Regenerative Agriculture and Farmscape Function

Subjects: Green & Sustainable Science & Technology

Contributor: Thomas O'Donoghue , Budiman Minasny , Alex McBratney

The concept of a regenerative agriculture can be traced back to the cusp of the 1980s and discussions of sustainability. Early authors stressed that to achieve sustainable food production, the resources agriculture depended upon initially needed to be restored from the degraded state conventional agriculture had caused. For modern authors, within and outside regenerative agriculture, these resources—soil, water, biota, and the long term viability of human agricultural labor—have continued to deteriorate. To prioritise the regeneration of these resources; as has begun with the concept of ecosystem functions, goods, and services generally; researchers must specifically determine the functions people require of their farmscapes so that agricultural systems can be iteratively designed to meet these needs.

regenerative agriculture | sustainable agriculture | farmscape function | agricultural movement | landscape ecology | Jethro Tull

1. Introduction

The concept of a regenerative agriculture can be traced back to the cusp of the 1980s and discussions of sustainability [1][2][3]. These early authors stressed that to achieve sustainable food production, the resources agriculture depended upon initially needed to be restored from the degraded state conventional agriculture had caused [1][2][3]. The idea of agricultural sustainability had been discussed since the 1950s and 1960s [4][5] and would become a key element of the United Nations (UN)-backed Brundtland Commission (1983–1987). For modern authors, within and outside regenerative agriculture, these resources—soil, water, biota, and the long term viability of human agricultural labor—have continued to deteriorate [6][7][8][9][10][11][12][13][14][15]. With global population predicted to exceed 9.7 billion by the midcentury [16] and the demands of this population anticipated to require a substantial increase in agricultural output (by 70–100% [17][18][19]), pressure for sustainable food production continues to grow. Discussions can, should, and have been had about minimizing food waste as well as the proportion of this projected increase that can be attributed to changing dietary needs and wants globally [20][21]. However, if the natural resources that humanity relies on are becoming less reliable, then meeting our production goals, wherever they rest, will become increasingly challenging. This fact has not escaped international political communities. In response, the United Nations (UN), along with various international and national bodies, has issued several calls to action. Recently, the UN declared 2021–2030 the decade of ecological renewal (www.decadeonrestoration.org, accessed on 19 August 2021).

1.1. International Impetus to Improve Ecosystem Function

The UN's Millennium Ecosystem Assessment (2000–2005) (MEA) built on Our Common Future [22] and stressed how human wellbeing is reliant on the goods (resources) and services a functioning ecosystem provides [7][23]. The assessment found that for all services (and sub-services) where change was determined (19 of the 24 considered), all except four had deteriorated since the 1950s at a rate more rapid and extensive than any other period in human history [7]. Of the four that had increased, three related to agricultural productivity and the fourth saw the global ecosystem become a sink rather than source for atmospheric carbon [7]. Even more concerningly, it was predicted that without correction, the provisioning of these already deteriorated services would likely worsen in the first half of this century because of population growth and the further conversion of natural landscapes to agricultural production [7]. This dire outlook was reflected in the proportional increase of environmentally focused UN development goals: from 1 of 8 Millennium Development Goals [24] to 5 of 17 Sustainable Development Goals [25].

As 37.5% of the Earths land surface [26] is dedicated to agricultural production, the clear question is, if that land was once providing multiple functions but now is focused on production alone, can humanity change how people practice agriculture to deliver at least a portion of those functions, services, and goods lost—be they resilience through biodiversity, carbon storage, freshwater provisioning, etc.—while producing food and fiber? Several recent Food and Agriculture Organization (FAO) publications are still seeking to promote and encourage further development and adoption of potential solutions to this question; *The State of the World's Biodiversity for Food and Agriculture* (2019), *The State of the World's Land and Water Resources for Food and Agriculture—Systems at Breaking Point* (2021), and *Recarbonizing Global Soils—a technical manual of recommended management practices* (2021).

1.2. Conventional Agriculture and Its Alternatives

In response to the apparent dichotomy between sustaining our growing human population through agricultural production and maintaining the ecosystem functions that humanity and production rely upon, conventional agriculture has, since the 1970s and 80s, been barraged by alternative methods of production [27]. Conservation agriculture, agroecology, precision agriculture, permaculture, organic agriculture, and biodynamic agriculture are a few examples. The origins of some stretch back to the early 20th century, but their promotion as alternatives is strongly linked to the idea of sustainability which, as outlined, was brought into focus on a global stage in the mid-1980s. Here, conventional agriculture will refer to the dominant system of production in a region, whereas an alternative to the conventional will be any system other than the conventional. This terminology has been adopted because dominant systems of production vary between regions [8][28]. For alternatives, further clarification is required. Alternative agriculture frequently refers to systems of production that are characterized by a turning away from "advancements" that have been adopted by the mainstream or towards other "advancements" that have not been acknowledged by the mainstream, the most prominent being organic agriculture. These systems of agricultural production, conventional and alternatives to the conventional, will be considered here within their wider political and social context as **agricultural movements** striving for change in agricultural practice. Regenerative agriculture is the most recent agricultural movement to gain a global presence as an alternative to the conventional.

1.3. Comparing Performance

With variation comes a need for comparison. Since the concept of Sustainable Development was formally adopted by the United Nations with the Rio Convention (1992), attempts to assess the sustainability of our food and fiber production systems have taken center stage and proliferated prodigiously. A 2020 review identified 19 applicable tools from a selection pool of 157 [29]; and another, for a single scenario in Denmark in 2015, from 48 indicator-based sustainability assessment tools found only four were applicable for the livestock systems being considered [30]. These assessments consider multiple scales; the field, farm, watershed, state; numerous methods of analysis; life cycle, cost benefit, environmental impact, criteria-indicator systems [31][32]; and centrally, the three pillars of sustainability as outlined by Brundtland [22]; environment, economy, and society. Variations in approach and scale make comparison between methods difficult. The three-pillared scope which is often simplified to a single variable output—euro/dollar, or CO_2 emissions—draws focus to a specific industry, if not a region, and can mask the contribution of individual elements within the system delivering those products. Specific farm management practices and the impacts of these can get lost within post farm product processing and transport variables (to name two smothering factors). Within these frameworks, identifying the contributions that agricultural systems make to ecosystem functions becomes difficult. Of these existing methods of analysis, criteria-indicator systems offer the potential for multi-variable output and are increasingly prominent [31][33].

Although the movement’s motivations and methods of practice have not yet been formally defined [8][34][35][36][37], assessment systems for regenerative agriculture have been brought forward in the image of the now ubiquitous sustainability assessment: life cycle—sheep production, Australia [38]; criteria-indicator—almond production, Spain [39]; criteria-indicator—almond production, CA, USA [40]. Unfortunately, these too suffer from the specificity of scale and industry.

One solution to simplify the comparison of agricultural systems, and to increase independence from the products they produce, is to consider what ecosystem goods and services are needed from agricultural landscapes (farmscapes) and to compare the ability of different agricultural systems to improve the functions that provision these over time. From this perspective, expected **farmscape functions** will include those of natural and productive landscapes. Determining the functions being pursued is where the motivations of the agricultural movement become of interest. Each will stress and may consider different farmscape functions as priorities [14]. For example, conservation agriculture, in many locations, is focused on increasing soil organic matter and plant-available water, whereas organic agriculture places an increased focus on above ground faunal diversity. While each movement may be seeking different outcomes, identifying what the intentions of these movements are, along with a set of intentions for farmscapes in general, will allow for the comparison of each according to: the movement’s own intentions, another movement’s intentions, or a third party’s intentions. Third party intentions could be drawn from the ecosystem functions considered by MEA [7], Costanza et al. [23], de Groot et al. [41], or other similar wide reaching frameworks, e.g., multifunctional agriculture [42] or multifunctional ecosystems [14]. Comparing agricultural systems over time based on farmscape function will prioritize the development of farmscapes that contribute to ecosystem functions, build the resources agriculture relies on, and in doing so, provide multiple goods and services to humanity.

2. Current and Early Alignment on the Intentions of Regenerative Agriculture

Original articulations of regenerative agriculture sought to:

- Repair the damage its supporters perceived had been done to natural resources and regional communities through conventional agriculture [1][2][3].
- Rodale identified that progress towards regenerative practice would be iterative and be achieved through increased natural complexity [2].
- Sampson highlighted a role for financial motivators in this process [3].
- The target resources for regeneration were identified—soil, biota, water, human endeavor, and energy [2][3], with the availability of all but energy to be increased. Energy, in nonrenewable and synthetic forms, was to be reduced and the capture of natural sources maximized.
- Soil fertility, integrated pest management, advances in plant breeding, and integrated crop-animal systems were flagged as pathways to achieving regenerative and, ideally, a sustainable agriculture [43].

Prior to the re-emergence of regenerative agriculture in the 2010s, innovations from farmers led to the development of practices and systems that sought inspiration from alternatives to the conventional and frequently through practices that relied on natural complexity. These farmers and supporters of their systems later rallied under the regenerative banner. The methods of management they developed and adopted began to turn greater profits [44][45][46][47]. Limited soil disturbance, holistic grazing, cover cropping, and resilience through biodiversity are key features of these systems [35][38][44][45]. Other outcomes from this current period include:

- Practices were perceived to be so successful that many have used them to define the movement [34][37].
- An intention to maintain iterative practice based on function principles that reflect the early resources, e.g., soil, water, biota, human, and energy, permeates the movement.
- Current academic work is growing to accept regenerative agriculture. Acceptance has focused on bringing the work of successful farmers to light [38][46][48]. Critical work continues to call for greater consideration of context and a validation of claims from successful practitioners [37][49].

Alignments exist between the original articulations and current practice through the focus on resources and the initial directive and subsequent iterative innovation through natural complexity. Soil, water, biota, human endeavor, and energy, are the five environmental dimensions of our farmscapes and the targets for regeneration. Add to this a harvestable crop, and these six dimensions encapsulate the intentions of a regenerative agriculture.

3. Sources of Potential

The level of existing farmer, consumer, and corporate support for regenerative agriculture offers a unique opportunity at this stage of the movement’s growth. The system the movement supports is yet to be formally defined [34][50]. Although, there is pressure from academics and industry for a definition based on performance [48][51][52][53]. Without a definition, further work will risk developments made in political, practical, and commercial aspects of the movement [34]. Existing regenerative systems offer the opportunity to identify exemplars and map transitions in practice to guide new adopters. Existing consumer markets offer a means to reward farmers immediately for practice change. Furthermore, corporate suppliers are financially assisting farmers to transition their practice [52][54]. With participation in carbon sequestration markets and other emerging ecosystem service markets (biodiversity [55]) will further incentivize farmer adoption.

To maintain momentum, the movement’s supporters need to be satisfied. Products need to perform. In the past, a lack of clarity about what is and is not organic has led to greenwashing and a loss in the social cache of the brand [56][57]. Current practice-based certification programs do not guarantee performance. Current outcome-based certification programs could offer a greater degree of transparency. Losing the increased market value of a certified product will lead to reservations about transitioning systems, for some. A sound definition will prevent the concept being co-opted or diluted [34][58]. This results in two questions.

- How do people ensure performance?
- How do people define regenerative agriculture?

Before these questions are addressed, regenerative agriculture needs to be placed among other major agricultural movements.

4. Other Agricultural Movements

A multitude of movements populate the agricultural landscape. Some of the more widespread/established movements have already been mentioned, and others are raised here, but this list will not be exhaustive. For the movements that are explored, the intentions, methods of application, and known degrees of success achieved are outlined. The collective focal points of these movements are demonstrated to share commonalities, while the methods employed to reach these goals differ.

The most prominent alternative to conventional systems worldwide is conservation agriculture [59]. In some regions, it has become the conventional; Australia and the Northern Plains of the U.S. are prime examples [8]. The second most prominent system globally is organic agriculture; however, its share of annual global cropland sits below 1% [60]. Both have intentions to conserve soil, improve on farm biodiversity, increase soil organic carbon, and improve farmers' socioeconomic outcomes [8][61]. Conservation agriculture also focuses on water-use efficiency [62] and quality [8], while organics place a high priority on aboveground biodiversity outside of commercial crops [63]. Conservation agriculture, developed off the back of the green revolution in the 1970s and 1980s, was enabled by the development of herbicides, e.g., glyphosate (Roundup^{TM}), that provided an option for weed control aside from tillage in broadacre cropping [8][59]. Conservation agriculture has three principles: minimize soil disturbance, increase ground cover, and increase biodiversity through crop rotations [62]. The application of these principles has predominantly been practice based: limiting tillage, retaining stubble and/or incorporate cover crops, and increasing the complexity of crop rotations [59]. Organic Agriculture has a longer history, a development attributed to several academics and agriculturalists, i.e., F. H. King, Lady Eve Balfour, Sir Albert Howard, Masanobu Fukuoka, and Lord Northbourne [8][63]. Initially, organics focused on agricultural system design and then on the use of compost in place of synthetic fertilizers [58][61]. The development of human-derived technologies, such as genetically modified organisms and *biocides* (fungicides, insecticides, and herbicides), saw the movement's priorities narrow. This phase, Organic 2.0, was characterized by certification through exclusion of GMO and synthetic inputs [61]. Many comparisons between organic, conservation, and conventional agriculture have been made. Conservation yields have been placed 10, ~5, and 2.5% below conventional yields (where only no-till, two of three, and all principles were adopted respectively) [64]. Several meta-analyses placed organic yields between 10–30% below conventional yields, depending on the crop [14][65][66][67]. In terms of both of the movement's goals, soil organic carbon gains for each have been debated. In conservation agriculture, initial increases were later linked with potential redistributions of soil carbon and compaction [28][68]. In some instances organic systems have been reported to have higher soil carbon contents, but skepticism exists around the scalability and level of organic inputs required to deliver these gains [65] especially in tillage-reliant systems [8]. Profits in organic agriculture, due to specialized markets, were found to be greater, as were biodiversity outcomes [14]. In recent years, organic agriculture has announced a new phase, Organic 3.0, where focus is shifting to become "less prescriptive and more descriptive" and is working towards outcome-based regulations adaptable to local contexts [61].

Many less prominent agricultural movements are principle based, with the difference from conservation agriculture here being the degree of interpretation required to develop practices from the guiding principles. Many of these began at a similar time or grew in prominence substantially during the 1970s and 1980s: permaculture, syntropic agriculture, agroecology, and agroforestry. Permaculture seeks to maximize the use of resources, i.e., soil, water, energy, and biota, and the mutually beneficial aspects of elements within the system [69]. Parallels are commonly drawn between regenerative agriculture and permaculture [70][71][72]. Syntropic agriculture shares principles with permaculture but enacts these through a focus on ecological succession [73][74]. Agroecology (simultaneously a science, movement, and agricultural system), in practice, focuses on soil organic matter and health, maintaining genetic diversity, animal integration, beneficial insect integration, and the championing of indigenous farming methods to improve system resilience [75]. Agroforestry, more simply, is "the intentional integration of trees and shrubs into crop and animal production to create environmental, economic, and social benefits” [76]. Unfortunately, the proportion of global acreage dedicated to these systems is smaller than organics, and because of this relatively small contribution to global production, the resources dedicated to the progress each makes on their intentions are limited. However, the benefits their perspectives could bring to agricultural production are being explored [77][78]. The advantage of these systems is that practices guided by principles become a means to an ends. This encourages innovation within the agricultural community in relation to a system of production’s context (climate, topography, geology, biology, and specific socioeconomic conditions), resulting in diverse systems of practice that reflect a region’s contextual variations. The reduced spread of these practices limits their ability to generate their own widespread markets, and while their focus on principle-based system design encourages innovation, the lack of quantified performance leaves these movements without hard numbers on the contributions made towards the goals they champion.

Agricultural movements without specified practices or principles also exist, with the most prominent being sustainable intensification [79], ecological intensification [80], and climate-smart agriculture [8]. The first two emerged in the late 1990s in response to the growing awareness of agriculture’s role in viable population growth, environmental degradation, and socioeconomic issues [79][80]. Sustainable intensification focuses on meeting food needs whilst also delivering positive environmental outcomes, specifically targeting water, soil, biodiversity, and land [10]. Ecological intensification focuses on closing the yield gap while meeting acceptable environmental standards [81]. Neither preferences a production system, emphasizing dual goals rather than means, and both saw innovations in biological and soil management, particularly in relation to hydrology, as the most immediate avenues for meeting projected food needs [79][80]. However, both have been criticized for their lesser focus on ecological dimensions [8][15]. Without specifying principles, applications of the movement’s intentions through practices were left open to interpretation. Sustainable intensification is a key example. The movement, which was envisaged with “regenerative” low input agriculture in mind [8], was proposed by Pretty [82] shortly after authoring *Regenerating Agriculture* [79]. In the 2010s, conservation agriculture was adopted in sustainable intensification’s name [59], with the point of contention being that in many regions (Australia and the U.S. in particular) conservation agriculture is associated with high input systems. The final nonpractice based movement considered here, climate-smart agriculture, came about in response to increasing pressure for action on climate change—coupled with the scale of agriculture, the degraded state of our soils [83], and conservation agriculture’s focus on building soil organic matter [8]. The movement was embraced by the FAO as climate-smart agriculture [59] or a way to build climate-smart soils [84]. Conservation agriculture’s credentials on both fronts have already been evaluated.

Collectively, the movements discussed previously, which all were or are alternatives to conventional agriculture, focus on productive outcomes, including food or fiber and various environmental and human-social outcomes. For example, there is focus on soil organic matter, biodiversity, limiting erosion, ethical labor conditions, and increasing water availability, etc., each of which align, to varying degrees, with the resources that regenerative agriculture seeks to rebuild within farmscapes: soil, water, biota, human, and energy [8][10][61][75][85]. This observation has been made by others and led to regenerative agriculture being proposed as an umbrella term for agricultural movements that seek environmentally and socially positive outcomes [34][51][71]. Similar observations have been made for conservation agriculture [8], sustainable intensification [10][79], and organic agriculture [3] recently [61], all of which have also been linked with regenerative systems. The progress of these movements on their respective intentions, demonstrates that while some success has been found (organics; biodiversity and profitability), a disconnect exists between intention, practice, and performance.

5. Assessing Agricultural System Performance

Assessing a single parameter for an agricultural system, e.g., gains in soil carbon or yields over time, while potentially indicative of a system's performance in a certain capacity, does not reflect performance on its collective intentions. Many attempts to assess agricultural systems have been made, but as outlined in the introduction, sustainability assessments are often simultaneously too broad, considering an agricultural product's life cycle, and too specific, usually holding an industry focus, to allow for comparison of farming system performance at the property or field level. For the preponderance of sustainability assessments, other systems of assessment have been created in their image: resilience [86][87], regenerative potential [53], and agricultural ecosystem multifunctionality [14]. These have focused on comparisons between systems, often simplifying output to a single value. Widespread, regular, open monitoring and, hence, change over time, has not yet been achieved. The growing urgency with which the international political community is seeking to restore ecosystem function is placing pressure on agricultural systems to deliver more than just productivity.

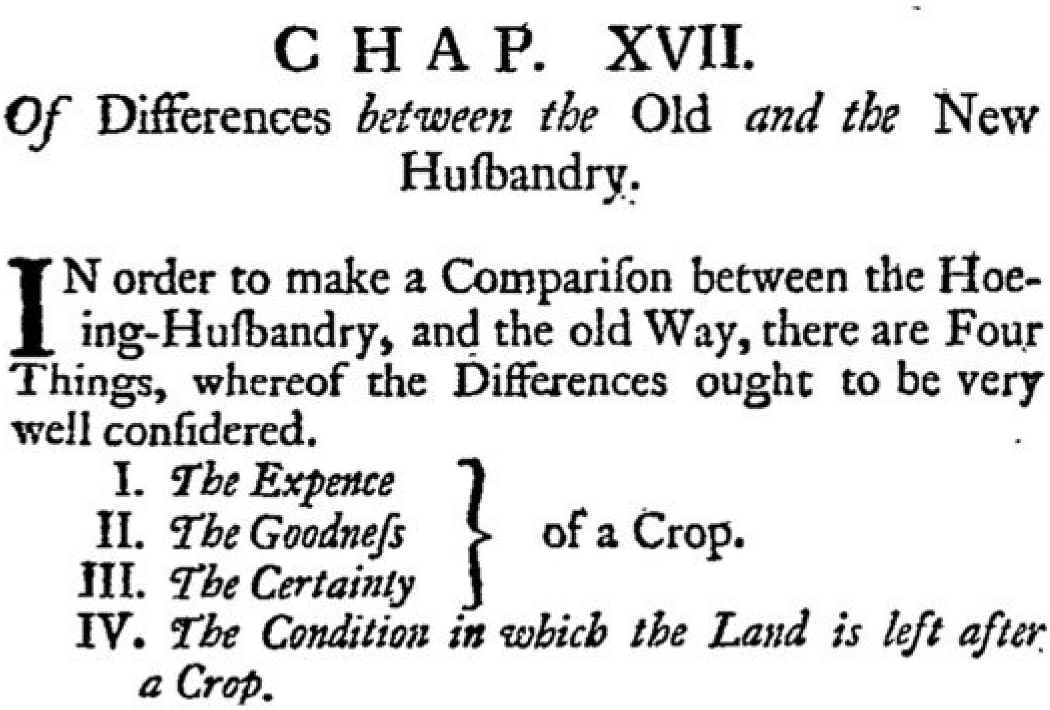
To assess the performance of a farming system against a desired set of farmscape functions, a logical place to start would be the goods and services it offers at a farm or field level. However, the heterogeneity of our global farmscapes would render direct comparison of goods and services, or even render the change, over time, meaningless, given the different capacities, initial condition, and potential for improvement. The varying capabilities of soil alone demonstrates this [88]. Furthermore, the sheer number of variables required to monitor all agricultural resources through existing approaches would make the endeavor unviable. Considering ecosystem services as a candidate framework, i.e., the MEA listed 24, Costanza in 1997 listed 17, and de Groot in 2002 listed 23, and each acknowledged that these services are dependent on a myriad of functions and goods [7][23][41]. Without a practical number of indicators to assess or a viable means to compare, it is understandable that practice/compliance-based methods of certification have dominated, historically.

The Savory Institute's Ecological Outcome Verification (EOV) system does consider indicators and respects the variation in the inherent capacity of our farmscapes. Encouragingly, this system did not develop in a vacuum. Just as the Savory Institute stresses the need to measure biodiversity, infiltration, and soil carbon, these elements are also reflected in Massy and Brown's major works. Massy refers to "landscape function" almost 60 times in his 500-page book [44], whereas Brown refers to soil health 75 times in his 200-page book [45]. Landscape function for Massy refers to the natural functions expected of a landscape, and soil health is defined by the U.S.-based Soil Health Institute as "the continued capacity of a soil to function as a vital living ecosystem that sustains plants, animals, and humans" [89]. Both terms focus on ecology and natural (ecosystem) functions. However, the two do not capture the productive or human-based capacity of our landscapes, hence why, at least in part, the term farmscape function has been adopted here.

Academically, the term landscape function can be traced back to several Australian works from the 1990s, which align closely with Massy and Brown's principles. *Landscape Ecology—function and management*, looked at the application of landscape ecology in Australian rangelands [90]. This work sought to build towards more sustainable rangeland management [91]. A major outcome of this work was the Landscape Function Analysis (LFA) monitoring procedure, which uses rapidly acquired soil-surface-focused indicators to assess the biogeochemical functioning of landscapes at the hillslope scale, specifically water infiltration, nutrient cycling, and signs of erosion. Indicators included soil cover, proportion of cover offered by perennials, litter cover, degree of decomposition, crusting, erosion type and severity, slake testing, soil texture, etc. The parallels between LFA and the Savory Institutes EOV are clear, even in the method of measurement along consistent trig lines and point stations. One addition to the LFA system is the inclusion of a sigmoidal response curve to track improvement in and to identify lower and upper capacity points for specific LFA indicators within a specific context [92]. From these lower and upper capacity points, incremental change can be used to standardize proportional improvement in resources over time across different contexts. In the 2000s, Landscape Function Analysis was expanded to Ecosystem Function Analysis (EFA) and has since been adopted by the mining sector for landscape rehabilitation [93]. Further academic work in farmscapes is scarce. The updates explore floral diversity and thus reflect a greater number of ecosystem functions. EFA is promising, but it does not offer indicators for fauna. These applications of the landscape ecology premise present a promising starting point; others have also seen the potential landscape ecology holds more generally to further agriculture's drive towards sustainability [94].

Landscape ecology sees a landscape as an aggregation of similar spatial units or landscape elements [95]. As those elements or the proportions of those elements begin to change spatially, so too does the landscape. Within this framework landscapes are fuzzy edged areas, potentially larger than watersheds but smaller than regions, in the order of 10 s–1000 s km across. Troll defined landscape ecology as the study of physical, chemical and biological relationships that determine relationships within and between landscape elements [96]. Monitoring landscape elements requires an understanding of their structure, function, and how they change geomorphically, both through the colonization patterns of organisms and due to disturbances [95]. The applications of landscape function analysis described previously considered fixed locations in a landscape (farmscape) element; however, a more robust application would look at the state of landscape elements, how they change, and how they interact. Across farmscapes, our structures are well-defined: fields, roadways, hedgerows, or fence-tree lines. Their functions are ecological and productive, which are prioritized is reflective of the agricultural movement being pursued. Monitoring change in organisms, soil condition, etc., due to different disturbance regimes, both natural and human-induced (farm management events), within and between farmscape elements, will indicate if ecosystem functions are being increased or reduced through the goods and services they generate, e.g., soil carbon accrual, the provisioning of plant-available water, and/or increased biodiversity and abundance. Initial farmscape element assessment of static characteristics, i.e., soil texture, regional species distributions, etc., establishes an element's current structure and state. Change over time can subsequently be monitored through a reduced number of variables, such as soil organic matter, organism community change, soil bulk density, etc. [92]. Measuring ecological change in farmscapes allows for the quantification of the contributions they make to farmscape functions outside of the provision of food and fiber.

The above-described landscape-ecology-based monitoring process will, with an additional lens, also allow for the appraisal of the productive potential of those farmscape elements in terms of inputs, outputs, and the reliability/certainty of a system. A suitable lens was proposed in 1730 when Jethro Tull found himself pleading with comparators to explore more than just yields when comparing his new “Hoeing Husbandry” and what he referred to as the “Old Way”. Curiously, at the time, while more profitable, his method yielded less [97]. An extract from the beginning of his chapter on the topic is shown below in **Figure 1**.



CHAP. XVII.

Of Differences *between the* Old *and the* New Huſbandry.

IN order to make a Compariſon between the Hoeing-Huſbandry, and the old Way, there are Four Things, whereof the Differences ought to be very well conſidered.

I. *The Expence*
II. *The Goodneſs* } of a Crop.
III. *The Certainty*
IV. *The Condition in which the Land is left after a Crop.*

Figure 1. Excerpt from Jethro Tull’s Horse Hoeing Husbandry … Second Edition (1751) p. 254.

Tull stressed that appropriate comparison begins with “the profit or loss arising from Land, [which] is not to be computed, only from the value of the Crop it produces; but from its Value, after all Expenses of Seed, Tillage, &c. are deducted” [97]. The above discussion on landscape ecology will add through the “&c.” additional ecological resource expenses. These resource indicators also better inform an appraisal of the condition of the land after a crop. For Tull, given the time, this was considered purely through personal experience and subsequent crop yields, “therefore [I] am convinced that the hoeing (if it be duly performed) enriches the soil more than Dung and Fallows” (p. 269), a point where his, Rodale’s, and many current academic’s opinions would diverge. Conversely, through a deduction that would ring true for many in our changing global climate, on crop certainty, he noted it “better to be secure of a moderate crop than to have but a mere hazard of a great one” (p. 263). In light of these comments, the significance of resource monitoring becomes incontrovertibly apparent. Connecting gains and losses in natural resources with crop quality and quantity will draw conclusions for seasonal productivity; however, by tracking these over time, second order effects on the reliability of agricultural systems can be demonstrated retrospectively, and this can be used to indicate future certainty through more informed and data-rich risk modelling, resulting in a far more reproducible assessment of land condition and productivity than Tull’s original. Certainty is, of course, expected to increase as ecosystem functions increase. Tull's second element of assessment, the goodness of a crop, here will not only consider the quality and quantity of the product harvested from the system but also the delivery of ecosystem services as sold into respective markets.

The above assessment has identified a series of ecosystem- and production-based relationships to assess farmscape function. These can be used to assess the outcome-based intentions of any agricultural movement. Pairing the relationships of condition, certainty, and expense, with the resources the respective movement seeks to rebuild will allow for change in each farmscape element to be quantified and tracked. Over time, monitoring will demonstrate the efficacy of the principles and practices employed by an agriculturalist to realize, in a specific context, the intentions an agricultural movement holds for farmscape functions. With this combined model, the appraisal of regenerative agricultural systems could look like **Figure 2**.

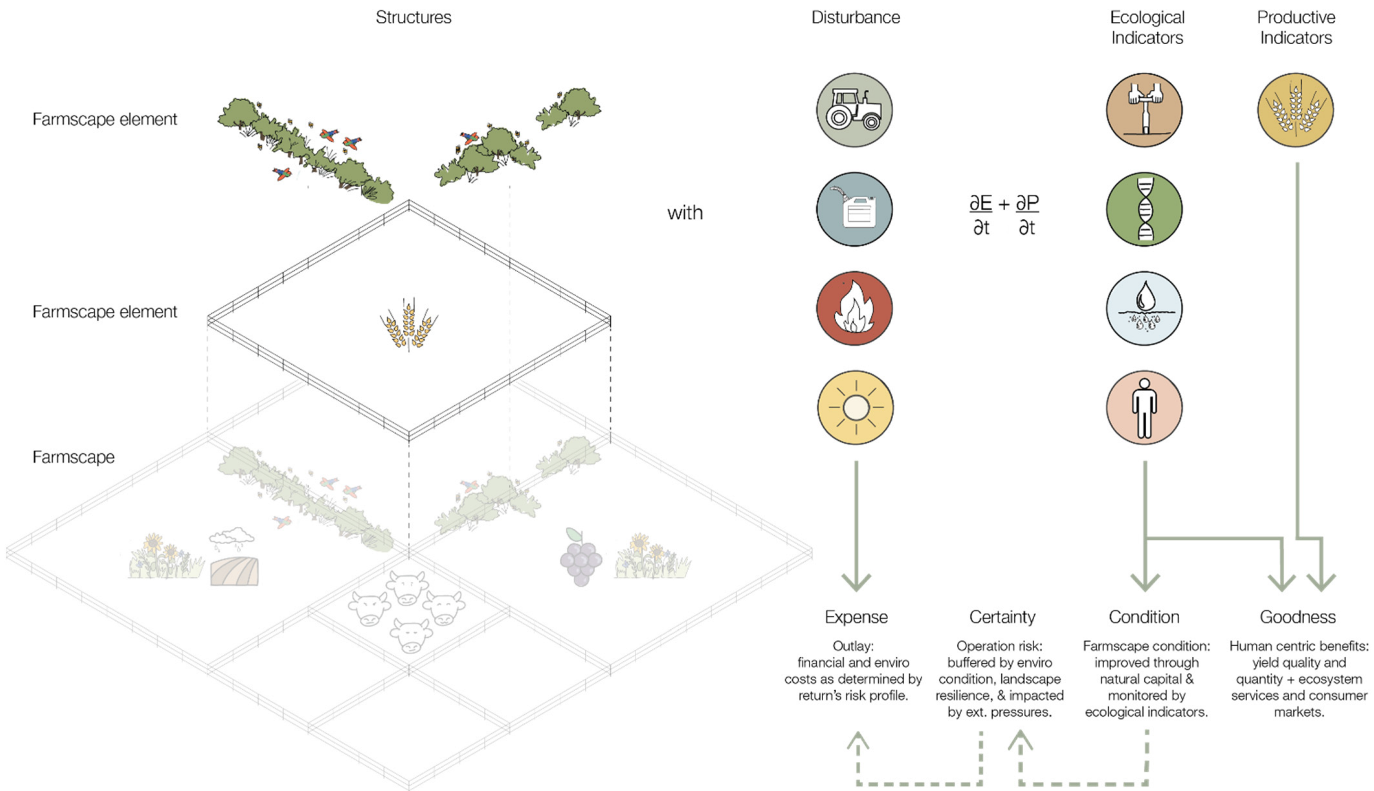


Figure 2. Farmscape Function framework, adapted from Jethro Tull's comparison of agricultural systems and landscape ecology. Within the framework, a farmscape will be divided into separate farmscape elements, based on (1) function; a hedgerow or field; and (2) history; time since establishment and hence development for a hedgerow, or management history/use, i.e., pasture, annual crop, or a perennial orchard/vineyard. Baseline measures will be taken of static and dynamic parameters at project outset; for regenerative agriculture, these will include soil, water, biota, and energy inputs. Over time, disturbance events will be recorded (solar radiation capture, farm management, energy inputs, and natural disturbances, such as flooding, fire, etc.) as ecological and productive indicators are monitored. Assessment of change over time will demonstrate the impact of management. Changes in indicators will then be used to quantify Tull's agricultural system comparison items: Goodness, productive and ecosystem service outcomes; Condition, ecosystem goods, stocks of natural capital; and Expense, management's

financial, environmental, and energy costs; while Certainty will be determined retrospectively based on relationships between productive performance, land condition, and expense.

This model proposes that monitoring should take place at a field/sub-field level. The global certification scheme for organic agriculture, GlobalG.A.P., and the Savory Institute's Land to Market program are testaments to the working potential of the concept of individual farm monitoring. Further confidence can be found in emerging agricultural technologies that will make this process cheaper and more streamlined. Many of these technologies are already either on farm or available and being used by farmers [98]. Precision agriculture has paved the way for this level of monitoring, and agroecology as a discipline will guide analysis and evaluation of the relationships observed [75].

References

1. Gabel, M. Ho-Ping: Food for Everyone, 1st ed.; Anchor Books: Garden City, NY, USA, 1979.
2. Sampson, R.N. Saving Agricultural Land: Environmental Issue of the 1980's. Environmentalist 1982, 2, 321–332.
3. Rodale, R. Breaking New Ground—The Search for a Sustainable Agriculture. The Futurist 1983, 1, 15–20.
4. Carson, R. Silent Spring; Hamish Hamilton: London, UK, 1963.
5. Ward, B.; Dubos, R.J.; René, J. Only One Earth; the Care and Maintenance of a Small Planet, 1st ed.; Norton: New York, NY, USA, 1972; ISBN 0393063917.
6. Amundson, R.; Berhe, A.A.; Hopmans, J.W.; Olson, C.; Sztein, A.E.; Sparks, D.L. Soil and Human Security in the 21st Century. Science 2015, 348, 1261071.
7. Millennium Ecosystem Assessment. Ecosystems and Human Wellbeing; Island Press: Washington, DC, USA, 2005; ISBN 1-59726-040-1.
8. Mitchell, J.P.; Reicosky, D.C.; Kueneman, E.A.; Fisher, J.; Beck, D. Conservation Agriculture Systems. CAB Rev. Perspect. Agric. Vet. Sci. Nutr. Nat. Resour. 2019, 14, 1–25.
9. Pearson, C.J. Regenerative, Semiclosed Systems: A Priority for Twenty-First-Century Agriculture. Bioscience 2007, 57, 409–418.
10. Pretty, J.; Bharucha, Z.P. Sustainable Intensification in Agricultural Systems. Ann. Bot. 2014, 114, 1571–1596.
11. Teague, W.R. Bridging the Research Management Gap to Restore Ecosystem Function and Social Resilience. In Global Soil Security; Progress in Soil Science Book Series; Springer: Cham, Switzerland, 2017; pp. 341–350.

12. IPCC. IPCC Climate Change 2021: The Physical Science Basis; Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., et al., Eds.; Cambridge University Press: Cambridge, UK, 2021.
13. Steffen, W.; Richardson, K.; Rockström, J.; Cornell, S.E.; Fetzer, I.; Bennett, E.M.; Biggs, R.; Carpenter, S.R.; De Vries, W.; De Wit, C.A.; et al. Planetary Boundaries: Guiding Human Development on a Changing Planet. Science 2015, 347, 1259855.
14. Wittwer, R.A.; Bender, S.F.; Hartman, K.; Hydbom, S.; Lima, R.A.A.; Loaiza, V.; Nemecek, T.; Oehl, F.; Olsson, P.A.; Petchey, O.; et al. Organic and Conservation Agriculture Promote Ecosystem Multifunctionality. Sci. Adv. 2021, 7, eabg6995.
15. Norton, L.R. Is It Time for a Socio-Ecological Revolution in Agriculture? Agric. Ecosyst. Environ. 2016, 235, 13–16.
16. United Nations, Department of Economic and Social Affairs, Population Dynamics. World Population Prospects 2019; UN: New York, NY, USA, 2019.
17. Alexandratos, N.; Bruinsma, J. World Agriculture towards 2030/2050: The 2012 Revision; FAO: Rome, Italy, 2012.
18. Beddington, J.R. The Future of Food and Farming. Int. J. Agric. Manag. 2011, 1, 11.
19. Richter, D.D.B.; Hofmockel, M.; Callaham, M.A.; Powlson, D.S.; Smith, P. Long-Term Soil Experiments: Keys to Managing Earth’s Rapidly Changing Ecosystems. Soil Sci. Soc. Am. J. 2007, 71, 266–279.
20. Bodirsky, B.; Rolinski, S.; Biewald, A.; Weindl, I.; Popp, A.; Lotze-Campen, H. Global Food Demand Scenarios for the 21st Century. PLoS ONE 2015, 10, e0139201.
21. Godfray, H.C.J.; Beddington, J.R.; Crute, I.R.; Haddad, L.; Lawrence, D.; Muir, J.F.; Pretty, J.; Robinson, S.; Thomas, S.M.; Toulmin, C. Food Security: The Challenge of Feeding 9 Billion People. Science 2010, 327, 812–818.
22. Brundtland, G.H. Our Common Future; Oxford paperbacks; Oxford University Press: Oxford, UK, 1987; ISBN 019282080X.
23. Costanza, R.; d’Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O’Neill, R.V.; Paruelo, J.; et al. The Value of the World’s Ecosystem Services and Natural Capital. Ecol. Econ. 1998, 25, 3–15.
24. United Nations (UN). Millennium Development Goals. Available online: https://www.un.org/millenniumgoals/ (accessed on 19 August 2021).
25. United Nations (UN). Sustainable Development Goals. Available online: https://sdgs.un.org/goals (accessed on 19 August 2021).

26. Ritchie, H.; Roser, M. Land Use. Our World in Data 2013. Available online: https://ourworldindata.org/land-use?fbclid=IwAR1OnVSd1Rhj7PKzA4xCejkIPKfiKJf84AXumZ2KvC4FXUBi7aLVzDwgbY4 (accessed on 19 August 2021).
27. Beus, C.E.; Dunlap, R.E. Conventional versus Alternative Agriculture: The Paradigmatic Roots of the Debate. Rural. Sociol. 1990, 55, 590–616.
28. Kirkegaard, J.A.; Conyers, M.K.; Hunt, J.R.; Kirkby, C.A.; Watt, M.; Rebetzke, G.J. Sense and Nonsense in Conservation Agriculture: Principles, Pragmatism and Productivity in Australian Mixed Farming Systems. Agric. Ecosyst. Environ. 2014, 187, 133–145.
29. Arulnathan, V.; Davoud, M.; Doyon, M.; Li, E.; Pelletier, N. Farm-Level Decision Support Tools: A Review of Methodological Choices and Their Consistency with Principles of Sustainability Assessment. J. Clean. Prod. 2020, 256, 120410.
30. De Olde, E.M.; Oudshoorn, F.W.; Sørensen, C.A.G.; Bokkers, E.A.M.; De Boer, I.J.M. Assessing Sustainability at Farm-Level: Lessons Learned from a Comparison of Tools in Practice. Ecol. Indic. 2016, 66, 391–404.
31. Van Cauwenbergh, N.; Biala, K.; Bielders, C.; Brouckaert, V.; Franchois, L.; Garcia Cidad, V.; Hermy, M.; Mathijs, E.; Muy, B.; Reijnders, J.; et al. SAFE—A hierarchical framework for assessing the sustainability of agricultural systems. Agric. Ecosyst. Environ. 2007, 120, 229–242.
32. Goswami, R.; Saha, S.; Dasgupta, P. Sustainability Assessment of Smallholder Farms in Developing Countries. Agroecol. Sustain. Food Syst. 2017, 41, 546–569.
33. Pintér, L.; Hardi, P.; Martinuzzi, A.; Hall, J. Bellagio STAMP: Principles for Sustainability Assessment and Measurement. Ecol. Indic. 2012, 17, 20–28.
34. Newton, P.; Civita, N.; Frankel-Goldwater, L.; Bartel, K.; Johns, C. What Is Regenerative Agriculture? A Review of Scholar and Practitioner Definitions Based on Processes and Outcomes. Front. Sustain. Food Syst. 2020, 4, 577723.
35. Schreefel, L.; Schulte, R.P.O.; de Boer, I.J.M.; Schrijver, A.P.; van Zanten, H.H.E. Regenerative Agriculture—The Soil Is the Base. Glob. Food Secur. 2020, 26, 100404.
36. Elevitch, C.R.; Mazaroli, N.D.; Ragone, D. Agroforestry Standards for Regenerative Agriculture. Sustainability 2018, 10, 3337.
37. Giller, K.E.; Hijbeek, R.; Andersson, J.A.; Sumberg, J. Regenerative Agriculture: An Agronomic Perspective. Outlook Agric. 2021, 50, 13–25.
38. Colley, T.A.; Olsen, S.I.; Birkved, M.; Hauschild, M.Z. Delta Life Cycle Assessment of Regenerative Agriculture in a Sheep Farming System. Integr. Environ. Assess. Manag. 2020, 16, 282–290.

39. Luján Soto, R.; Cuéllar Padilla, M.; de Vente, J. Participatory Selection of Soil Quality Indicators for Monitoring the Impacts of Regenerative Agriculture on Ecosystem Services. Ecosyst. Serv. 2020, 45, 101157.
40. Fenster, T.L.D.; Oikawa, P.Y.; Lundgren, J.G. Regenerative Almond Production Systems Improve Soil Health, Biodiversity, and Profit. Front. Sustain. Food Syst. 2021, 5, 664359.
41. De Groot, R.S.; Wilson, M.A.; Boumans, R.M.J. A Typology for the Classification, Description and Valuation of Ecosystem Functions, Goods and Services. Ecol. Econ. 2002, 41, 393–408.
42. Renting, H.; Rossing, W.A.H.; Groot, J.C.J.; Van der Ploeg, J.D.; Laurent, C.; Perraud, D.; Stobbelaar, D.J.; Van Ittersum, M.K. Exploring Multifunctional Agriculture. A Review of Conceptual Approaches and Prospects for an Integrative Transitional Framework. J. Environ. Manag. 2009, 90, S112–S123.
43. Francis, C.A.; Harwood, R.R.; Parr, J.F. The Potential for Regenerative Agriculture in the Developing World. Am. J. Altern. Agric. 1986, 1, 65–74.
44. Massy, C. Call of the Reed Warbler; University of Queensland Press: Brisbane, Australia, 2017.
45. Brown, G. Dirt to Soil, One Family’s Jurney into Regenerative Agriculture; Chelsea Green Publishing: White River Junction, VT, USA, 2018.
46. LaCanne, C.E.; Lundgren, J.G. Regenerative Agriculture: Merging Farming and Natural Resource Conservation Profitably. PeerJ 2018, 2018, e4428.
47. Gosnell, H. Regenerating Soil, Regenerating Soul: An Integral Approach to Understanding Agricultural Transformation. Sustain. Sci. 2021, 17, 603–620.
48. Gosnell, H.; Gill, N.; Voyer, M. Transformational Adaptation on the Farm: Processes of Change and Persistence in Transitions to ‘Climate-Smart’ Regenerative Agriculture. Glob. Environ. Change 2019, 59, 101965.
49. White, R.E.; Andrew, M. Orthodox Soil Science versus Alternative Philosophies: A Clash of Cultures in a Modern Context. Sustainability 2019, 11, 2919.
50. Merfield, C.N. An Analysis and Overview of Regenerative Agriculture; Report Number 2-2019; The BHU Future Farming Centre: Lincoln, New Zealand, 2019.
51. Anderson, M.D.; Rivera-Ferre, M. Food System Narratives to End Hunger: Extractive versus Regenerative. Curr. Opin. Environ. Sustain. 2021, 49, 18–25.
52. General Mills Regenerative Agriculture. Available online: https://www.generalmills.com/Responsibility/Sustainability/Regenerative-agriculture (accessed on 12 July 2021).

53. Lundgren, J.G.; Fenster, T.L.D.; LaCanne, C.E.; Pecenka, J.R.; Schmid, R.B.; Bredeson, M.M.; Busenitz, K.M.; Michels, A.M.; Welch, K.D. Defining and Validating Regenerative Farm Systems Using a Composite of Ranked Agricultural Practices. F1000Research 2021, 10, 115.
54. Cargill Regenerative Agriculture. Available online: https://www.cargill.com/sustainability/regenerative-agriculture (accessed on 12 July 2021).
55. Department of the Environment and Energy. About the Climate Solutions Fund—Emissions Reduction Fund. Available online: http://www.environment.gov.au/climate-change/government/emissions-reduction-fund/about (accessed on 19 August 2021).
56. Moon, S.J.; Costello, J.P.; Koo, D.M. The Impact of Consumer Confusion from Eco-Labels on Negative WOM, Distrust, and Dissatisfaction. Int. J. Advert. 2017, 36, 246–271.
57. Northern, G. Greenwashing the Organic Label: Abusive Green Marketing in an Increasingly Eco-Friendly Marketplace. J. Food Law Policy 2010, 7, 101–134.
58. Dahlberg, K. Roundtable Sustainable Agriculture-Fad Harbinger? Bioscience 1991, 41, 337–340.
59. Giller, K.E.; Andersson, J.A.; Corbeels, M.; Kirkegaard, J.; Mortensen, D.; Erenstein, O.; Vanlauwe, B. Beyond Conservation Agriculture. Front. Plant Sci. 2015, 6, 870.
60. Meemken, E.M.; Qaim, M. Organic Agriculture, Food Security, and the Environment. Annu. Rev. Resour. Econ. 2018, 10, 39–63.
61. Arbenz, M.; Gould, D.; Stopes, C. ORGANIC 3.0—the Vision of the Global Organic Movement and the Need for Scientific Support. Org. Agric. 2017, 7, 199–207.
62. Food and Agriculture Organization of the United Nations. Conservation Agriculture Principles. Available online: http://www.fao.org/conservation-agriculture/overview/principles-of-ca/en/ (accessed on 14 August 2020).
63. Heckman, J. A History of Organic Farming: Transitions from Sir Albert Howard’s War in the Soil to USDA National Organic Program. Renew. Agric. Food Syst. 2006, 21, 143–150.
64. Pittelkow, C.M.; Liang, X.; Linquist, B.A.; Van Groenigen, L.J.; Lee, J.; Lundy, M.E.; Van Gestel, N.; Six, J.; Venterea, R.T.; Van Kessel, C. Productivity Limits and Potentials of the Principles of Conservation Agriculture. Nature 2015, 517, 365–368.
65. Seufert, V.; Ramankutty, N. Many Shades of Gray—The Context-Dependent Performance of Organic Agriculture. Sci. Adv. 2017, 3, e1602638.
66. De Ponti, T.; Rijk, B.; Van Ittersum, M.K. The Crop Yield Gap between Organic and Conventional Agriculture. Agric. Syst. 2012, 108, 1–9.
67. Ponisio, L.C.; M’gonigle, L.K.; Mace, K.C.; Palomino, J.; De Valpine, P.; Kremen, C. Diversification Practices Reduce Organic to Conventional Yield Gap. Proc. R. Soc. B Biol. Sci. 2015, 282,

20141396.

68. Powlson, D.S.; Stirling, C.M.; Jat, M.L.; Gerard, B.G.; Palm, C.A.; Sanchez, P.A.; Cassman, K.G. Limited Potential of No-till Agriculture for Climate Change Mitigation. Nat. Clim. Change 2014, 4, 678–683.
69. Mollison, B. Permaculture: A Designer's Manual; Togari Books: Tyalgum, Australia, 1988.
70. Savory, A.; Duncan, T. Regenerating Agriculture to Sustain Civilization; Elsevier Inc.: Amsterdam, The Netherlands, 2016; Volume 1, ISBN 9780128013533.
71. McLennon, E.; Dari, B.; Jha, G.; Sihi, D.; Kankarla, V. Regenerative Agriculture and Integrative Permaculture for Sustainable and Technology Driven Global Food Production and Security. Agron. J. 2021, 113, 4541–4559.
72. Rhodes, C.J. Feeding and Healing the World: Through Regenerative Agriculture and Permaculture. Sci. Prog. 2013, 95, 345–446.
73. Gotsch, E. Break-Through in Agriculture; AS-PTA: Brasilia, Brazil, 1995.
74. Andrade, D.; Pasini, F.; Scarano, F.R. Syntropy and Innovation in Agriculture. Curr. Opin. Environ. Sustain. 2020, 45, 20–24.
75. Wezel, A.; Bellon, S.; Doré, T.; Francis, C.; Vallod, D.; David, C. Agroecology as a Science, a Movement and a Practice. Sustain. Agric. 2009, 2, 27–43.
76. USDA. Agroforestry Strategic Framework. Fiscal Years 2019–2024; USDA: Washington, DC, USA, 2019.
77. Krebs, J.; Bach, S. Permaculture-Scientific Evidence of Principles for the Agroecological Design of Farming Systems. Sustainability 2018, 10, 3218.
78. Hirschfeld, S.; Van Acker, R. Review: Ecosystem Services in Permaculture Systems. Agroecol. Sustain. Food Syst. 2021, 45, 794–816.
79. Pretty, J. The Sustainable Intensification of Agriculture. Nat. Resour. Forum 1997, 26, 17–18.
80. Cassman, K.G. Ecological Intensification of Cereal Production Systems: Yield Potential, Soil Quality, and Precision Agriculture. Proc. Natl. Acad. Sci. USA 1999, 96, 5952–5959.
81. Cassman, K. Ecological Intensification of Maize-Based Cropping Systems. Better Crop. 2017, 101, 4–6.
82. Pretty, J. Regenerating Agriculture; Springer: Berlin/Heidelberg, Germany, 1995; ISBN 9788578110796.
83. Lal, R. Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. Science 2004, 304, 1623–1627.

84. Paustian, K.; Lehmann, J.; Ogle, S.; Reay, D.; Robertson, G.P.; Smith, P. Climate-Smart Soils. Nature 2016, 532, 49–57.
85. FAO. Final Report for the International Symposium on Agroecology for Food Security and Nutrition; FAO: Rome, Italy, 2015.
86. Altieri, M.A.; Nicholls, C.I.; Henao, A.; Lana, M.A. Agroecology and the Design of Climate Change-Resilient Farming Systems. Agron. Sustain. Dev. 2015, 35, 869–890.
87. Meuwissen, M.P.M.; Feindt, P.H.; Spiegel, A.; Termeer, C.J.A.M.; Mathijs, E.; de Mey, Y.; Finger, R.; Balmann, A.; Wauters, E.; Urquhart, J.; et al. A Framework to Assess the Resilience of Farming Systems. Agric. Syst. 2019, 176, 102656.
88. McBratney, A.; Field, D.J.; Koch, A. The Dimensions of Soil Security. Geoderma 2014, 213, 203–213.
89. Norris, C.E.; Mac Bean, G.; Cappellazzi, S.B.; Cope, M.; Greub, K.L.H.; Liptzin, D.; Rieke, E.L.; Tracy, P.W.; Morgan, C.L.S.; Honeycutt, C.W. Introducing the North American Project to Evaluate Soil Health Measurements. Agron. J. 2020, 112, 3195–3215.
90. Ludwig, J.; Tongway, D.; Freudenberger, D.; Noble, J.; Hodgkinson, K. Landscape Ecology Function and Managment; CSIRO Publishing: Collingwood, Australia, 1997.
91. Hancock, G.R.; Ovenden, M.; Sharma, K.; Rowlands, W.; Gibson, A.; Wells, T. Soil Erosion—The Impact of Grazing and Regrowth Trees. Geoderma 2020, 361, 114102.
92. Tongway, D.; Hindley, N. Landscape Function Analysis: A System for Monitoring Rangeland Function. Afr. J. Range Forage Sci. 2004, 21, 109–113.
93. Lacy, H.; File, T.; Biggs, B. Ecosystem Function Analysis: Measuring and Monitoring for Mine Closure and Completion in Australia and Abroad—1994 to 2008. In Proceedings of the Third International Seminar on Mine Closure, Johannesburg, South Africa, 14–17 October 2008; pp. 321–333.
94. Pearson, D.; Gorman, J.; Aspinall, R. Multiple Roles for Landscape Ecology in Future Farming Systems: An Editorial Overview. Land 2022, 11, 288.
95. Forman, R.T.T.; Godron, M. Landscape Ecology; Wiley: New York, NY, USA, 1986; ISBN 0471870374.
96. Troll, C. Landscape Ecology (Geoecology) and Biogeocenology—A Terminological Study. Geoforum 1971, 8, 43–46.
97. Tull, J. Horse-Hoeing Husbandry: Or an Essay on the Principles of Vegetation and Tillage. Designed to Introduce a New Method of Culture; Whereby the Produce of the Land Will Be Increased and the Usual Expense Lessened. Together with Accurate Descriptions and Cuts, 3rd ed.; Andrew Millar: London, UK, 1751.

98. Al-Kaisi, M.M.; Lal, R. Aligning Science and Policy of Regenerative Agriculture. Soil Sci. Soc. Am. J. 2020, 84, 1808–1820.