Global Food Security 26 (2020) 100404

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

Regenerative agriculture – the soil is the base

L. Schreefel[a,b,c,*], R.P.O. Schulte[b], I.J.M. de Boer[c], A. Pas Schrijver[b], H.H.E. van Zanten[c]

[a] TiFN, P.O. Box 557, 6700, AN, Wageningen, the Netherlands
[b] Farming Systems Ecology Group, Wageningen University & Research, P.O. Box 430, 6700, AK, Wageningen, the Netherlands
[c] Animal Production Systems Group, Wageningen University & Research, P.O. Box 338, 6700, AH, Wageningen, the Netherlands

ARTICLE INFO

Keywords:
Regenerative agriculture
Circular agriculture
Organic agriculture
Soil health
Literature review
Cultural domain analysis

ABSTRACT

Regenerative agriculture (RA) is proposed as a solution towards sustainable food systems. A variety of actors perceive RA differently, and a clear scientific definition is lacking. We reviewed 28 studies to find convergence and divergence between objectives and activities that define RA. Our results show convergence related to objectives that enhance the environment and stress the importance of socio-economic dimensions that contribute to food security. The objectives of RA in relation to socio-economic dimensions, however, are general and lack a framework for implementation. From our analysis, we propose a provisional definition of RA as an approach to farming that uses soil conservation as the entry point to regenerate and contribute to multiple ecosystem services.

1. Introduction

The global food system currently releases about 25% of annual anthropogenic greenhouse gas (GHG) emissions, causes about one-third of terrestrial acidification and is responsible for the majority of global eutrophication of surface waters (Poore and Nemecek, 2018). If our food system continues with current practices, using synthetic pesticides, artificial fertilizers, fossil fuels and producing food waste, the carrying capacity of the planet is likely to be surpassed (Campbell et al., 2017). Therefore, the key challenge for humanity is to produce enough safe and nutritious food for a growing and wealthier population within the carrying capacity of the planet (Willett et al., 2019). The importance of producing food within the carrying capacity of the planet is also increasingly acknowledged in policies - for example, the EU Circular Economy Action Plan (European Commission, 2015), the Paris Climate Agreement (United Nations, 2015) and the Common Agricultural Policy (European Commission, 2019a).

This challenge has led to new narratives for sustainable agriculture. Some of these narratives are production-oriented and find their solutions in approaches such as sustainable intensification, which explores increased production yields to reduce the environmental impact (Cole and McCoskey, 2013; Garnett et al., 2013). Another narrative argues that the production-oriented approach is not sufficient to deal with the key challenge for humanity and that consumption patterns should be adjusted for the global food system to function within the boundaries of our planet (Garnett et al., 2013; Stehfest et al., 2009; The Eat-Lancet Commission, 2019; Tilman and Clark, 2014). Building on both the production and consumption-oriented approaches for example Van Zanten et al. (2018) argues that production and consumption-oriented approaches are needed together and should be in balance with their ecological environment. Their narrative takes a food systems perspective and aims at safeguarding natural resources by closing of nutrients and carbon cycles in the food system as far as possible, also referred to as a circular food system (de Boer and van Ittersum, 2018).

Farming approaches within these narratives often share similar desires to reach an objective, such as achieve global food security, reduced use of external inputs and reduced environmental damage. Some of these farming approaches have definitions that are comprehensively described in the scientific literature and regulated, for example, organic agriculture (European Commission, 2019b; IFOAM - Organics International, 2019), climate-smart agriculture (FAO, 2018) and sustainable intensification (FAO, 2013), while others remain yet as theoretical and mainly scientific concepts such as circular agriculture. An approach that recently gained attention in the literature as a solution for a sustainable food system is regenerative agriculture (RA) (LaCanne and Lundgren, 2018; Shelef et al., 2017). Currently, RA does not have a comprehensively described scientific definition (Elevitch et al., 2018).

In absence of such a scientific definition, a variety of researchers may foster diverging perceptions of RA. For example, Malik and Verma (2014) describe RA as dynamically advanced modified technique involving the use of organic farming methods, while Elevitch et al. (2018) describe RA as a farming approach that has the capacity for

* Corresponding author.
E-mail address: loekie.schreefel@wur.nl (L. Schreefel).

https://doi.org/10.1016/j.gfs.2020.100404
Received 19 March 2020; Received in revised form 17 June 2020; Accepted 29 June 2020
Available online 6 August 2020

self-renewal and resiliency, contributes to soil health, increases water percolation and retention, enhances and conserves biodiversity, and sequesters carbon. Therefore, in this review, we assess the background and core themes of RA by examining the convergence and divergence between definitions in peer-reviewed articles. An assessment of the background and core themes of RA allows the establishment of an evidence-based provisional definition. Such a definition forms a basis for further discussion not only within science but also among a large group of actors (e.g. governmental agencies, sector organisations, industries and farmers). This large group of actors may foster different definitions dependent on their particular interests. A provisional definition is, therefore, essential to establish a common definition in which more views are included and indicators that enables actors to assess their performance towards a sustainable food system. Indicators, for example, enables governments and industries to monitor their performance towards the Sustainable Development Goals (SDG's), it enables policy-makers to create supporting policies for actors in the field, it enables researchers to have a scientific basis to accumulate knowledge and it enables farmers to assess which activities to adjust. To illustrate the convergence between sustainable farming approaches we relate RA to organic agriculture as an example of a regulated farming approach and circular agriculture which remains yet a theoretical concept.

2. Materials and methods

We systematically studied peer-reviewed articles to find definitions of RA using the methodological framework PRISMA-P (Preferred Reporting Items for Systematic Reviews) (Shamseer et al., 2015). A checklist of the suggested items reported in PRISMA-P is given in supplementary materials A and a detailed overview of the review and analytical process is presented in supplementary materials B. Five journal databases (Scopus, Web of Science, Agricola, CAB Abstracts and Medline) were searched for definitions of RA in December 2019. Keywords used to create a search string to find articles that include a definition for RA build upon the words 'regenerative' and 'farming' (see supplementary materials B10). For 'farming' different synonyms were used, including agriculture, agronomy and food system. Search terms such as 'agronomy' and 'food system' were included to capture definitions for RA embedded in the transition towards a regenerative food system.

The database search yielded 279 articles mentioning 'regenerative' and 'farming' (see Fig. 1). These 279 articles were screened on their abstract and titles and narrowed down to 43 articles. The eligibility criteria to narrow down articles based on their titles and abstracts were to exclude: duplicates, unavailable articles within the selected databases, articles which were not peer-reviewed and articles unrelated to agriculture. After excluding fifteen articles which did not contain a definition of RA, 28 articles (Supplementary materials C) remained for further synthesis. Reference checking using the snowballing technique (Jalali and Wohlin, 2012) did not yield more articles. No articles were excluded based on the year of publication. The PRISMA workflow in the supplementary materials D provides a more extensive overview of the methodical process of inclusion and exclusion of articles.

We analysed the background (e.g. actor and scale to which the definition applies) and different definitions of RA in the reviewed articles using a cultural domain analysis and inductive coding. A cultural domain analysis (Borgatti, 1994) and inductive coding (Thomas, 2006) are both synthesis methods to cluster segments of text, based on their coherence. Following these methods, the definitions were split-up into text segments called *issues* (e.g. improve soil carbon, minimize tillage). These issues were categorised into *objectives* (e.g. improve soil carbon, interspecies equity) and *activities* (e.g. minimize tillage, use natural pest control). In this review, objectives capture the desire of researchers to achieve a certain goal, whereas activities capture operationalizations, for example, suggested farm practices. If these objectives or activities were mentioned at least five times in the literature, then we grouped them into themes (e.g. improve soil physical quality, improve human health). The criterion to have at least five convergent objectives or activities to form a theme was based on a sensitivity analysis (see supplementary materials B15c, in which different numbers (3 till 7) of convergent issues were assessed on their inclusiveness of specific themes. The allocation process of issues was done by all co-authors independently to reduce interpretation bias, and any disagreement on the allocation of issues was solved by discussion. Supplementary materials E shows the allocation framework used. All the different themes together form the core of RA. The following four aspects were analysed to determine the themes of RA: i) the number of articles referring to the themes, ii) the number of converging and diverging interpretations of nomenclature within themes, iii) the classifications of themes among objectives or activities and iv) the relation of themes with the three dimensions of sustainability, i.e. people, planet and profit (Elkington, 1997). Converging themes indicate that authors of different articles

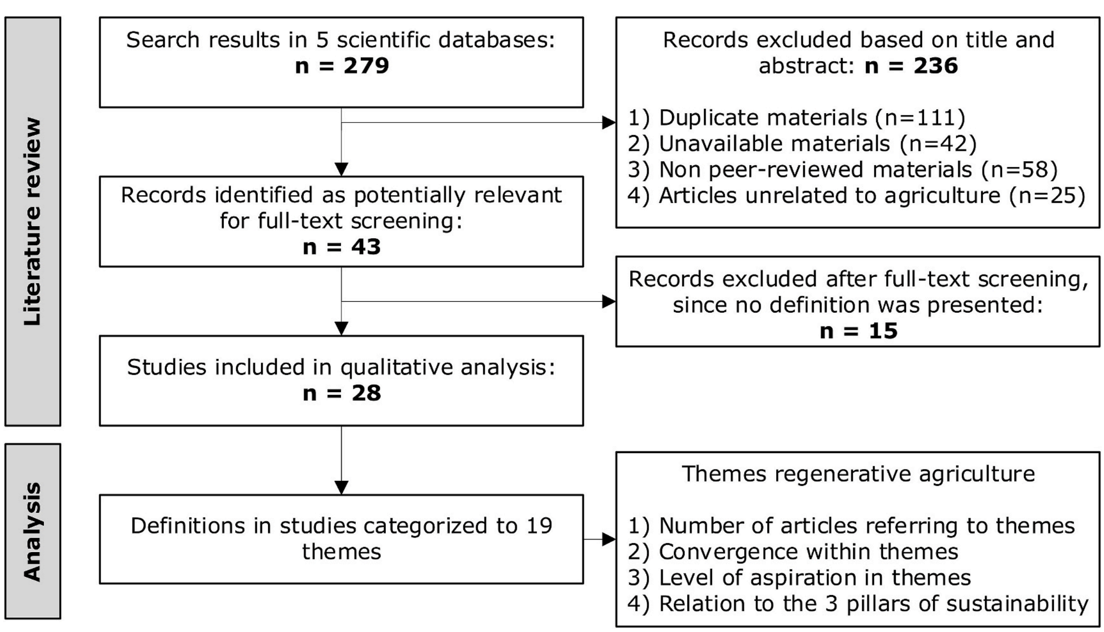

Fig. 1. Illustration of the research methodology to analyse existing definitions of regenerative agriculture, in which 'n' represents the number of search records.

present similar objectives within their definitions. Diverging themes present contradictions or issues which are unclear. The triple bottom line approach (people, planet and profit) was used to categorize themes among social (e.g. maintain cultural diversity), environmental (e.g. improve soil structure) and economic (e.g. create long-term economic sustainability) aspects (Elkington, 1997; Slingerland et al., 2003). Furthermore, we analysed whether definitions were based on the objectives of researchers or farmers and to which scale (farm, regional or systems-level) they relate. Fig. 1 illustrates the steps required to analyse the existing definitions of RA.

3. Results and analysis

3.1. The core themes of regenerative agriculture

In the 28 peer-reviewed articles we found that definitions addressed different issues (e.g. soil health, climate change) and scales (e.g. farm, food systems-level), resulting in different levels of implementation. Our review yielded 214 objectives and 77 activities. The assessment of the convergence among objectives and activities, which was based on the underlying issues, resulted in thirteen themes for objectives and seven themes for activities (Fig. 2).

These twenty themes referred mostly to the environmental dimension of sustainability (seventeen out of nineteen). Environmental issues were addressed from farm to food systems-levels (Fig. 2). Of these, all activities and four objectives specifically focussed on soil issues: *enhance and improve soil health*, *improve soil carbon*, *improve soil physical quality* and *improve (soil) biodiversity*. The multiple aggregation levels and quantity of articles referring to environmental issues indicated that RA focusses specifically on environmental issues, and in particular soil issues.

We will first discuss the environmental themes that show most convergence among definitions (see section 3.2), followed by themes with divergence (see section 3.3). The specific issues among the themes can be found in supplementary materials E.

3.2. Themes in RA showing convergence

All reviewed articles related RA with the environment (planet) and mainly with improving environmental issues, which is referred to as *regenerate the system*, *reduce environmental externalities* and *improve the ecosystem*. Convergent objectives were mentioned regarding reducing environmental externalities e.g. 'reduce environmental damage' (Teague, 2018, P.1520) and 'reduce environmental pollution' (Rhodes, 2012, P.345). Similarly, there was convergence about the improvement of the ecosystem. A healthy agroecosystem was referred to as a resilient ecosystem that enables the provision of ecosystems services, such as provisioning, regulating, habitat and supporting services (e.g. Gosnell et al., 2019; Rhodes, 2017; Teague, 2017). These three environmental themes were further articulated by four themes that refer to the improvement of the food system: *enhance and improve soil health* (n = 15), *optimize resource management* (n = 13), *alleviate climate change* (n = 8) and *improve water quality and availability* (n = 5).

The theme *enhance and improve soil health* received most attention; seventeen of 28 articles explicitly mentioned improving soil quality in a variety of synonymous objectives, such as 'improve soil quality' (Mahtab and Karim, 1992, P.54), 'contribute to soil fertility' (Elevitch et al., 2018, P.2), 'enhance soil health' (Sherwood and Uphoff, 2000, P.86) and 'improve their soils' (White and Andrew, 2019, P.2). A synthesis of the issues among the objective to improve soil quality is that a healthy soil is the basis for RA and therefore degraded agricultural soils should be restored to healthy soils. This is expressed by, for example, Rhodes (2012, P.380) who mentioned that RA 'regenerates the soil' and by Diop (1999, P.296) who mentioned that RA 'gives the soil as a resource the first priority'.

Thirteen out of 28 studies mentioned objectives to *optimize resource*

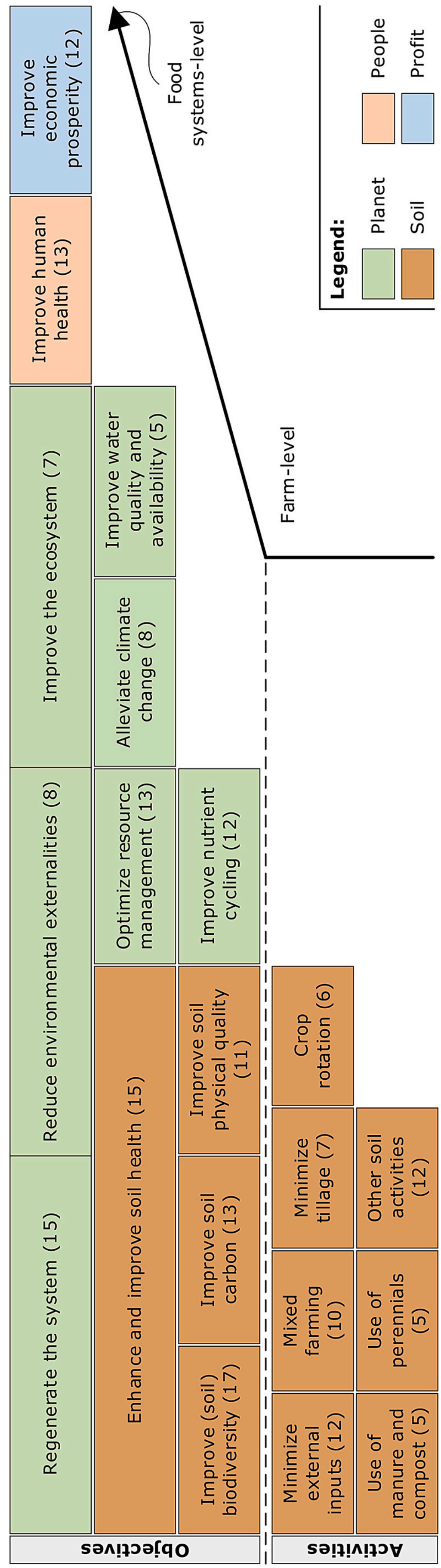

Fig. 2. The core themes of regenerative agriculture, in which 'the number between brackets' represents the number of search records.

management. Reviewed articles highlight objectives towards recusing waste and optimal nutrient availability. They indicated RA as a system which has the objective to regenerate resources in an integrated manner for sustained soil fertility and desired crop and animal productivity. They mentioned, for example, issues as 'minimize waste' (Teague, 2015, P.5), 'synergisms in different combinations and methods of management' (Teague and Barnes, 2017, P.80), 'regeneration of natural resources' (Teague, 2015, P.5), 'improve nutrient retention and availability' (Diop, 1999, P.295) and 'encompass solid-waste management' (Mahtab and Karim, 1992, P.54).

Themes *alleviate climate change* and *improve water quality and availability* received less attention compared to other themes with objectives. Moreover, eight of 28 articles have the objective to *alleviate climate change*. Studies mentioned for example to 'reduce GHG emissions' (Teague, 2018, P.1520), 'invert carbon emissions of our current agriculture' (Elevitch et al., 2018, P.2) and 'mitigate climate change' (Rhodes, 2012, P.434). Similarly, five of the 28 studies mentioned issues supporting the theme of *improve water quality and availability*. For example, to 'improve water quality' (Elevitch et al., 2018, P.4), 'achieve clean and safe water runoff' (Elevitch et al., 2018, P.2), 'reduce water shortages' (Rhodes, 2012, P.380) and 'protect freshwater supply' (Rhodes, 2017, P.95). Other studies did not mention such objectives about the alleviation of climate change or the improvement of water quality and availability.

The objectives *enhance and improve soil health* that received most attention were further articulated by more specific objectives which include *improve (soil) biodiversity* (n = 17), *improvement of soil carbon* (n = 13) and *soil physical quality* (n = 11). An objective frequently mentioned (13 out of 28) is to *improve (soil) biodiversity* for improved soil functioning, which relates to above and below ground biodiversity. The issues among this theme showed convergence, although different issues are mentioned in the reviewed articles: the improvement of soil biodiversity by 'promoting soil biology' (LaCanne and Lundgren, 2018, P.7) or more general statements such as 'increase the biodiversity' (de Haas et al., 2019, P.548). Although biodiversity is clearly an important theme, it remains unspecified what is meant with the improvement of biodiversity (below or above-ground biodiversity, to which scale does it relate). Most studies expect or assume, however, that RA will improve biodiversity, which in general is seen as a precondition for a sustainable food system.

Another objective which shows convergence and is frequently mentioned (13 out of 28) is to *improve soil carbon*, articulated in the reviewed article as for example 'build soil organic matter' (e.g. Diop, 1999, P.290; Rhodes, 2017, P.100), and 'increasing carbon sequestration' (e.g. Elevitch et al., 2018, P.2; Provenza et al., 2019, P.3; Sambell et al., 2019, P.3). The improvement of soil carbon is considered a cross-cutting issue across the three spheres of soil science (soil chemistry, soil physics and soil biology) since it affects all three aspects (Ontl, 2018). Improving soil carbon levels affects, for example, soil structure and porosity; water infiltration rate and moisture holding capacity of soils; biodiversity and activity of soil organisms; and plant nutrient availability (Bot and Benites, 2005).

The last objective related to *enhance and improve soil health* is to *improve soil physical quality*. Similarly, to the previous theme, eleven of 28 articles mentioned improving soil physical characteristics and reducing threats to soil quality. Examples of improvements in soil physical characteristics include 'improvement of water infiltration' (Teague, 2017, P.348), 'improvement of water holding capacity' (Diop, 1999, P.290) and 'improvement of soil aeration' (Teague, 2018, P.1528). Mitigation of soil threats included 'minimizing erosion' (Francis et al., 1986, P.70), 'improving soil structure' (Rhodes, 2017, P.123) and 'reducing soil degradation' (Rhodes, 2012, P.345).

An underlying theme of *optimize resource management* is to *improve nutrient cycling*. Twelve out of 28 articles mentioned convergent issues regarding nutrient cycling and these articles share the ambition to work towards closed nutrient loops. Examples are 'improve nutrient cycling' (Teague and Barnes, 2017, P.1527), 'tendencies towards closed nutrient loops' (Mitchell et al., 2019, P.7) and 'more on-farm recycling' (Teague, 2015, P.5).

In addition to objectives, most of the reviewed articles (20 of 28) also mentioned activities to define RA (Fig. 2). Activities showing convergence in the literature are for example *minimizing external inputs* (e.g. Lockeretz, 1988; Rhodes, 2017), *minimizing tillage* (e.g. Francis et al., 1986; LaCanne and Lundgren, 2018)*, using mixed farming* (Diop, 1999; LaCanne and Lundgren, 2018)*, improving crop rotations* (e.g. Francis et al., 1986; Rhodes, 2012), and using *manure and compost* (Diop, 1999; Rhodes, 2017). These activities direct towards a food system that builds on its ecological cycles and as a co-benefit reduces environmental externalities. The suggested activities promote the integration of crop-livestock operations (e.g. Dahlberg, 1994; Diop, 1999), in which animals are primarily valued for their capabilities to build soil, besides their role in producing food and fibre (Teague et al., 2016). Livestock breeds are, therefore, chosen for their compatibility with their local environment (Gosnell et al., 2019; Steenwerth et al., 2014). The suggested activities also shift from single to multi-cropping systems (e.g. Francis et al., 1986), in which the use of perennials is favoured over annuals (e.g. Elevitch et al., 2018; LaCanne and Lundgren, 2018), because perennials have more extensive and deeper root systems and don't leave fields fallow in between growing seasons. Therefore, perennials are more resilient to weather extremes (LaCanne and Lundgren, 2018), reduce soil erosion (Pimentel et al., 1997), reduce nutrient runoff (Teague, 2018), improve water conservation (Glover et al., 2010) and carbon sequestration (Elevitch et al., 2018). Relying on ecological cycles also resulted in a preference for animal manures over artificial fertilizers (e.g. Pearson, 2007), and for the use of natural pest control over synthetic pesticides (e.g. Rhodes, 2017). Minimizing tillage is a specific crop management technique valued to reduce soil disturbance, due to the absence of heavy tillage machinery, allowing earthworms to aerate the soil and increase nutrient distribution (Shah et al., 2017). Activities among the theme 'other soil conservation practices' did not necessarily represent divergence, however they presented various activities that were not clustered as a separate theme, such as the use of windbreaks (Diop, 1999), silvopasture (Elevitch et al., 2018), and managed grazing (Provenza et al., 2019). These activities are in line with the objectives of RA, without being clustered into separate themes.

3.3. *Themes in RA showing divergence*

Although the reviewed articles may show convergence upon most of the themes, we can discern three themes showing a degree of divergence: *regenerate the system*, *improve human health* and *improve economic prosperity*. These themes show divergence because they embrace a sum of issues which do not meet the requirement of at least five convergent issues to form a separate theme.

One of the key objectives of RA is that it is part of a regenerative system. A large number of articles (15 out of 28) referred to environmental objectives regarding the theme *regenerate the system*. A total of fourteen environmental objectives showed that RA is aimed towards productive agriculture that focusses on the health of nature through the regeneration of the resources the system requires (e.g. energy, water, nutrients and carbon). The objectives within this theme remain rather vague because the reviewed articles did not define what is meant by objectives such as RA: should be able to 'restore earth' (Shelef et al., 2017, P.2), 'regenerates the natural system' (Dahlberg, 1994, P.173) and creates a 'long-term rehabilitative strategy' (Diop, 1999, P.296). Such objectives may require a more elaborate description of, for example, the capture of socio-economic aspects and how such objectives can be implemented.

The theme *improve human health* relates to the objectives to provide goods and services for human health to ensure global food security through RA. The quantity of studies (13 out of 28) mentioning social issues is large, however, no themes could be formed with lower levels of aggregation due to a lack of studies mentioning convergent issues. This theme, therefore, showed high variability between issues. A total number of 27 issues was related to this theme and based on the issues we can express that RA aims for sustainable food production which should be in balance with both environmental and social issues. The reviewed articles highlight the quality of human life emphasizing the need to invest in 'regenerating the social system' (Dahlberg, 1994, P.173), 'restoring human health' (Shelef et al., 2017, P.2), 'interspecies equity' (Dahlberg, 1994, P.173), 'social justice' (Dahlberg, 1994, P.173), 'regenerating farm families' (Dahlberg, 1991, P.2), 'supporting local populations' (Teague, 2017, P.348), 'sustainable food supply' (Francis et al., 1986, P.68) and 'reducing food shortages' (Rhodes, 2012, P.345). Other issues mentioned were *fitting social costs* (Dahlberg, 1994, P.174), 'improvements in animal welfare' (Colleya et al., 2019, P.3), 'cultural re-appreciation' (van den Berg et al., 2018, P.314) and 'social diversity, with a variety of knowledge and diverse economies' (Zazo-Moratalla et al., 2019, P.16). This theme presents different issues in which we can discriminate human health and wellbeing issues relating to different scales (e.g. farm families, local populations). For example, some articles mentioned human health issues (e.g. physical conditions) and other human wellbeing issues (e.g. happiness of the farmer). An issue which is recognized by only one author is that RA values spirituality in their holistic approach of farming (Dahlberg, 1994).

The theme of *improve economic prosperity* refers to the economic sustainability of farmers: twelve out of 28 studies mentioned a total number of fifteen issues regarding economic prosperity. Issues among this theme showed some divergence but lacked operationalisation. Studies presenting economic issues mentioned that regenerative agriculture creates e.g. 'long-term economic sustainability' (Teague and Barnes, 2017, P.83), 'improves crop yields' (Rhodes, 2017, P.80), 'improves soil productivity' (Francis et al., 1986, P.68) and 'political-economic repositioning' (van den Berg et al., 2018, P.315). Although these issues present various diverging objectives, they all reflect that regenerative economics work towards a sustained farm income providing goods and services that contribute to human well-being and global food security. From the objectives within this theme, it remains unclear what activities are involved to reach for example long-term economic sustainability.

4. General discussion

This study is the first to systematically review the background and core themes of RA based on peer-reviewed articles. Analysis of the 28 included articles showed that there is currently no uniform scientific definition. Instead, multiple combinations and variations of objectives and activities together define RA. The convergence within these definitions resulted in the core themes of RA. These core themes are compatible with the ecosystem services described by TEEB (2010). Themes such as *enhance and improve soil health*, *optimize resource management*, *alleviate climate change and water quality and availability* are contributing to multiple provisioning and regulating ecosystem services. These provisioning and regulating ecosystem services described by TEEB (2010) contribute to food security and relate to the core themes of RA by for example regulating climate, soil erosion and water purification to provide i.e. food, feed and fuel. Themes such as *improve soil physical quality* and *improve nutrient cycling* are aspects that come back as supporting ecosystem services. The socio-economic dimension we found in RA, *improve human health* and *improve economic prosperity* relates, furthermore, to some components of cultural ecosystems services. From our review we, therefore, propose a provisional definition in which RA is defined as: *an approach to farming that uses soil conservation as the entry point to regenerate and contribute to multiple provisioning, regulating and* supporting *ecosystem services, with the objective that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production.* We acknowledge that RA is a rapidly evolving farming approach in which more views and studies could allow further refinement of the proposed definition. Although for example, Diop (1999) and LaCanne and Lundgren (2018) based their study on farmers perception in relation to RA, we used peer-reviewed articles including opinion, review and research articles mainly focusing on environmental aspects of RA. These peer-reviewed articles articulated insights of natural scientists rather than other actors such as farmers and policy makers.

Related to this description, we will further discuss 1) the core themes of RA, 2) the relation of RA with circular and organic agriculture to show their convergence and 3) the next step in fostering the transition towards RA.

i) The core themes of RA

In this study we reviewed 28 peer-reviewed articles which enabled us to describe themes that together characterize RA. These peer-reviewed articles mentioned in general convergent objectives related to environmental themes such as resource management, water quality and availability, alleviate climate change, with a strong focus on improving soil quality (Fig. 2). This shows that the soil is the base of RA and that RA strongly focusses on the environmental dimension of sustainability. Although socio-economic objectives are mentioned in reviewed articles, the issues raised did not result in underlying themes (issues needed to be mentioned five times to become a theme).

The themes are, however, sensitive to the amount of convergent issues appropriate to form a theme. From the sensitivity analysis, we learnt that, had we chosen three convergent issues to form a theme, then *cultural diversity* would have been underlying to the theme *improve human health.* In addition, eight other themes could then have been formed as well, which include *minimize waste* underlying to *optimize resource management*; *minimize erosion, improve water holding capacity and improve water infiltration* underlying to *improve soil physical quality*; *intercropping, the use of windbreaks, forest farming, riparian buffers, silvopasture and managed grazing* in addition to *minimize fertilizer and pesticide use* among activities.

ii) The relation of RA with circular and organic agriculture

In order to illustrate the convergence between sustainable farming approaches, we relate the themes of RA to circular agriculture (CA) which remains yet a theoretical concept and organic agriculture (OA) as an example of a regulated farming approach.

CA originates from a much broader concept than RA, the circular economy (CE) using the 4R-framework (reuse, repair, refurbish and recycle) as a base-line (Fan et al., 2020; Jurgilevich et al., 2016). CA uses the themes of industrial ecology as it promotes the circular utilization of agricultural resources and waste products (Fan et al., 2020; Kusano et al., 2019; Zhu et al., 2019). The entry point in CA is, therefore, to keep flows of mass and energy of products at their highest utility through a positive developing cycle (Blau et al., 2018; Van Zanten et al., 2018). RA has a different entry point namely healthy soils and environmental issues which should be in balance with social values (e.g. Diop, 1999). While, RA and CA may have different entry points in their approaches, both rely strongly on the environmental dimension of sustainability, since they share similar objectives regarding e.g. reducing environmental externalities and optimizing resource management. Nevertheless, RA also shows to relate to a social dimension. By contrast, it is unclear to which extent CA also relates to this social dimension, since the current reviewed articles about CA did not mentioned social issues within their definitions. The different entry points of RA and CA may lead to a different focus in their farming approach, in which CA focuses on topics such as avoidance of waste and the reuse of resources. Recently, this 4R framework from CE is translated to themes related to circularity in agricultural production – referred to as circular food systems (de Boer and van Ittersum, 2018; Van Zanten et al., 2019). The themes of circular food systems go beyond agriculture production and also take into account consumption, therefore circular food systems work on a larger scale compared to RA and also includes issues such as reuse of by-products and feed-food competition (Van Zanten et al., 2019).

OA is an example of a farming approach that has a comprehensively described scientific definition and is regulated by different authorities worldwide, e.g. European Commission (2019) and USDA (2019). The timeline of organic agriculture is described by Arbenz et al. (2016) in which OA started very similar to RA, with a pioneering phase (known as Organic 1.0). In this pioneering phase objectives where used to define OA as a farming approach that contribute to sustainable global food security while respecting all dimensions of sustainability. RA, as shown in this paper, is currently in this pioneering phase and the regenerative themes defined in this paper are to varying extents convergent with aspects mentioned in OA as IFOAM – Organics International (2019) focuses on the health of soils, ecosystems, people and their management which relies on ecological processes (e.g. nutrient cycling, biodiversity). The objectives in the pioneering phase, evolved into Organic 2.0 in which OA was regulated by certification of standards (Arbenz et al., 2016). These standards presented as a set of technical checklists (e.g. USDA, 2019), described mostly what 'not to do', for example, 'Do not use synthetic pesticides'. Synthetic pesticides are replaced by 'natural inputs' such as organic pesticides (zinc and copper oxide) which, however, still have a damaging effect on the environment (e.g. loss of biodiversity) (Kuehne et al., 2017). These standards, therefore, often fail to entirely capture the aspects that are at the core of the organic philosophy (Arbenz et al., 2016) and it may be that some organic farmers are 'locked' into organic regulations to guarantee the delivery of products that conform to organic standards. The Organic 3.0 strategy recognizes this and aims to change this by becoming less prescriptive and more descriptive, working towards the replacement of the list of 'do's and don'ts', with a mode of outcome-based regulations which should continuously be adaptable to local contexts (Arbenz et al., 2016). This requires a systemic shift towards an integrative farming approach like RA (LaCanne and Lundgren, 2018). Such an integrative farming approach does not focus on individual (pre-decided) sustainable activities, but on improving ecological and social processes and observable outcomes which enable a larger solution space for implementing sustainable activities. Some authors, therefore, mention that regenerative activities are organic, however, other reviewed articles showed that not all organic activities are regenerative (e.g. Pearson, 2007; Rhodes, 2017) for example the use of organic pesticides and raw minerals. Not all objectives of OA however are centre-stage in RA, with one difference being the objective to promote animal welfare (European Commission, 2019b). Improvement of animal welfare is mentioned in one peer-reviewed article defining RA, although certification frameworks for RA such as Regenerative Organic Certification do put animal welfare centre-stage. As RA is currently in the pioneering phase, there is merit in building on the learnings from the evaluation of OA through the last hundred years, to avoid and leapfrog similar pitfalls that may arise.

iii) The next step in fostering the transition towards RA

This review showed the core themes of RA from the many definitions that are presented in peer-reviewed articles. These core themes of RA, enable to define indicators to allow actors to regulate and control their activities to foster the transition towards RA. The reviewed articles do show indicators on some specific practices of RA, for example, Elevitch et al. (2018) provide regenerative agroforestry standards. They present a measure which should increase biodiversity throughout the life of the agroforest: at least eight plant families, genera, species, and/or varieties of woody perennials per 100 m^2. It is, however, unclear if this measure refers to each category (e.g. families, genera, species) individually or whether it refers to the sum of the individual categories. Furthermore, the applicability of these standards to other farming practices is limited. Based on the current reviewed articles we were therefore unable to identify specific indicators which allow for a generic assessment of RA. Other research, however, shows a wide range of indicators are already available for sustainability assessments (De Olde et al., 2016) which can be related to each of the themes underpinning RA. Having derived a clear provisional definition, our next step is to link these indicators to the themes of RA described in this paper, in order to facilitate a comprehensive assessment of RA and potentially refine the definition.

5. Conclusion

This review has systematically assessed definitions of RA in 28 peer-reviewed articles. Our analysis has shown that such definitions are based on several combinations and variations of recurring objectives and activities from scientists. The convergence within these definitions allowed us to formulate core themes of RA. Our findings show that RA focuses strongly on the environmental dimension of sustainability, which includes themes such as *enhance and improve soil health*, *optimize resource management*, *alleviate climate change, improve nutrient cycling* and *water quality and availability*, articulated by both objectives (e.g. improve soil quality) and activities (e.g. use perennials). These themes enhance food security by contributing to provisioning (e.g. food, feed and fibre), regulating (e.g. climate regulation, soil erosion and water purification) and supporting (e.g. nutrient cycling and soil formation) ecosystem services. We also found a socio-economic dimension in RA, *improve human health* and *improve economic prosperity,* which relate to aspects of cultural ecosystem services. This socio-economic dimension, however, relies currently on divergent objectives and lacks a framework forimplementation. Therefore, we propose a provisional definition which defines RA as an approach to farming that uses soil conservation as the entry point to regenerate and contribute to multiple provisioning, regulating and supporting services, with the objective that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production. To foster the transition towards RA, this review contributes to establishing a uniform definition; subsequently, indicators and benchmarks should be created to assess RA.

Declaration of competing interest

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.

Acknowledgements

The work presented in this paper is part of TiFN's Regenerative Farming project, a public - private partnership on precompetitive research in food and nutrition. The authors have declared that no competing interests exist in the writing of this publication. Funding for this research was obtained from FrieslandCampina, Cosun, BO Akkerbouw, TKI Agri & Food and TiFN.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gfs.2020.100404.

References

Arbenz, M., Gould, D., Stopes, C., 2016. Organic 3.0 – for Truly Sustainable Farming and Consumption (Bonn).
Blau, M., Luz, F., Panagopoulos, T., 2018. Urban river recovery inspired by nature-based solutions and biophilic design in Albufeira. Portugal. Land 7, 141. https://doi.org/10.3390/land7040141.
Borgatti, S.P., 1994. Cultural domain analysis. J. Quant. Anthropol. 4, 261–278.
Bot, A., Benites, J., 2005. The Importance of Soil Organic Matter. FAO, Rome.
Campbell, B.M., Beare, D.J., Bennett, E.M., Hall-Spencer, J.M., Ingram, J.S.I., Jaramillo, F., Ortiz, R., Ramankutty, N., Sayer, J.A., Shindell, D., 2017. Agriculture

production as a major driver of the earth system exceeding planetary boundaries. Ecol. Soc. 22 https://doi.org/10.5751/ES-09595-220408.

Cole, J.R., McCoskey, S., 2013. Does global meat consumption follow an environmental Kuznets curve? Sustain. Sci. Pract. Pol. 9, 26–36. https://doi.org/10.1080/15487733.2013.11908112.

Colleya, T.A., Olsena, S.I., Birkved, M., Hauschilda, M.Z., 2019. Delta LCA of regenerative agriculture in a sheep farming system. Integr. Environ. Assess. Manag. https://doi.org/10.1002/ieam.4238, 0–3.

Dahlberg, K.A., 1994. A transition from agriculture to regenerative food systems. Futures 26, 170–179. https://doi.org/10.1016/0016-3287(94)90106-6.

Dahlberg, K.A., 1991. Sustainable agriculture - fad or harbinger? Bioscience 41, 337–340. https://doi.org/10.2307/1311588.

de Boer, I.J.M., van Ittersum, M.K., 2018. Circularity in agricultural production. Mansholt Lect 1–74.

de Haas, B.R., Hoekstra, N.J., van der Schoot, J.R., Visser, E.J.W., de Kroon, H., van Eekeren, N., 2019. Combining agro-ecological functions in grass-clover mixtures. AIMS Agric. Food 4, 547–567. https://doi.org/10.3934/agrfood.2019.3.547.

De Olde, E.M., Oudshoorn, F.W., Sørensen, C.A.G., Bokkers, E.A.M., De Boer, I.J.M., 2016. Assessing sustainability at farm-level: lessons learned from a comparison of tools in practice. Ecol. Indicat. 66, 391–404. https://doi.org/10.1016/j.ecolind.2016.01.047.

Diop, A.M., 1999. Sustainable agriculture: new paradigms and old practices? Increased production with management of organic inputs in Senegal. Environ. Dev. Sustain. 1, 285–296.

Elevitch, C.R., Mazaroli, D.N., Ragone, D., 2018. Agroforestry standards for regenerative agriculture. Sustain 10, 1–21. https://doi.org/10.3390/su10093337.

Elkington, J., 1997. Cannibals with Forks: the Triple Bottom Line of 21st Century Business. Capstone Publishing Ltd, Oxford, UK.

European Commission, 2019a. The Common Agricultural Policy: Separating Fact from Fiction.

European Commission, 2019b. Organic at a glance [WWW Document]. Eur. Comm. URL. https://ec.europa.eu/info/food-farming-fisheries/farming/organic-farming/organics-glance. accessed 6.25.19.

European Commission, 2015. Closing the Loop - an EU Action Plan for the Circular Economy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Com 614 final, p. 21.

Fan, W., Dong, X., Wei, H., Weng, B., Liang, L., 2020. Is it true that the longer the extended industrial chain , the better the circular agriculture ? A case study of circular agriculture industry company in Fuqing. Fujian 189, 718–728. https://doi.org/10.1016/j.jclepro.2018.04.119.

FAO, 2018. Climate-smart Agriculture Case Studies 2018. Successful Approaches from Different Regions (Rome).

FAO, 2013. Policy Support Guidelines for the Promotion of Sustainable Production Intensification and Ecosystem Services (Rome).

Francis, C.A., Harwood, R.R., Parr, J.F., 1986. The potential for regenerative agriculture in the developing world. Am. J. Alternative Agric. 1, 65–74. https://doi.org/10.1017/S0889189300000904.

Garnett, A.T., Appleby, M.C., Balmford, A., Bateman, I.J., Benton, T.G., Burlingame, B., Dawkins, M., Dolan, L., Fraser, D., Herrero, M., Hoffmann, I., Thornton, P.K., Toulmin, C., Vermeulen, S.J., Godfrey, H.C.J., 2013. Sustainable intensification in agriculture : premises and policies. Science 341, 33–34.

Glover, J.D., Reganold, J.P., Bell, L.W., Borevitz, J., Brummer, E.C., Buckler, E.S., Cox, C. M., Cox, T.S., Crews, T.E., Culman, S.W., DeHaan, L.R., Eriksson, D., Gill, B.S., Holland, J., Hu, F., Hulke, B.S., Ibrahim, A.M.H., Jackson, W., Jones, S.S., Murray, S. C., Peterson, A.H., Ploschuk, E., Sacks, E.J., Snapp, S., Tao, D., Van Tassel, D.L., Wade, L.J., Wyse, D.L., Xu, Y., 2010. Increased food and ecosystem security via perennial grains. Science 328, 1638–1639. https://doi.org/10.1126/science.1188761.

Gosnell, H., Gill, N., Voyer, M., 2019. Transformational adaptation on the farm: processes of change and persistence in transitions to 'climate-smart' regenerative agriculture. Global Environ. Change 59. https://doi.org/10.1016/j.gloenvcha.2019.101965, 101965.

IFOAM - Organics International, 2019. Definition of organic agriculture [WWW Document]. IFOAM - Org. Int. URL. https://www.ifoam.bio/en/organic-landmarks/definition-organic-agriculture. accessed 10.2.19.

Jalali, S., Wohlin, C., 2012. Systematic literature studies: database searches vs. Backward snowballing. In: 6th Int. Symp. Empir. Softw. Eng. Meas., pp. 29–38. https://doi.org/10.1145/2372251.2372257.

Jurgilevich, A., Birge, T., Kentala-Lehtonen, J., Korhonen-Kurki, K., Pietikäinen, J., Saikku, L., Schösler, H., 2016. Transition towards circular economy in the food system. Sustain 8, 1–14. https://doi.org/10.3390/su8010069.

Kuehne, S., Roßberg, D., Röhrig, P., Von Mehring, F., Weihrauch, F., Kanthak, S., Kienzle, J., Patzwahl, W., Reiners, E., Gitzel, J., 2017. The use of copper pesticides in Germany and the search for minimization and replacement strategies. Org. Farming 3. https://doi.org/10.12924/of2017.03010066.

Kusano, E., Yin, C., Chien, H., 2019. Fertilizer-use efficiency of farmers using manure in Liaozhong County. China 53, 127–133.

LaCanne, C.E., Lundgren, J.G., 2018. Regenerative agriculture: merging farming and natural resource conservation profitably. Peer J. 6, 1–12. https://doi.org/10.7717/peerj.4428.

Lockeretz, W., 1988. Open questions in sustainable agriculture. Am. J. Alternative Agric. 3, 174–181. https://doi.org/10.1017/S0889189300002460.

Mahtab, F.U., Karim, Z., 1992. Population and agricultural land use: towards a sustainable food production system in Bangladesh. Ambio 21, 50–55.

Malik, P., Verma, M., 2014. Organic agricultural crop nutrient. Res. J. Chem. Sci. 4, 94–98.

Mitchell, J.P., Reicosky, D.C., Kueneman, E.A., Fisher, J., Beck, D., 2019. Conservation agriculture systems. CAB Rev. Perspect. Agric. Vet. Sci. Nutr. Nat. Resour. 14 https://doi.org/10.1079/PAVSNNR201914001.

Ontl, T., 2018. Soil carbon storage. Soil carbon storage. https://doi.org/10.1016/c2016-0-03949-9.

Pearson, C.J., 2007. Regenerative, semiclosed systems: a priority for twenty-first-century agriculture. Bioscience 57, 409–418. https://doi.org/10.1641/B570506.

Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J., Tran, Q., Saltman, T., Cliff, B., 1997. Economic and environmental benefits of biodiversity. Bioscience 47, 747–757. https://doi.org/10.2307/1313097.

Poore, J., Nemecek, T., 2018. Reducing food's environmental impacts through producers and consumers. Science 360, 987–992. https://doi.org/10.1126/science.aaq0216.

Provenza, F.D., Kronberg, S.L., Gregorini, P., 2019. Is grassfed meat and dairy better for human and environmental health? Front. Nutr. 6 https://doi.org/10.3389/fnut.2019.00026.

Rhodes, C.J., 2017. The imperative for regenerative agriculture. Sci. Prog. 100, 80–129. https://doi.org/10.3184/003685017X14876775256165.

Rhodes, C.J., 2012. Feeding and healing the world: through regenerative agriculture and permaculture. Sci. Prog. 95, 345–446. https://doi.org/10.3184/003685012X13504990668392.

Sambell, R., Andrew, L., Godrich, S., Wolfgang, J., Vandenbroeck, D., Stubley, K., Rose, N., Newman, L., Horwitz, P., Devine, A., 2019. Local challenges and successes associated with transitioning to sustainable food system practices for a west Australian context: multi-sector stakeholder perceptions. Int. J. Environ. Res. Publ. Health 16. https://doi.org/10.3390/ijerph16112051.

Shah, A.N., Tanveer, M., Shahzad, B., Yang, G., Fahad, S., Ali, S., Bukhari, M.A., Tung, S. A., Hafeez, A., Souliyanonh, B., 2017. Soil compaction effects on soil health and cropproductivity: an overview. Environ. Sci. Pollut. Res. 24, 10056–10067. https://doi.org/10.1007/s11356-017-8421-y.

Shamseer, L., Moher, D., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L.A., Group, P., 2015. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation 7647, 1-25. https://doi.org/10.1136/bmj.g7647.

Shelef, O., Weisberg, P.J., Provenza, F.D., 2017. The value of native plants and local production in an era of global agriculture. Front. Plant Sci. 8, 2069. https://doi.org/10.3389/fpls.2017.02069.

Sherwood, S., Uphoff, N., 2000. Soil health: research, practice and policy for a more regenerative agriculture. Appl. Soil Ecol. 15, 85–97. https://doi.org/10.1016/S0929-1393(00)00074-3.

Slingerland, M., Klijn, J., Jongman, R.H.G., van der Schans, J.W., 2003. The Unifying Power of Sustainable Development; towards Balanced Choices between People, Planet and Profit in Agricultural Production Chains and Rural Land Use: the Role of Science (Wageningen).

Steenwerth, K.L., Hodson, A.K., Bloom, A.J., Carter, M.R., Cattaneo, A., Chartres, C.J., Hatfield, J.L., Henry, K., Hopmans, J.W., Horwath, W.R., Jenkins, B.M., Kebreab, E., Leemans, R., Lipper, L., Lubell, M.N., Msangi, S., Prabhu, R., Reynolds, M.P., Solis, S. S., Sischo, W.M., Springborn, M., Tittonell, P., Wheeler, S.M., Vermeulen, S.J., Wollenberg, E.K., Jarvis, L.S., Jackson, L.E., 2014. Climate-smart agriculture global research agenda: scientific basis for action. Agric. Food Secur. 3, 1–39, 2014.

Stehfest, E., Bouwman, L., van Vuuren, D.P., den Elzen, M.G.J., Eickhout, B., Kabat, P., 2009. Climate benefits of changing diet. Climatic Change 95, 83–102. https://doi.org/10.1007/s10584-008-9534-6.

Teague, R., Barnes, M., 2017. Grazing management that regenerates ecosystem function and grazingland livelihoods. Afr. J. Range Forage Sci. 34, 77–86. https://doi.org/10.2989/10220119.2017.1334706.

Teague, W.R., 2018. Forages and pastures symposium: cover crops in livestock production: whole-system approach: managing grazing to restore soil health and farm livelihoods. J. Anim. Sci. 96, 1519–1530. https://doi.org/10.1093/jas/skx060.

Teague, W.R., 2017. Bridging the research management gap to restore ecosystem function and social resilience. Prog. soil Sci. 341–350.

Teague, W.R., 2015. Toward restoration of ecosystem function and livelihoods on grazed agroecosystems. Crop Sci. 55, 2550–2556. https://doi.org/10.2135/cropsci2015.06.0372.

Teague, W.R., Apfelbaum, S., Lal, R., Kreuter, U.P., Rowntree, J., Davies, C.A., Conser, R., 2016. The role of ruminants in reducing agriculture's carbon footprint in North America, 71, 156–164. https://doi.org/10.2489/jswc.71.2.156.

TEEB, 2010. The Economics of Ecosystems and Biodiversity: Economic and Ecological Foundations. Earthscan, London and Washington.

The Eat-Lancet Commission, 2019. Healthy diets from planet. Food Planet Health 32.

Thomas, D.R., 2006. A general inductive approach for analyzing qualitative evaluation data. Am. J. Eval. 27, 237–246. https://doi.org/10.1177/1098214005283748.

Tilman, D., Clark, M., 2014. Global diets link environmental sustainability and human health. Nature 515, 518–522. https://doi.org/10.1038/nature13959.

United Nations, 2015. Convention on climate change: climate agreement of Paris, 1–27. https://doi.org/10.1017/s0020782900004253.

USDA, 2019. USDA organic regulations, title 7: agriculture, part 205 - national organic program, subpart C - organic production and handling requirements. §205.206 Crop pest, weed, and disease management practice standard. [WWW Document]. URL. https://www.ecfr.gov/cgi-bin/text-idx?SID=58c3968b394f3c5590a2f4aefe7f817a&mc=true&node=se7.3.205_1206&rgn=div8. accessed 10.22.19.

van den Berg, L., Roep, D., Hebinck, P., Teixeira, H.M., van den Berg, L., Roep, D., Hebinck, P., Teixeira, H.M., 2018. Reassembling nature and culture: resourceful farming in Araponga, Brazil. J. Rural Stud. 61, 314–322. https://doi.org/10.1016/j.jrurstud.2018.01.008.

Van Zanten, H.H.E., Herrero, M., Van Hal, O., Röös, E., Muller, A., Garnett, T., Gerber, P. J., Schader, C., De Boer, I.J.M., 2018. Defining a land boundary for sustainable livestock consumption. Global Change Biol. 24, 4185–4194. https://doi.org/10.1111/gcb.14321.
Van Zanten, H.H.E., Van Ittersum, M.K., De Boer, I.J.M., 2019. The role of farm animals in a circular food system. Glob. Food Sec. 21, 18–22. https://doi.org/10.1016/j.gfs.2019.06.003.
White, R.E., Andrew, M., 2019. Orthodox soil science versus alternative philosophies: a clash of cultures in a modern context. Sustain 11, 2–7. https://doi.org/10.3390/su11102919.
Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., Declerck, F., 2019. The lancet commissions food in the anthropocene: the EAT – lancet commission on healthy diets from sustainable food systems 6736. https://doi.org/10.1016/S0140-6736(18)31788-4.
Zazo-Moratalla, A., Troncoso-González, I., Moreira-Muñoz, A., 2019. Regenerative food systems to restore urban-rural relationships: insights from the concepción metropolitan area foodshed (Chile). Sustain 11. https://doi.org/10.3390/su11102892.
Zhu, Q., Jia, R., Lin, X., 2019. Building sustainable circular agriculture in China : economic viability and entrepreneurship. https://doi.org/10.1108/MD-06-2018-0639.