, farmers are expected to receive support in organic production and processing (push). At the same time, the corresponsive organic farming action plan envisages measures to increase the demand for organic products, for example by integrating them in school meals and workplace canteens (pull) (EU Commission, 2021).

Overall, the paper aims to answer the question as to how organic farming regulations need to be developed to, for example, overcome imminent nutrient supply shortages and face today's agricultural challenges successfully and how this could be transferred to an overarching legal framework valid to all farmers in Europe. This is done by considering the limitations of the organic farming sector and the future challenges in the agricultural sector as outlined in section 2. Section 3 describes the methodology of the paper. The qualitative governance analysis applied in section 4.1 firstly discusses an amendment of the legal framework of organic farming. It inter alia incorporates major factors which influence the yield gap such as the strict limitation of external inputs. In continuation, section 4.2 discusses a potential extension of the amended regulatory framework to all farmers. The discussion includes legal barriers that hinder overall sustainable agricultural practices in the EU, and outlines potential legal starting points to overcome the dichotomy between conventional and organic farming systems. This would create overall sustainable agricultural practices being a 'blend of organic and other innovative farming systems' (Garibaldi et al., 2017; Reganold and Wachter, 2016; Seufert et al., 2012).

Thus far, scientific policy analyses regularly appear to be locked in the strict separation between organic and conventional farming, without truly considering an approach which merges the two systems (Galli et al., 2020; Pe'er et al., 2020; Reganold and Wachter, 2016). At best, studies propose a 'third way for European agriculture' (Morris and Winter, 1999), as in the case of integrated farming systems (Edwards et al., 1993; Morris and Winter, 1999; Wijnands et al., 2018). Integrated farming systems are based on the sustainable use of natural resources and seek to replace potentially polluting inputs (Wijnands et al., 2018). However, while integrated farming systems combine many valuable sustainable farming practices, necessary regulatory amendments to implement the approach are still missing. This paper seeks to address this research gap.

2. Background

The agricultural sector faces three challenges: Firstly, in line with the PA, the agricultural sector has to reduce its GHG emissions to a minimum within a maximum of two decades (Ekardt et al., 2018; IPCC, 2019; Rockström et al., 2017) and at the same time, enhance its natural sink capacities in order to compensate for residual emissions (IPCC, 2019; Wieding et al., 2020). Secondly, agriculture needs to contribute to halting and reversing biodiversity loss (which is closely related with climate change) in accordance with the CBD – rather than harming biodiversity. Thirdly, yield stability has to be achieved to secure world nutrition to guarantee the right to food as set out inter alia in Art. 11 of the International Covenant on Economic, Social and Cultural Rights (UN, 1976) as well as Art. 2, 3 and 6 of the Charter of Fundamental Rights of the European Union (Ekardt and Hyla, 2017; OJEU, 2012).

These challenges call a number of agricultural practices and structures into question:

- The regular usage of mineral P and synthetic N fertilisers can negatively affect soil organic matter and soil health, and pose potential threats to adjacent ecosystems by leaking nutrients (Heinze et al., 2010; Maltas et al., 2018). Apart from that, the production of synthetic N fertilisers is highly energy-intensive. Therefore, the production can hardly be maintained on an equal level when being based on renewable energy resources in the future (Kyriakou et al., 2020; Smith et al., 2020; Tallaksen et al., 2015). Additionally, remaining phosphate rock reserves are increasingly polluted with heavy metals like cadmium and uranium. This poses a risk for soils, plants, animals, and humans. Furthermore, mineral P has to be transported over large distances and the production of every ton mineral P fertiliser (measured in phosphorus pentoxide (P_2O_5)) causes on average 5 tons of radioactive and toxic phosphogypsum (Garske and Ekardt, 2021; Sarvajayakesavalu et al., 2018; Stubenrauch et al., 2018).
- The frequent use of chemical pesticides can be harmful. Pesticides contribute as an additional stressor (next to habitat loss, climate change, fertiliser inputs, introduced species) to a decline in terrestrial and aquatic biodiversity (Brühl and Zaller, 2019; Geiger et al., 2010; Hallmann et al., 2017). Evidence from Europe also reveals that regular use of insecticides and fungicides has a consistently negative effect on biodiversity, that can only be overcome if an EU-wide shift towards a minimal usage of pesticides takes places in large areas (Beketov et al., 2013; Geiger et al., 2010).
- Intensive animal farming is another major threat to ecosystem biodiversity and climate and conflicts with sustainable agriculture (Buckwell and Nadeu, 2018; Ekardt et al., 2018; IPBES, 2019). Livestock production is responsible for a high amount of GHG emissions, nutrient hotspots causing eutrophication and indirect land-use changes for fodder production (Bajželj et al., 2014; Benton et al., 2021; Mueller and Lassaletta, 2020; Weishaupt et al., 2020).

These above-mentioned issues challenge conventional as well as organic farming systems in distinct ways. Firstly, livestock numbers need to be drastically reduced (see also section 1). Yet, minimising livestock farming and simultaneously phasing out fossil fuels will decrease the availability of fertilisers. Thus, creating closed nutrient cycles might be hampered because of too little animal-derived organic fertilisers and mineral/synthetic fertilisers. Therefore, strengthened nutrient recycling and the implementation of a circular economy approach based on renewable energies will be necessary (Nesme and Withers, 2016; Robles et al., 2020). However, neither conventional nor organic farming implement circular economy sufficiently to date, especially with regard to recovering nutrients from wastewater and further municipal waste streams (Robles et al., 2020). Nutrient flowback from society is extremely low in organic farming. It is estimated that only 2% of the nutrient supply is generated back from society (Nowak et al., 2013). Increasing this share could not only address this shortage but could also contribute to reduce the yield gap between organic and conventional farming. This is because the yield gap is rooted in nutrient supply shortages, next to the ban on pesticides and especially affects arable organic farms without livestock (de Ponti et al., 2012; Ottman et al., 2000; Seufert et al., 2012). The circular economy concept, however, generally calls for a better integration of crop and livestock production (Martin et al., 2016; Mueller and Lassaletta, 2020) and the increased usage of recycled fertilisers from urban waste streams (Reimer et al., 2020; Röös et al., 2018; O. M. Smith et al., 2019).

Secondly, evidence shows that further diversification in farming practices can enhance yield stability and significantly reduce the yield gap (Ponisio et al., 2015; Raseduzzaman and Jensen, 2017), particularly if combined with no-tillage agriculture. Yet, no-tillage agriculture is not mandatory in organic farming thus far (Henneron et al., 2015; Nunes et al., 2018; Yadav et al., 2019). Besides, diversified crop rotations including a high variety of cover and catch crops such as legumes, as well as green and organic fertilisers can positively affect soil health, soil organic matter and microbial life and as a side-effect strengthen natural pest control (Birkhofer et al., 2008; Gentsch et al., 2020; Kumar et al., 2018; Lichtenberg et al., 2017).

Thirdly, more importance should be given to maintaining or strengthening ecosystem services – although organic farming already incorporates this dimension into their practice (Bommarco et al., 2018; Ewel et al., 2019; Philip Robertson et al., 2014). Evidence shows that in many conventional farming systems soil organic matter and thus soil quality and fertility decrease (Lal, 2004). Yet, by weakening these ecosystem processes, they undermine long-term yield stability. This is why under less favourable conditions like water stress, degraded and compacted soils in development countries, organic farming already achieves equal or even higher yields compared to conventional farming (UNEP-UNCTAD, 2008; Wilbois and Schmidt, 2019). The yield gap of organic farms might therefore be even surpassed in the future. This is because organic farming creates higher resilience through additional ecosystem services as one component of a multifunctional agriculture (Barot et al., 2017; Zhang et al., 2007). By maintaining soil fertility, a better regulation of water cycle and of diseases and pest control, agricultural production will then be better capable to withstand challenging and changing environmental conditions and mitigate climate change (Bennet et al., 2014; Darnhofer et al., 2010; Diserens et al., 2018). This is why the maintenance or strengthening of ecosystem services should also be better emphasized in agriculture in general (Bommarco et al., 2018; Ewel et al., 2019; Philip Robertson et al., 2014).

Last but not least, precision farming and digitalisation may help to further increase efficiency in agricultural resource use (Dalezios et al., 2019; EU Commission, 2019; Finger et al., 2019). However, it is important to not consider possibilities of digitalisation as a substitute for necessary system re-design and adaptation in the agriculture sector as described above (Garske et al., 2021).

Altogether, innovative farming practices like minimised and at the same time better integrated livestock farming, enhanced diversification, no-tillage farming and precision agriculture combined with enhanced nutrient recycling could mark a breakthrough to ensure high yield stability and to move towards resource-efficient and sustainable agriculture (Möller et al., 2018; Reimer et al., 2020; O. M. Smith et al., 2019).

3. Methods

This article contributes to the interdisciplinary sustainability research focusing on agricultural governance. The article applies a qualitative governance analysis (or steering analysis). Since the EU as supranational organisation provides one of the most detailed legislation on agriculture, EU legislation is used as an example. The qualitative governance analysis triangulates findings from a wide variety of disciplinary and methodological backgrounds (Ekardt, 2019; Garske and Ekardt, 2021) (see figure 1). The method requires (1) a comprehensive understanding of the natural environment to answer the question how to shape sustainable farming systems in a post-fossil world, (2) an understanding of human behaviour to determine how to design effective policy instruments to achieve (environmental) targets and (3) based on (2), the awareness of typically recurring governance problems that have to be circumvented. Prominent governance problems in agriculture include rebound and shifting effects (geographical and sectoral), poor target stringency as well as problems of enforcement and depicting (Ekardt, 2019; Paul et al., 2019; van den Berg et al., 2020). To avoid shifting effects to other countries or sectors, policy instruments should be implemented on a preferably broad geographical scale, which further supports an investigation at EU level. However, the basic findings on the necessary design and combination of policy instruments can also be applied to other regions of the world.

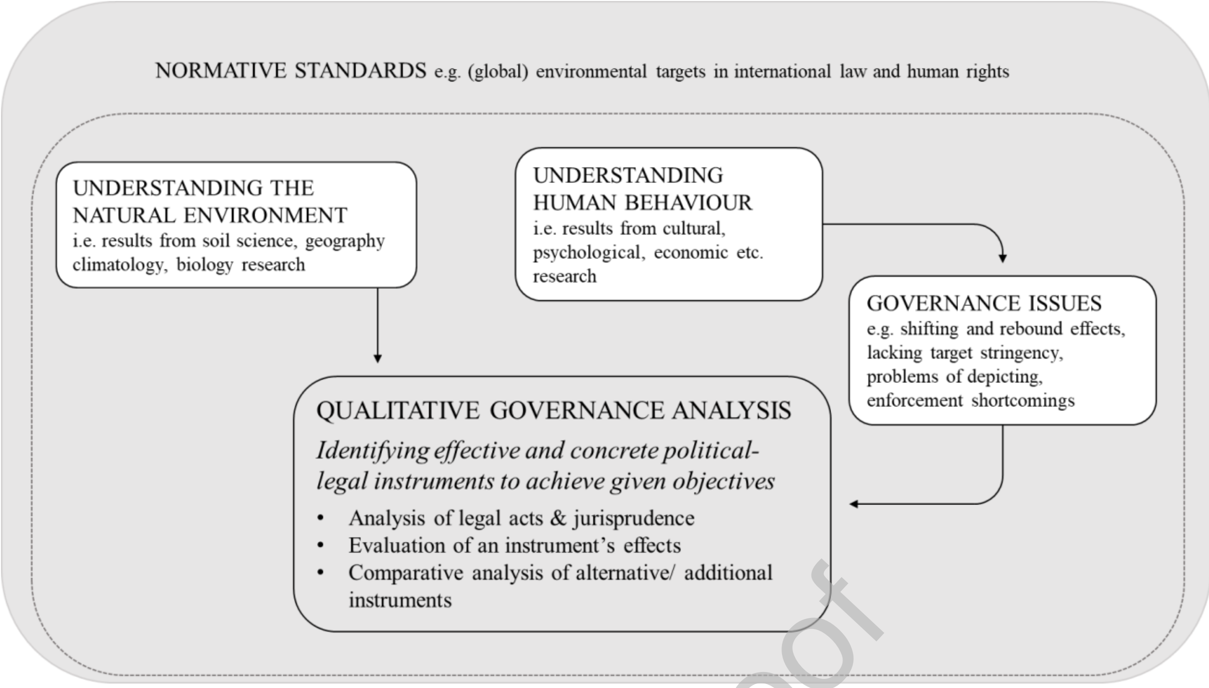


Figure 1: Elements of a qualitative governance analysis (own graphic)

In the qualitative governance analysis, the effectiveness of existing policy instruments and potential alternative policy instruments is assessed against normative standards. In the present study, these normative standards include the human right to food as well as the legally binding environmental targets established in Art. 2 para. 1 PA that aims at halting global temperature increase to well below 2 °C and pursuing efforts to reach 1.5 °C and the CBD. The Strategic Goals A and B of the CBD's Aichi targets aim to address the underlying causes of biodiversity loss and reduce direct pressures by promoting sustainable land use (Aichi target 7).

The advantages of the qualitative governance analysis are that it constantly reviews the effectiveness of policy instruments in relation to overarching international targets and thereby avoids expectable governance problems. In doing so, this method omits 'ostensible solutions', that for example simply shift existing problems to other world regions or sectors and are not in line with global environmental targets in the long-term. It furthermore enables including important indicators to comprehensively assess the impacts of agriculture on the environment – which most life cycles assessments fail to do (van der Werf, 2020).

Precisely, the current governance analysis seeks to answer the question as to how legislation in the organic farming sector and the agricultural sector in general could respond to the immanent challenges outlined in section 2. Thus, based on this scientific background, the article assesses chosen principles and production rules of the organic farming regulation against their ability to (a) respond to identified shortcomings of the organic farming sector and (b) to contribute to the targets of the PA and CBD in the long-term. Particularly, it is elaborated whether there is a need to conditionally soften or strengthen the EU's organic farming regulation, and proposals for their amendment are introduced (section 4.1). In a second step, the governance analysis aims to determine how existing command-and-control legislation as well as subsidy schemes such as the EU's Common Agricultural Policy – which is applicable to all farmers – could benefit from adopting specific 'organic' regulations.

Necessary adaptation of existing EU regulations and the need for newly developed policy instruments will be pointed out. In this context, the analysis also incorporates the objectives of the EU Farm to Fork Strategy as key element of the EU Green Deal, as well as their potential legal implementation (EU Commission, 2020a). The governance analysis concludes with a discussion on the extent to which promising regulatory measures can be extended to apply to the entire agricultural sector (section 4.2).

4. Results and discussion

4.1 The objectives and principles of organic farming – critical assessment

In the EU, the objectives and principles of organic farming are laid down in Regulation (EU) 2018/848 (OJEU, 2018) that will enter into force in January 2022, replacing Regulation (EC) 834/2007 (OJEC, 2007), and the implementing Regulation (EC) No 889/2008 (OJEC, 2008).

Building on the scientific knowledge summarised in section 2, the most important objectives, principles and production rules of organic farming are listed in Table 1. Although those objectives correspond well to the aforementioned challenges, they require further tightening (highlighted green) and softening (highlighted red).

Table 1: Selected objectives, principles and production rules of organic farming (Regulation (EU) 2018/484)

Objectives of Article 4 a-f
(1) contribute to the protection of environment and climate, a high level of biodiversity, a non-toxic environment, high animal welfare standards
(2) maintain long-term fertility of soils
(3) encourage short distribution channels and local production
General principles
(1) limiting the use of non-renewable resources and external inputs to a minimum (Art. 6 b)
(2) recycling wastes and by-products of plant and animal origin as input in plant and livestock production (Art. 6 c)
(3) maintaining plant health by preventive measures (Art. 6 d)
(4) continuing health of the aquatic environment and the quality of surrounding aquatic and terrestrial ecosystems (Art. 6 o)

General principle / production rules on soil fertility
(1) maintaining and enhancing soil life and natural soil fertility, soil stability, soil water retention and soil biodiversity; preventing and combating loss of soil organic matter, soil compaction and soil erosion; nourishing plants primarily through the soil ecosystem (Art. 6 a)
(2) maintaining and increasing fertility and biological activity of the soil by using multiannual crop rotation including mandatory leguminous crops as the main or cover crop for rotating crops and other green manure crops (Annex II, Part I, No 1.9.2 a)
(3) limiting external inputs, inter alia, to low solubility mineral fertilisers (Art. 5 g (i), (iii)) and banning mineral (meaning synthetic) nitrogen fertilisers (Annex II Part I, No 1.9.8)
General principles / production rules on pest and weed control
(1) limiting external inputs to natural or naturally-derived substances (Art. 5 g (i))
(2) preventing damage caused by pests and weeds primarily through the protection by natural enemies, choice of species, varieties and heterogeneous material, crop rotation, cultivation techniques and thermal processes (Annex II, Part I, No 1.10.1)
General principles / production rules on livestock farming
(1) adopting soil-related crop cultivation and land-related as well as site-adapted livestock production (Art. 5 f (ii) in conjunction with Art. 6 k)
(2) obtaining feed for livestock primarily from the agricultural holding where animals are kept or from organic units belonging to other holdings in the same region (Annex II, Part II, No 1.4.1 a)
(3) having a maximum total stocking density and total amount of livestock manure of 170 kg of nitrogen per year/hectare of agricultural area used (Annex II, Part I, No 1.9.4, Part II, No 1.6.6)
(4) limiting the number of livestock to minimise overgrazing, poaching of soil, erosion, and pollution caused by animals or by the spreading of their manure (Annex II, Part II, No 1.7.4)

The concrete amendment requirements of the status quo of the organic farming legislation are as follows:

Firstly, the recycling principle of Art. 6 c Regulation (EU) 2018/484 requires an expansion. ‘The recycling of wastes and by-products of plant and animal origin’ should be expanded to include ‘*human origin*’. This would incorporate valuable urban organic waste and wastewater- based residues into the recycling principle paving the way to ensure better cycling of nutrients (Möller et al., 2018; Weissengruber et al., 2018). Besides, the regulation could be based on a ‘pollutant-to-nutrient ratio’ (Weissengruber et al., 2018) to effectively hinder soil contamination by high-quality fertiliser products. Newly developed bio-fertilisers in combination with proven principles of green manuring have the potential to additionally contribute to enhanced carbon sequestration (Diacono et al., 2019).

Secondly, the restriction of using external inputs to low solubility mineral fertilisers has to be reconsidered.

- P fertilising: Thus far, the positive list of Annex I of Regulation (EC) 889/2008 enables the application of, inter alia, low solubility soft ground rock phosphate. However, these fertilisers may contain up to 90 milligram of cadmium per kilogram phosphate (mg Cd/kg P_2O_5). This limit value even exceeds the (still relatively high) limit value in conventional agriculture (60 mg Cd/kg P_2O_5). It does not protect soils against pollutants (OJEU, 2019). At the same time, the list lacks high-quality recycled P fertilisers like struvite from waste water or other innovative fertilisers like sulfur-enriched bone char, which frequently a have a high plant P availability comparable to conventional mineral or synthetic fertilisers (Hukari et al., 2016; Möller et al., 2018; Zimmer et al., 2019). These fertilisers can therefore not be used to prevent P nutrient shortages in organic farming even if they would contribute significantly to implementing the circular economy approach and closing the yield gap.
- N fertilising: It is worth discussing whether the general prohibition of all synthetic N fertilisers is reasonable or whether, in exceptional cases, fast-dissolving synthetic N fertilisers based on renewable energies could be approved for application in organic farming. At the same time, legume crop cultivation offers an alternative way to supply N to plants – in contrast to P supply (Mahmud et al., 2020; Röös et al., 2020; Signorelli et al., 2020). Therefore, this regulatory extension appears to be less urgent but could nevertheless be useful to ensure yield stability (Barbieri et al., 2021) if the overarching principles of organic farming are kept up. Besides, this extension would establish a broad basis for the precise application of N fertilisers to avoid supply shortages and environmental harmful overfertilisation (Rütting et al., 2018).

Consequently, it appears useful to extend the positive list to include (a) high-quality recycled P fertilisers (see also Möller et al., 2018), and (b) synthetic N fertilisers based on renewable energies. Even if the latter would represent a deviation from the hitherto established principles of organic farming (Watson et al., 2008), such an extension seems appropriate to prevent P and N deficiencies in exceptional cases. This would address one major reason of the differing yield gaps in organic and conventional agriculture (de Ponti et al., 2012; Ottman et al., 2000; Seufert et al., 2012). Besides, enabling the application of high-quality P fertilisers as well as renewable synthetic N fertilisers would bring organic and conventional farming closer together.

Thirdly, the question arises if the general ban on chemical pesticides in organic farming should be softened. Under certain precisely defined circumstances, where there is an exceptional high threat to the harvest from pests and weeds or where using precisely metered small quantities could have less negative impact on the ecosystem than potential alternatives, individual chemical substances could be authorised in addition to existing measures. McGuire (2017) emphasises that 'specific uses and rates […] can be the best solution to specific agricultural problems' and that a complete rejection of pesticides in organic farming is an ideological question that should be overcome (McGuire, 2017). However, other measures like diverse crop management and natural pest controls always have to be prioritised (Blundell et al., 2020; Brzozowski and Mazourek, 2018). In turn, exemption clauses could apply to, for example, extreme weather events causing extraordinary pest infestation or plant diseases (Deutsch et al., 2018; Fand et al., 2018; Savary et al., 2019). Enabling the application of certain pesticides under specific and clearly defined circumstances can then also contribute to stabilising yields in the long-term, especially against the background of aggravated production conditions due to climate change (Ahanger et al., 2013; Juroszek et al., 2020).

Finally, the livestock stocking densities of the organic regulations require further tightening. So far, specific stocking densities are laid down in Annex VI of the implementing Regulation (EC) 889/2008 in accordance with the Nitrates Directive 91/676/EEC (European Commission, 1991). This provision is legally binding for all farms. However, considering the climate target of the PA, this livestock density might not achieve a sufficient reduction in animal numbers (Weishaupt et al., 2020; Ekardt, 2019). Therefore, an additional regulation in line with climate and biodiversity targets and applicable to all farms appears useful (see section 4.2). At the same time, Regulation (EU) No 848/2018 establishes that in the future responsible authorities will determine livestock numbers for organic farming (Annex II Part II 1.6.6 and 1.6.7 Regulation (EU) No 848/2018). It therefore depends on the local authorities whether site-adapted animal husbandry takes place. However, stricter overall restrictions are not yet foreseen.

4.2 Discussion and key findings– is an adapted organic approach transferable to all farms?

Should the objectives and modified principles and production rules of organic farming be valid for all farms in Europe? Are there any legal developments which point in that direction? The objectives and the general principles in Table 1, including comprehensive waste recycling from all sources as well as a livestock-to-land ratio in line with international climate and biodiversity targets, are necessary to effectively address the challenges in the agricultural sector (section 2). Legally, these measures could be incorporated in an overarching EU-wide agricultural legislation or an EU soil protection legislation, or a reformed fertiliser legislation. However, none of these legal initiatives thus far exists. Still, the EU Biodiversity Strategy establishes the framework for the development of a new EU Soil Strategy (EU Commission, 2020b) which is a welcome initiative although still a rather small step forward compared to the legally binding Soil Framework Directive that was withdrawn in 2014 (Chen, 2019; Commission (EU), 2006; Paleari, 2017).

In addition to these soil provisions, the whole livestock sector requires amended measures. However, a stricter livestock-to-land ratio alone might not prevent rebound effects. In fact, in total, more animals could be kept on an increasing number of farms. Besides, heterogeneous emission values of different animals make it administratively very challenging to implement an area commitment in line with climate targets (Weishaupt et al., 2020). Therefore, a separate EU emissions trading scheme (ETS) that limits animal products in accordance with the 1.5 °C temperature limit appears useful to effectively reduce the overall number of animals (Weishaupt et al., 2020; Ekardt et al., 2018). This ETS could target the processing companies (slaughterhouses and dairies) to keep the number of addressees and the transaction costs manageable. The ETS could furthermore be complemented by a livestock-to-land ratio in line with biodiversity targets as minimum standard to avoid nutrient hotspots (EU Commission, 2021, p. 21; Leip et al., 2010; Sampat et al., 2021).

Provisions on plant protection that allow pesticides use in exceptional cases only and instead strengthen diversification and natural pest management could be enshrined in the future EU plant protection legislation. When adopting a benevolent view, the EU Chemicals Strategy for Sustainability Towards a Toxic-Free Environment points in the right direction (EU Commission, 2020b). The strategy aims to ban all harmful chemicals unless their use is 'proven essential'. However, the strategies' focus on pesticide use is on strengthening synergistic effects and adapting maximum residue levels of pesticides under the Regulation on Plant Protection Products (EU Commission, 2020b, p. 12). Besides, the EU Farm to Fork Strategy aims to reduce the overall use and risks of chemical and hazardous pesticides by 50% by 2030 and promote integrated pest management. Thus far, however, the EU's plant protection legislation is far from being adapted to the current goals of the Farm to Fork Strategy and even further away from an approach that prohibits pesticides use as a standard agricultural practice in general (EU Commission, 2017; Storck et al., 2017).

Fertiliser provisions also require amendments. The promotion of organic and recycled fertilisers – combined with the phasing out of mineral/synthetic fertilisers not based on renewable resources – could be achieved by integrating all fossil fuels into the existing EU ETS. In fact, the necessary decarbonisation of fertiliser use is often overlooked, yet indispensable in a post-fossil world (Bocklet et al., 2019; Garske and Ekardt, 2021; Houser and Stuart, 2020). Besides, the promotion of innovative fertilisers based on renewable energies requires an amendment of the EU Fertilising Products Regulation (EU) 2019/1009 (OJEU, 2019). Albeit the regulation now covers organic and recycled fertilisers from secondary raw materials, it also keeps up the parallel markets of fertilisers. Provisions neither clearly support organic, recycled or other innovative fertilisers, nor limit or prohibit fertilisers that are not based on renewable resources (Garske et al., 2020; Stubenrauch, 2019). Apart from that, the Farm to Fork Strategy aims to reduce nutrient losses by at least 50% and the use of fertilisers by at least 20% by 2030 (EU Commission, 2020a). According to an earlier statement of the EU Commission, 30% of mineral/synthetic fertilisers shall be replaced by recycled nutrients (EU Commission, 2018). These targets need therefore (a) to be legally binding and implemented and (b) be reinforced after 2030.

Finally, the subsidy scheme of the Common Agricultural Policy (CAP) should promote and financially support a change in the agricultural sector. The CAP is the central policy instrument for the agricultural sector of the EU and should therefore encourage the discussed objectives, principles and production rules derived from the organic farming approach. Although ETS approaches on livestock products, fossil fuels and maybe also pesticides would already contribute significantly to reaching the PA and CBD targets, subsidy schemes that provide direct income support for farmers like the CAP also have to be clearly aligned with these targets. However, according to the draft regulations for the CAP after 2023 (EU Commission, 2018a; Fortuna G, 2020) such strict alignment with the PA and the CBD is missing (Heyl et al., 2020; Pe'er et al., 2020). In fact, the objectives laid down in Art. 6 of the CAP proposal (EU Commission, 2018a) are neither specific enough nor translatable into quantified targets. A 'race to the bottom' concerning environmental standards might even occur, as Member States are given higher sovereignty in implementing the CAP (Court of Auditors, 2018; Heyl et al., 2020). Generally, CAP subsidies are expected to be paid under the present two-pillar approach, divided in mainly hectare-based payments under the first pillar (market support) and support for rural management under the second pillar (EU Commission, 2018a; Heyl et al., 2020). To receive direct payments, farmers have to comply with statutory management requirements (SMRs) and standards for good agricultural and environmental conditions (GAECs) forming the new 'conditionality' (EU Commission, 2018a). GAEC 7 and GAEC 8 require no bare soil in most sensitive periods and crop rotations, thus stimulating diversified farming (EU Commission, 2018b). Apart from that, farmers can participate in eco-schemes. Eco-schemes aim to strengthen the environmental performance of the CAP and should be used to foster organic farming. Currently, only 1.8 % of the CAP support organic farming (EU Commission, 2021, p. 11). However, eco-schemes will most likely only receive a very limited budget (20% or a maximum of 30% of total first pillar funding) (EU Commission, 2021; Röder and Matthews, 2021). In contrast, the interventions for rural development of the second pillar go beyond minimum requirements and include inter alia environmental, climate and other management commitments (Art. 64 CAP proposal). Yet, the second pillar struggles with chronic underfunding, and the CAP fails to sufficiently incorporate the targets of the Farm to Form Strategy (Guyomard et al., 2020). Therefore, a comprehensive revision is essential to give 'an accountable transformational perspective' (Zagaria et al., 2021) to farmers and accelerate the needed transition. Whether or to what extent agricultural subsidies, e.g., in the EU should be abolished after a transitional period to, inter alia, avoid market distorting effects on third countries, remains an open research question.

5. Conclusion

The future challenges in the agricultural sector are immense. Protecting climate and biodiversity, closing nutrient cycles with sharply minimised livestock farming, and achieving high yields in resilient agricultural systems require further developing organic and conventional farming. Importantly, any future political initiative related to the agricultural sector has to consider the long-term climate and biodiversity goals. This inevitably implies converging the two farming approaches. The organic farming legislation already provides important starting points. Slightly softening provisions on the strict limitation of external inputs while tightening provisions in livestock farming appear promising instruments to move the entire sector towards a sustainable transformation.

Besides, overarching legal instruments necessary from a climate and biodiversity perspective include: one ETS that phases out fossil fuels within a maximum of two decades and a second ETS for animal products that would align the number of animals with the climate target and at the same time be beneficial for biodiversity. Both instruments would affect all sectors including agriculture very strongly, especially when combined with a pesticide reduction strategy (maybe also done by a cap-and-trade approach). Going beyond such comprehensive instruments, the article pointed out specific ways to adapt the organic approach and the regulatory framework on EU level valid for all farmers. Besides an alignment with the PA and the CBD, fostering the circular economy approach through a highly diversified agriculture securing the nutrient flow-back from diverse waste streams and waste waters was identified as a core element of a more sustainable agriculture. On EU level, this requires a thoroughly adaptation of existing command-and-control legislation in the field of agricultural and environmental law, the development of suitable economic policy instruments to clearly minimise critical resource use and a reshaping of the CAP. This does not only ensure a simple minimisation and substitution of resources, but a continuous improvement of farming practices.

Future research should focus on overcoming nutrient supply shortages without relying on fossil-fuel based fertilisers, and pest management strategies in favour of biodiversity protection. Besides, research will have to further discuss how those measures can be brought from science to practice by appropriate legal instruments.

CRediT authorship contribution statement:

Jessica Stubenrauch: Conceptualization, Writing - Original draft preparation **Felix Ekardt:** Methodology, Writing - Review & Editing **Katharine Heyl**: Writing – Review & Editing **Beatrice Garske:** Writing - Review & Editing **Valentina Louise Schott:** Investigation **Susanne Ober:** Investigation

Funding:

This work was supported by the German Federal Ministry of Education and Research (BMBF), funding the BonaRes project InnoSoilPhos (No. 031B0509) and partly by the Helmholtz-Centre for Environmental Research, Leipzig. This research was also performed within the scope of the Leibniz ScienceCampus Phosphorus Research Rostock.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Agovino, M., Casaccia, M., Ciommi, M., Ferrara, M., Marchesano, K., 2019. Agriculture, climate change and sustainability: The case of EU-28. Ecol. Indic. 105, 525–543. https://doi.org/10.1016/j.ecolind.2018.04.064.

Ahanger, R., Bhat, H., Bhat, Tauseef, Ganie, S., Lone, A., Wani, I., Ganai, D., Haq, S., Khan, O., Junaid, J., Bhat, Tariq, 2013. Impact of Climate Change on Plant Diseases 2013, 105–115.

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M.J., Avilés-Vázquez, K., Samulon, A., Perfecto, I., 2007. Organic agriculture and the global food supply. Renew. Agric. Food Syst. 22, 86–108. https://doi.org/10.1017/S1742170507001640.

Bajželj, B., Richards, K.S., Allwood, J.M., Smith, P., Dennis, J.S., Curmi, E., Gilligan, C.A., 2014. Importance of food-demand management for climate mitigation. Nat. Clim. Change 4, 924–929. https://doi.org/10.1038/nclimate2353.

Barbieri, P., Pellerin, S., Seufert, V., Smith, L., Ramankutty, N., Nesme, T., 2021. Global option space for organic agriculture is delimited by nitrogen availability. Nat. Food. https://doi.org/10.1038/s43016-021-00276-y.

Barot, S., Allard, V., Cantarel, A., Enjalbert, J., Gauffreteau, A., Goldringer, I., Lata, J.-C., Le Roux, X., Niboyet, A., Porcher, E., 2017. Designing mixtures of varieties for multifunctional agriculture with the help of ecology. A review. Agron. Sustain. Dev. 37, 13. https://doi.org/10.1007/s13593-017-0418-x.

Beketov, M.A., Kefford, B.J., Schäfer, R.B., Liess, M., 2013. Pesticides reduce regional biodiversity of stream invertebrates. Proc. Natl. Acad. Sci. U. S. A. 110, 11039–11043. https://doi.org/10.1073/pnas.1305618110.

Bennet, E., Carpenter, S.R., Gordon, L.J., Ramankutty, N., Balvanera, P., Campbell, B.M., Cramer, W., Foley, J., Folke, C., Karlberg, J., Liu, J., Lotze-Campen, H., Mueller, N., Peterson, G., Polasky, S., Rockström, J., Scholes, R., Spierenburg, M.J., 2014. Toward a more resilient agriculture. Solutions: For a sustainable and desirable future, 5 (5) 65–75. http://www.thesolutionsjournal.com/node/237202.

Benton, T.G., Bieg, C., Harwatt, H., Pudasaini, R., Wellesley, L., 2021. Food system impacts on biodiversity loss. Three levers for food system transformation in support of nature. Chatham House.

Birkhofer, K., Bezemer, T.M., Bloem, J., Bonkowski, M., Christensen, S., Dubois, D., Ekelund, F., Fließbach, A., Gunst, L., Hedlund, K., Mäder, P., Mikola, J., Robin, C., Setälä, H., Tatin-Froux, F., Van der Putten, W.H., Scheu, S., 2008. Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity. Spec. Sect. Enzym. Environ. 40, 2297–2308. https://doi.org/10.1016/j.soilbio.2008.05.007.

Blundell, R., Schmidt, J.E., Igwe, A., Cheung, A.L., Vannette, R.L., Gaudin, A.C.M., Casteel, C.L., 2020. Organic management promotes natural pest control through altered plant resistance to insects. Nat. Plants 6, 483–491. https://doi.org/10.1038/s41477-020-0656-9.

Bocklet, J., Hintermayer, M., Schmidt, L., Wildgrube, T., 2019. The reformed EU ETS - Intertemporal emission trading with restricted banking. Energy Econ. 84, 104486. https://doi.org/10.1016/j.eneco.2019.104486.

Bommarco, R., Vico, G., Hallin, S., 2018. Exploiting ecosystem services in agriculture for increased food security. Glob. Food Secur. 17, 57–63. https://doi.org/10.1016/j.gfs.2018.04.001.

Brühl, C.A., Zaller, J.G., 2019. Biodiversity Decline as a Consequence of an Inappropriate Environmental Risk Assessment of Pesticides. Front. Environ. Sci. 7, 177. https://doi.org/10.3389/fenvs.2019.00177.

Brzozowski, L., Mazourek, M., 2018. A Sustainable Agricultural Future Relies on the Transition to Organic Agroecological Pest Management. Sustainability 10. https://doi.org/10.3390/su10062023.

Buckwell, A., Nadeu, E., 2018. What is the safe operating space for EU livestock? RISE Foundation, Brussels, Belgium.

Chen, Y., 2019. Withdrawal of European Soil Framework Directive: Reasons and Recommendations. J. Sustain. Dev. 13, 1. https://doi.org/10.5539/jsd.v13n1p1.

Clark, M., Tilman, D., 2017. Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. Environ. Res. Lett. 12, 064016. https://doi.org/10.1088/1748-9326/aa6cd5.

Clark, M.A., Domingo, N.G.G., Colgan, K., Thakrar, S.K., Tilman, D., Lynch, J., Azevedo, I.L., Hill, J.D., 2020. Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. Science 370, 705. https://doi.org/10.1126/science.aba7357.

Commission (EU), 2006. Proposal for a Directive of the European Parliament and of the Council establishing a framework for the protection of soil and amending Directive 2004/35/EC, COM(2006) 232 final, 22 September 2006, COM(2006) 232 final.

Dalezios, N.R., Dercas, N., Spyropoulos, N.V., Psomiadis, E., 2019. Remotely Sensed Methodologies for Crop Water Availability and Requirements in Precision Farming of Vulnerable Agriculture. Water Resour. Manag. 33, 1499–1519. https://doi.org/10.1007/s11269-018-2161-8.

Darnhofer, I., Fairweather, J., Moller, H., 2010. Assessing a farm's sustainability: Insights from resilience thinking. Int. J. Agric. Sustain. 8, 186–198. https://doi.org/10.3763/ijas.2010.0480

de Ponti, T., Rijk, B., van Ittersum, M.K., 2012. The crop yield gap between organic and conventional agriculture. Agric. Syst. 108, 1–9. https://doi.org/10.1016/j.agsy.2011.12.004.

Deutsch, C.A., Tewksbury, J.J., Tigchelaar, M., Battisti, D.S., Merrill, S.C., Huey, R.B., Naylor, R.L., 2018. Increase in crop losses to insect pests in a warming climate. Science 361, 916. https://doi.org/10.1126/science.aat3466.

Diacono, M., Persiani, A., Testani, E., Montemurro, F., Ciaccia, C., 2019. Recycling Agricultural Wastes and By-products in Organic Farming: Biofertilizer Production, Yield Performance and Carbon Footprint Analysis. Sustainability 11. https://doi.org/10.3390/su11143824.

Diserens, F., Choptiany, J., Barjolle, D., Graeub, B., Durand, C., Six, J., 2018. Resilience Assessment of Swiss Farming Systems: Piloting the SHARP-Tool in Vaud. Sustainability 10, 4435. https://doi.org/10.3390/su10124435.

Edwards, C.A., Grove, T.L., Harwood, R.R., Pierce Colfer, C.J., 1993. The role of agroecology and integrated farming systems in agricultural sustainability. Agric. Environ. 46, 99–121. https://doi.org/10.1016/0167-8809(93)90017-J.

Ekardt, F., 2019. Sustainability. Transformation, Governance, Ethics, Law, Environmental Humanities: Transformation, Governance, Ethics, Law. Springer International Publishing.

Ekardt, F., Hyla, A., 2017. Human Rights, the Right to Food, Legal Philosophy, and General Principles of International Law : Human Rights, the Right to Food, Legal Philosophy, and General Principles of International Law. Arch. Für Rechts- Sozialphilosophie 103, 221–238.

Ekardt, F., Wieding, J., Zorn, A., 2018. Paris Agreement, Precautionary Principle and Human Rights: Zero Emissions in Two Decades? Sustainability 10, 1–15. https://doi.org/10.3390/su10082812.

EU Commission, 2021. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of Regions on an action plan for the development of organic production. COM(2021) 141 final. EU Commission, Brussels, Belgium.

EU Commission, 2020a. Communication from the Commission to the European Parliament the Council, the European Economic and Social Committee and the Committe of the Regions. A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system COM(2020) 381 final. EU Commission, Brussels, Belgium.

EU Commission, 2020b. Communication from the Commission to the European Parliament the Council, the European Economic and Social Committee and the Committe of the Regions. EU Biodiversity Strategy for 2030. Bringing nature back into our lives. COM(2020) 380 final. EU Commission, Brussels, Belgium.

EU Commission, 2019. Declaration: A smart and sustainable digital future for European agriculture and rural areas. EU Commission, Brussels, Belgium.

EU Commission, 2018a. Proposal for a Regulation of the European Parliament and of the Council establishing rules on support for strategic plans to be drawn up by Member States under the Common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulation (EU) No 1305/2013 of the European Parliament and of the Council and Regulation (EU) No 1307/2013 of the European Parliament and of the Council. COM(2018) 392 final.

EU Commission, 2018b. Annexes to the Proposal for a Regulation of the European Parliament and of the Council establishing rules on support for strategic plans to be drawn up by Member States under the Common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulation (EU) No 1305/2013 of the European Parliament and of the Council and Regulation (EU) No 1307/2013 of the European Parliament and of the Council. COM(2018) 392 final.

EU Commission, 2017. Report from the Commission to the European Parliament and the Council On Member State National Action Plans and on progress in the implementation of Directive 2009/128/EC on the sustainable use of pesticides. COM(2017) 587 final. EU Commission, Brussels, Belgium.

Ewel, J.J., Schreeg, L.A., Sinclair, T.R., 2019. Resources for Crop Production: Accessing the Unavailable. Trends Plant Sci. 24, 121–129. https://doi.org/10.1016/j.tplants.2018.10.008.

Eyhorn, F., Muller, A., Reganold, J.P., Frison, E., Herren, H.R., Luttikholt, L., Mueller, A., Sanders, J., Scialabba, N.E.-H., Seufert, V., Smith, P., 2019. Sustainability in global agriculture driven by organic farming. Nat. Sustain. 2, 253–255. https://doi.org/10.1038/s41893-019-0266-6.

Fand, B.B., Tonnang, H.E.Z., Bal, S.K., Dhawan, A.K., 2018. Shift in the Manifestations of Insect Pests Under Predicted Climatic Change Scenarios: Key Challenges and Adaptation Strategies, in: Bal, S.K., Mukherjee, J., Choudhury, B.U., Dhawan, Ashok

Kumar (Eds.), Advances in Crop Environment Interaction. Springer Singapore, Singapore, pp. 389–404. https://doi.org/10.1007/978-981-13-1861-0_15.

FAO, 2020a. Emissions due to agriculture. Global, regional and country trends 2000–2018. FAOSTAT Analytical Brief 18. FAO, Rome, Italy.

FAO, 2020b. Livestock and environment statistics. manure and greenhouse gas emissions. Global, regional and country trends 1990-2018. FAOSTAT Analytical Brief 14. FAO, Rome, Italy.

Finger, R., Swinton, S.M., El Benni, N., Walter, A., 2019. Precision Farming at the Nexus of Agricultural Production and the Environment. Annu. Rev. Resour. Econ. 11, 313–335. https://doi.org/10.1146/annurev-resource-100518-093929.

Galli, F., Prosperi, P., Favilli, E., D'Amico, S., Bartolini, F., Brunori, G., 2020. How can policy processes remove barriers to sustainable food systems in Europe? Contributing to a policy framework for agri-food transitions. Sustain. Food Syst. Healthy Diets Eur. Cent. Asia 96, 101871. https://doi.org/10.1016/j.foodpol.2020.101871.

Garibaldi, L.A., Gemmill-Herren, B., D'Annolfo, R., Graeub, B.E., Cunningham, S.A., Breeze, T.D., 2017. Farming Approaches for Greater Biodiversity, Livelihoods, and Food Security. Trends Ecol. Evol. 32, 68–80. https://doi.org/10.1016/j.tree.2016.10.001.

Garrett, R.D., Koh, I., Lambin, E.F., le Polain de Waroux, Y., Kastens, J.H., Brown, J.C., 2018. Intensification in agriculture-forest frontiers: Land use responses to development and conservation policies in Brazil. Glob. Environ. Change 53, 233–243. https://doi.org/10.1016/j.gloenvcha.2018.09.011.

Garske, B., Bau, A., Ekardt, F., 2021. Digitalization and AI in European Agriculture: Strategy for achieving climate and biodiversity targets? Sustainability. https://doi.org/submitted

Garske, B., Ekardt, F., 2021. Economic policy instruments for sustainable phosphorus management: taking into account climate and biodiversity targets. Environ. Sci. Eur. 33, 56. https://doi.org/10.1186/s12302-021-00499-7.

Garske, B., Stubenrauch, J., Ekardt, F., 2020. Sustainable phosphorus management in European agricultural and environmental law. Rev. Eur. Comp. Int. Environ. Law. https://doi.org/10.1111/reel.12318.

Geiger, F., Bengtsson, J., Berendse, F., Weisser, W.W., Emmerson, M., Morales, M.B., Ceryngier, P., Liira, J., Tscharntke, T., Winqvist, C., Eggers, S., Bommarco, R., Pärt, T., Bretagnolle, V., Plantegenest, M., Clement, L.W., Dennis, C., Palmer, C., Oñate, J.J., Guerrero, I., Hawro, V., Aavik, T., Thies, C., Flohre, A., Hänke, S., Fischer, C., Goedhart, P.W., Inchausti, P., 2010. Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. Basic Appl. Ecol. 11, 97–105. https://doi.org/10.1016/j.baae.2009.12.001.

Gentsch, N., Boy, J., Batalla, J.D.K., Heuermann, D., von Wirén, N., Schweneker, D., Feuerstein, U., Groß, J., Bauer, B., Reinhold-Hurek, B., Hurek, T., Céspedes, F.C., Guggenberger, G., 2020. Catch crop diversity increases rhizosphere carbon input and soil microbial biomass. Biol. Fertil. Soils 56, 943–957. https://doi.org/10.1007/s00374-020-01475-8.

Guyomard, H., Bureau, J., Chatellier, V., Detang-Dessendre, C., Dupraz, P., Jacquet, F., Reboud, X., Requillart, V., Soler, L., Tysebaert, M., 2020. Research for AGRI Committee - The Green Deal and the CAP: policy implications to adapt farming practices and to preserve the EU’s natural resources. European Parliament, Brussels, Belgium.

Hallmann, C.A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörren, T., Goulson, D., de Kroon, H., 2017. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PLOS ONE 12, e0185809. https://doi.org/10.1371/journal.pone.0185809.

Hedenus, F., Wirsenius, S., Johansson, D.J.A., 2014. The importance of reduced meat and dairy consumption for meeting stringent climate change targets. Clim. Change 124, 79–91. https://doi.org/10.1007/s10584-014-1104-5.

Heinze, S., Raupp, J., Joergensen, R.G., 2010. Effects of fertilizer and spatial heterogeneity in soil pH on microbial biomass indices in a long-term field trial of organic agriculture. Plant Soil 328, 203–215. https://doi.org/10.1007/s11104-009-0102-2.

Henneron, L., Bernard, L., Hedde, M., Pelosi, C., Villenave, C., Chenu, C., Bertrand, M., Girardin, C., Blanchart, E., 2015. Fourteen years of evidence for positive effects of conservation agriculture and organic farming on soil life. Agron. Sustain. Dev. 35, 169–181. https://doi.org/10.1007/s13593-014-0215-8.

Houser, M., Stuart, D., 2020. An accelerating treadmill and an overlooked contradiction in industrial agriculture: Climate change and nitrogen fertilizer. J. Agrar. Change 20, 215–237. https://doi.org/10.1111/joac.12341.

Hukari, S., Hermann, L., Nättorp, A., 2016. From wastewater to fertilisers — Technical overview and critical review of European legislation governing phosphorus recycling. Spec. Issue Sustain. Phosphorus Tak. Stock Phosphorus Supply Nat. Anthropog. Pools 21st Century 542, 1127–1135. https://doi.org/10.1016/j.scitotenv.2015.09.064.

IPBES, 2019. The global assessment report on biodiversity and ecoystem services. Summary for Policymakers. IPBES, Bonn, Germany.

IPCC, 2019. Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. IPCC, Geneva Switzerland.

Jarosch, K., Oberson, A., Emmanuel, F., Gunst, L., Dubois, D., Mäder, P., Mayer, J., 2017. Phosphorus (P) balances and P availability in a field trial comparing organic and conventional farming systems since 35 years, in: EGU General Assembly Conference Abstracts, EGU General Assembly Conference Abstracts. p. 15377.

Juroszek, P., Racca, P., Link, S., Farhumand, J., Kleinhenz, B., 2020. Overview on the review articles published during the past 30 years relating to the potential climate change effects on plant pathogens and crop disease risks. Plant Pathol. 69, 179–193. https://doi.org/10.1111/ppa.13119.

Kumar, S., Meena, R.S., Lal, R., Singh Yadav, G., Mitran, T., Meena, B.L., Dotaniya, M.L., EL-Sabagh, A., 2018. Role of Legumes in Soil Carbon Sequestration, in: Meena, R.S., Das, A., Yadav, G.S., Lal, R. (Eds.), Legumes for Soil Health and Sustainable Management. Springer Singapore, Singapore, pp. 109–138. https://doi.org/10.1007/978-981-13-0253-4_4.

Kyriakou, V., Garagounis, I., Vourros, A., Vasileiou, E., Stoukides, M., 2020. An Electrochemical Haber-Bosch Process. Joule 4, 142–158. https://doi.org/10.1016/j.joule.2019.10.006.

Lal, R., 2004. Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. Science 304, 1623. https://doi.org/10.1126/science.1097396.

Leip, A., Gilles, B., Garnier, J., Grizetti, B., Lassaletta, L., Reis, S., Simpson, D., Sutton, M.A., de Vries, W., Weiss, F., Westhoek, H., 2015. Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity. Env. Res Lett 10, 11504. https://doi.org/10.1088/1748-9326/10/11/115004.

Leip A., Weiss, F., Wassenaar T., Perez I., Fellmann T., Loudjani P., Tubiello F., Grandgirard D., Monni S. and Biala K., 2010. Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS) – final report. European Commission, Joint Research Centre, Brussels, Belgium.

Lichtenberg, E.M., Kennedy, C.M., Kremen, C., Batáry, P., Berendse, F., Bommarco, R., Bosque-Pérez, N.A., Carvalheiro, L.G., Snyder, W.E., Williams, N.M., Winfree, R., Klatt, B.K., Åström, S., Benjamin, F., Brittain, C., Chaplin-Kramer, R., Clough, Y., Danforth, B., Diekötter, T., Eigenbrode, S.D., Ekroos, J., Elle, E., Freitas, B.M., Fukuda, Y., Gaines-Day, H.R., Grab, H., Gratton, C., Holzschuh, A., Isaacs, R., Isaia, M., Jha, S., Jonason, D., Jones, V.P., Klein, A.-M., Krauss, J., Letourneau, D.K., Macfadyen, S., Mallinger, R.E., Martin, E.A., Martinez, E., Memmott, J., Morandin, L., Neame, L., Otieno, M., Park, M.G., Pfiffner, L., Pocock, M.J.O., Ponce, C., Potts, S.G., Poveda, K., Ramos, M., Rosenheim, J.A., Rundlöf, M., Sardiñas, H., Saunders, M.E., Schon, N.L., Sciligo, A.R., Sidhu, C.S., Steffan-Dewenter, I., Tscharntke, T., Veselý, M., Weisser, W.W., Wilson, J.K., Crowder, D.W., 2017. A global synthesis of the effects of diversified farming systems on arthropod diversity within fields and across agricultural landscapes. Glob. Change Biol. 23, 4946–4957. https://doi.org/10.1111/gcb.13714.

Liu, X., Gu, S., 2016. A brief discussion on energy use and greenhouse gas emmision in organic farming. Int. J. Plant Prod. 10, 85–95.

Mahmud, K., Makaju, S., Ibrahim, R., Missaoui, A., 2020. Current Progress in Nitrogen Fixing Plants and Microbiome Research. Plants 9. https://doi.org/10.3390/plants9010097.

Maltas, A., Kebli, H., Oberholzer, H.R., Weisskopf, P., Sinaj, S., 2018. The effects of organic and mineral fertilizers on carbon sequestration, soil properties, and crop yields from a long-term field experiment under a Swiss conventional farming system. Land Degradation & Development 29. https://doi.org/10.1002/ldr.2913.

Martin, G., Moraine, M., Ryschawy, J., Magne, M.-A., Asai, M., Sarthou, J.-P., Duru, M., Therond, O., 2016. Crop–livestock integration beyond the farm level: a review. Agron. Sustain. Dev. 36, 53. https://doi.org/10.1007/s13593-016-0390-x.

McGuire, A.M., 2017. Agricultural Science and Organic Farming: Time to Change Our Trajectory. Agric. Environ. Lett. 2, 170024. https://doi.org/10.2134/ael2017.08.0024.

Möller, K., Oberson, A., Bünemann, E.K., Cooper, J., Friedel, J.K., Glæsner, N., Hörtenhuber, S., Løes, A.-K., Mäder, P., Meyer, G., Müller, T., Symanczik, S., Weissengruber, L., Wollmann, I., Magid, J., 2018. Chapter Four - Improved Phosphorus Recycling in Organic Farming: Navigating Between Constraints, in: Sparks, D.L. (Ed.), Advances in Agronomy. Academic Press, pp. 159–237. https://doi.org/10.1016/bs.agron.2017.10.004.

Morris, C., Winter, M., 1999. Integrated farming systems: the third way for European agriculture? Land Use Policy 16, 193–205. https://doi.org/10.1016/S0264-8377(99)00020-4.

Mueller, N.D., Lassaletta, L., 2020. Nitrogen challenges in global livestock systems. Nat. Food 1, 400–401. https://doi.org/10.1038/s43016-020-0117-7.

Nesme, T., Withers, P.J.A., 2016. Sustainable strategies towards a phosphorus circular economy. Nutr. Cycl. Agroecosystems 104, 259–264. https://doi.org/10.1007/s10705-016-9774-1

Nowak, B., Nesme, T., David, C., Pellerin, S., 2013. To what extent does organic farming rely on nutrient inflows from conventional farming? Environ. Res. Lett. 8, 044045. https://doi.org/10.1088/1748-9326/8/4/044045.

Nunes, M.R., van Es, H.M., Schindelbeck, R., Ristow, A.J., Ryan, M., 2018. No-till and cropping system diversification improve soil health and crop yield. Geoderma 328, 30–43. https://doi.org/10.1016/j.geoderma.2018.04.031.

Ohm, M., Paulsen, H.M., Moos, J.H., Eichler-Löbermann, B., 2017. Long-term negative phosphorus budgets in organic crop rotations deplete plant-available phosphorus from soil. Agron. Sustain. Dev. 37, 17. https://doi.org/10.1007/s13593-017-0425-y.

OJEC, 2008. Commission Regulation (EC) No 889/2008 of 5 September 2008 laying down detailed rules for the implementation of Council Regulation (EC) No 834/2007 on organic production and labelling of organic products with regard to organic production, labelling and control, OJ L 189/1.

OJEC, 2007. Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91, OJ L 189/1.

OJEC, 1991. Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources, OJ L 375/1.

OJEU, 2019. Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003 [2019] OJ L 170/1.

OJEU, 2018. Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007, OJ L 150/1.

OJEU, 2012. Charter of Fundamental Rights of the European Union, C 325/391.

Ottman, M.J., Doerge, T.A., Martin, E.C., 2000. Durum Grain Quality as Affected by Nitrogen Fertilization near Anthesis and Irrigation During Grain Fill. Agron. J. 92, 1035–1041. https://doi.org/10.2134/agronj2000.9251035x.

Paleari, S., 2017. Is the European Union protecting soil? A critical analysis of Community environmental policy and law. Land Use Policy 64, 163–173. https://doi.org/10.1016/j.landusepol.2017.02.007.

Pe'er, G., Bonn, A., Bruelheide, H., Dieker, P., Eisenhauer, N., Feindt, P.H., Hagedorn, G., Hansjürgens, B., Herzon, I., Lomba, Â., Marquard, E., Moreira, F., Nitsch, H., Oppermann, R., Perino, A., Röder, N., Schleyer, C., Schindler, S., Wolf, C., Zinngrebe, Y., Lakner, S., 2020. Action needed for the EU Common Agricultural Policy to address sustainability challenges. People Nat. https://doi.org/10.1002/pan3.10080.

Philip Robertson, G., Gross, K.L., Hamilton, S.K., Landis, D.A., Schmidt, T.M., Snapp, S.S., Swinton, S.M., 2014. Farming for Ecosystem Services: An Ecological Approach to Production Agriculture. BioScience 64, 404–415. https://doi.org/10.1093/biosci/biu037.

Ponisio, L.C., M'Gonigle, L.K., Mace, K.C., Palomino, J., de Valpine, P., Kremen, C., 2015. Diversification practices reduce organic to conventional yield gap. Proc. R. Soc. B Biol. Sci. 282, 20141396. https://doi.org/10.1098/rspb.2014.1396.

Prăvălie, R., Patriche, C., Borrelli, P., Panagos, P., Roșca, B., Dumitraşcu, M., Nita, I.-A., Săvulescu, I., Birsan, M.-V., Bandoc, G., 2021. Arable lands under the pressure of multiple land degradation processes. A global perspective. Environ. Res. 194, 110697. https://doi.org/10.1016/j.envres.2020.110697.

Raseduzzaman, Md., Jensen, E.S., 2017. Does intercropping enhance yield stability in arable crop production? A meta-analysis. Eur. J. Agron. 91, 25–33. https://doi.org/10.1016/j.eja.2017.09.009.

Reganold, J.P., Wachter, J.M., 2016. Organic agriculture in the twenty-first century. Nat. Plants 2, 15221. https://doi.org/10.1038/nplants.2015.221.

Reimer, M., Hartmann, T.E., Oelofse, M., Magid, J., Bünemann, E.K., Möller, K., 2020. Reliance on Biological Nitrogen Fixation Depletes Soil Phosphorus and Potassium Reserves. Nutr. Cycl. Agroecosystems 118, 273–291. https://doi.org/10.1007/s10705-020-10101-w.

Robles, Á., Aguado, D., Barat, R., Borrás, L., Bouzas, A., Giménez, J.B., Martí, N., Ribes, J., Ruano, M.V., Serralta, J., Ferrer, J., Seco, A., 2020. New frontiers from removal to recycling of nitrogen and phosphorus from wastewater in the Circular Economy. Bioresour. Technol. 300, 122673. https://doi.org/10.1016/j.biortech.2019.122673.

Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., Schellnhuber, H.J., 2017. A roadmap for rapid decarbonization. Science 355, 1269. https://doi.org/10.1126/science.aah3443.

Röder, N., Matthews, A., 2021. Eco-schemes a work in progress. http://capreform.eu/eco-schemes-a-work-in-progress/ (accessed 19 March 2021).

Röös, E., Carlsson, G., Ferawati, F., Hefni, M., Stephan, A., Tidåker, P., Witthöft, C., 2020. Less meat, more legumes: prospects and challenges in the transition toward sustainable diets in Sweden. Renew. Agric. Food Syst. 35, 192–205. https://doi.org/10.1017/S1742170518000443.

Röös, E., Mie, A., Wivstad, M., Salomon, E., Johansson, B., Gunnarsson, S., Wallenbeck, A., Hoffmann, R., Nilsson, U., Sundberg, C., Watson, C.A., 2018. Risks and opportunities of increasing yields in organic farming. A review. Agron. Sustain. Dev. 38, 14. https://doi.org/10.1007/s13593-018-0489-3.

Rütting, T., Aronsson, H., Delin, S., 2018. Efficient use of nitrogen in agriculture. Nutr. Cycl. Agroecosystems 110, 1–5. https://doi.org/10.1007/s10705-017-9900-8.

Sampat, A.M., Hicks, A., Ruiz-Mercado, G.J., Zavala, V.M., 2021. Valuing economic impact reductions of nutrient pollution from livestock waste. Resour. Conserv. Recycl. 164, 105199. https://doi.org/10.1016/j.resconrec.2020.105199.

Sarvajayakesavalu, S., Lu, Y., Withers, Paul.J.A., Pavinato, P.S., Pan, G., Chareonsudjai, P., 2018. Phosphorus recovery: a need for an integrated approach. Ecosyst. Health Sustain. 4, 48–57. https://doi.org/10.1080/20964129.2018.1460122.

Savary, S., Willocquet, L., Pethybridge, S.J., Esker, P., McRoberts, N., Nelson, A., 2019. The global burden of pathogens and pests on major food crops. Nat. Ecol. Evol. 3, 430–439. https://doi.org/10.1038/s41559-018-0793-y.

Schrama, M., de Haan, J.J., Kroonen, M., Verstegen, H., Van der Putten, W.H., 2018. Crop yield gap and stability in organic and conventional farming systems. Agric. Ecosyst. Environ. 256, 123–130. https://doi.org/10.1016/j.agee.2017.12.023.

Seufert, V., Ramankutty, N., 2017. Many shades of gray—The context-dependent performance of organic agriculture. Sci. Adv. 3, e1602638. https://doi.org/10.1126/sciadv.1602638.

Seufert, V., Ramankutty, N., Foley, J.A., 2012. Comparing the yields of organic and conventional agriculture. Nature 485, 229–232. https://doi.org/10.1038/nature11069.

Signorelli, S., Sainz, M., Tabares-da Rosa, S., Monza, J., 2020. The Role of Nitric Oxide in Nitrogen Fixation by Legumes. Front. Plant Sci. 11, 521. https://doi.org/10.3389/fpls.2020.00521.

Skinner, C., Gattinger, A., Krauss, M., Krause, H.-M., Mayer, J., van der Heijden, M.G.A., Mäder, P., 2019. The impact of long-term organic farming on soil-derived greenhouse gas emissions. Sci. Rep. 9, 1702. https://doi.org/10.1038/s41598-018-38207-w.

Smith, C., Hill, A.K., Torrente-Murciano, L., 2020. Current and future role of Haber–Bosch ammonia in a carbon-free energy landscape. Energy Environ. Sci. 13, 331–344. https://doi.org/10.1039/C9EE02873K.

Smith, L.G., Kirk, G.J.D., Jones, P.J., Williams, A.G., 2019. The greenhouse gas impacts of converting food production in England and Wales to organic methods. Nat. Commun. 10, 4641. https://doi.org/10.1038/s41467-019-12622-7.

Smith, O.M., Cohen, A.L., Rieser, C.J., Davis, A.G., Taylor, J.M., Adesanya, A.W., Jones, M.S., Meier, A.R., Reganold, J.P., Orpet, R.J., Northfield, T.D., Crowder, D.W., 2019. Organic Farming Provides Reliable Environmental Benefits but Increases Variability in Crop Yields: A Global Meta-Analysis. Front. Sustain. Food Syst. 3, 82. https://doi.org/10.3389/fsufs.2019.00082.

Springmann, M., Wiebe, K., Mason-D'Croz, D., Sulser, T., Rayner, M., Scarborough, P., 2018. Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. Lancet Planet Health 2, 451–461. https://doi.org/10.1016/S2542-5196(18)30206-7.

Storck, V., Karpouzas, D.G., Martin-Laurent, F., 2017. Towards a better pesticide policy for the European Union. Sci. Total Environ. 575, 1027–1033. https://doi.org/10.1016/j.scitotenv.2016.09.167.

Stubenrauch, J., 2019. Phosphor-Governance in ländervergleichender Perspektive - Deutschland, Costa Rica, Nicaragua. Ein Beitrag zur Nachhaltigkeits- und Bodenschutzpolitik, Beiträge zur sozialwissenschaftlichen Nachhaltigkeitsforschung. Metropolis, Marburg.

Stubenrauch, J., Garske, B., Ekardt, F., 2018. Sustainable Land Use, Soil Protection and Phosphorus Management from a Cross-National Perspective. Sustainability 10, 1–23. https://doi.org/10.3390/su10061988.

Tallaksen, J., Bauer, F., Hulteberg, C., Reese, M., Ahlgren, S., 2015. Nitrogen fertilizers manufactured using wind power: greenhouse gas and energy balance of community-scale ammonia production. J. Clean. Prod. 107, 626–635. https://doi.org/10.1016/j.jclepro.2015.05.130.

Techen, A.-K., Helming, K., 2017. Pressures on soil functions from soil management in Germany. A foresight review. Agron. Sustain. Dev. 37, 64. https://doi.org/10.1007/s13593-017-0473-3.

Tuomisto, H.L., Hodge, I.D., Riordan, P., Macdonald, D.W., 2012. Does organic farming reduce environmental impacts? – A meta-analysis of European research. J. Environ. Manage. 112, 309–320. https://doi.org/10.1016/j.jenvman.2012.08.018.

UN, 1992. Convention on Biological Diversity. UN, New York, USA.

UN, 1976. International Covenant on Economic, Social and Cultural Rights. Adopted and opened for signature, ratification and accession by General Assembly resolution 2200A (XXI) of 16 December 1966.

UNEP-UNCTAD, 2008. Organic Agriculture and Food Security in Africa. United Nations, New York and Geneva.

UNFCCC, 2015. Decision on the Paris Agreement; Decision 1/CP.21. UNFCCC, Bonn, Germany.

van der Werf, H.M.G., Knudsen, M.T., Cederberg, C., 2020. Towards better representation of organic agriculture in life cycle assessment. Nat. Sustain. 3, 419–425. https://doi.org/10.1038/s41893-020-0489-6.

Watson, C., Walker, R., Stockdale, E., 2008. Research in organic production systems - Past, present and future. J. Agric. Sci. 146, 1–19. https://doi.org/10.1017/S0021859607007460.

Weishaupt, A., Ekardt, F., Garske, B., Stubenrauch, J., Wieding, J., 2020. Land Use, Livestock, Quantity Governance, and Economic Instruments—Sustainability Beyond Big Livestock Herds and Fossil Fuels. Sustainability 12. https://doi.org/10.3390/su12052053.

Weissengruber, L., Möller, K., Puschenreiter, M., Friedel, J.K., 2018. Long-term soil accumulation of potentially toxic elements and selected organic pollutants through application of recycled phosphorus fertilizers for organic farming conditions. Nutr. Cycl. Agroecosystems 110, 427–449. https://doi.org/10.1007/s10705-018-9907-9.

Wieding, J., Stubenrauch, J., Ekardt, F., 2020. Human Rights and Precautionary Principle: Limits to Geoengineering, SRM, and IPCC Scenarios. Sustainability 12. https://doi.org/10.3390/su12218858.

Wijnands, F., Malavolta, Carlo, Alaphilippe, A., Gerowitt, B., Baur, R., 2018. General Technical Guidelines for Integrated Production of Annual and Perennial Crops. 4th edition 2018. IOBC - WPRS, Zurich, Switzerland.

Wilbois, K.-P., Schmidt, J.E., 2019. Reframing the Debate Surrounding the Yield Gap between Organic and Conventional Farming. Agronomy 9. https://doi.org/10.3390/agronomy9020082.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L.J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J.A., De Vries, W., Majele Sibanda, L., Afshin, A., Chaudhary, A., Herrero, M., Agustina, R., Branca, F., Lartey, A., Fan, S., Crona, B., Fox, E., Bignet, V., Troell, M., Lindahl, T., Singh, S., Cornell, S.E., Srinath Reddy, K., Narain, S., Nishtar, S., Murray, C.J.L., 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet 393, 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4.

Yadav, G.S., Lal, R., Meena, R.S., Babu, S., Das, A., Bhowmik, S.N., Datta, M., Layak, J., Saha, P., 2019. Conservation tillage and nutrient management effects on productivity and soil carbon sequestration under double cropping of rice in north eastern region of India. Ecol. Indic. 105, 303–315. https://doi.org/10.1016/j.ecolind.2017.08.071.

Zagaria, C., Schulp, C., Zavalloni, M., Viaggi, D., Verburg, P., 2021. Modelling transformational adaptation to climate change among crop farming systems in Romagna, Italy. Agric. Syst. 188. https://doi.org/10.1016/j.agsy.2020.103024.

Zhang, W., Ricketts, T.H., Kremen, C., Carney, K., Swinton, S.M., 2007. Ecosystem services and dis-services to agriculture. Spec. Sect. - Ecosyst. Serv. Agric. 64, 253–260. https://doi.org/10.1016/j.ecolecon.2007.02.024.

Zimmer, D., Panten, K., Frank, M., Springer, A., Leinweber, P., 2019. Sulfur-Enriched Bone Char as Alternative P Fertilizer: Spectroscopic, Wet Chemical, and Yield Response Evaluation. Agriculture 9. https://doi.org/10.3390/agriculture9010021.