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# Regenerative Agriculture and Its Potential to Improve Farmscape Function

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**Abstract:** Recent reviews have identified major themes within regenerative agriculture—soil health, biodiversity, and socioeconomic disparities—but have so far been unable to clarify a definition based on practice and/or outcomes. In recent years, the concept has seen a rapid increase in farming, popular, and corporate interest, the scope of which now sees regenerative agriculture best viewed as a movement. To define and guide further practical and academic work in this respect, the authors have returned to the literature to explore the movement's origins, intentions, and potential through three phases of work: early academic, current popular, and current academic. A consistent intention from early to current supporters sees the regeneration, or rebuilding, of agricultural resources, soil, water, biota, human, and energy as necessary to achieve a sustainable agriculture. This intention aligns well with international impetus to improve ecosystem function. The yet to be confirmed definition, an intention for iterative design, and emerging consumer and ecosystem service markets present several potential avenues to deliver these intentions. To assist, the authors propose the Farmscape Function framework, to monitor the impact of change in our agricultural resources over time, and a mechanism to support further data-based innovation. These tools and the movement's intentions position regenerative agriculture as a state for rather than type of agriculture.

**Keywords:** regenerative agriculture; sustainable agriculture; farmscape function; agricultural movement; landscape ecology; Jethro Tull; Intentions Principles Practices Indicators (IPPI)



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## 1. Introduction

The concept of a regenerative agriculture can be traced back to the cusp of the 1980s discussions of sustainability [1–3]. 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 [1–3]. 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 [6–15]. 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% [17–19]), 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 we 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 system. 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 [8,34–37], 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.

### *1.4. Article Outline*

The origins of regenerative agriculture align chronologically and intentionally with the drive for sustainability, but substantial confusion exists around the movement's current intentions and direction [34,35,37]. Here, considering the above outlined perspective on farmscape function, the intentions of regenerative agriculture as a movement and its potential to deliver those intentions have been reviewed. Of special interest is whether the current resurgence of interest aligns with the movement's initial intentions. These are compared with other major and minor agricultural movements and a framework to assess the performance of agricultural systems in terms of their intentions for farmscape function is presented. In addition, a mechanism to facilitate innovation towards higher levels of functioning is also presented.

## 2. Methods

Recent reviews of regenerative agriculture have collated in the order of 200–300 peer-reviewed articles [34,35]. Review criteria in both studies reduced these, based on the presence of definitions, to between 20 and 30 articles. (Although, the former study expanded their criteria to include looser descriptions, adding an additional 99 articles to their analysis.) These small pools of articles span four decades and a considerable shift in topic prevalence [34,37] from near obscurity to almost common popular vernacular across various sectors. Preliminary research, as part of this review, also identified a substantial shift in the movement's supporter/follower demographics before its recent popularization, from principally academic to being predominantly farmer and consumer based. These factors are highly likely to have affected how authors have approached the subject over time. For these reasons, resources for this study were sourced from within and beyond the peer-reviewed literature and grouped by time and source of publication.

The limited barrier to entry for non-peer-reviewed literature posed a substantial hurdle to the practical execution of this survey. The sheer quantity of literature available and the credibility of these works, in terms of representing the collective view of the regenerative agriculture movement, required a justification of significance for inclusion. Fortunately, considering that

(a) efforts had already been made to identify suitable non-peer-reviewed literature as part of the Newton et al. study [34] and less formally in Giller et al. [37], and
(b) the quick succession of the three reviews of 2020 and 2021 [34,35,37], which present a wide-reaching fulcrum for the modern regenerative agriculture movement, before which no central authority had been declared for a definition and after which a considerable point of reference had been made for subsequent work,

These reviews present a prism through which both peer-reviewed and popular literature can be identified. By beginning with the reviews and snowballing outwards (backwards and forwards) [43] the scope of the resulting pool of resources would consider a variety of viewpoints: academic and popular, including farmer, public, and corporate interests.

Based on the above, this review identified relevant resources for inclusion in this study through the three 2020–2021 reviews; Schreefel et al. [35], Newton et al. [34], and Giller et al. [37]; in line with the following process.

1. Backward snowballing considered all references listed for the three 2020–2021 reviews.
2. Peer-reviewed snowballed resources were screened for relevance by title and abstract.
3. For non-peer-reviewed resources:
    a. Significance was first determined by influence. Where a non-peer-reviewed resource was referred to by multiple resources, it was deemed to have substantial influence over the development of regenerative agriculture.
    b. Significant non-peer-reviewed resources were screened for relevance by title and abstract/introduction, if available. If an abstract or introduction was not available, as is often the case with website resources, the text body was consulted.
4. Relevant resources were considered for inclusion in this study based on their discussion of the intentions, goals, practices, scope, performance, and potential of regenerative agriculture.
5. Subsequent backward snowballing considered the reference lists of relevant resources only. With relevance of subsequent resources again being determined according to items 2–4 above.
6. Forward snowballing used Scopus (scopus.com, accessed on 19 August 2021) citation metrics from the three 2020–2021 review articles and was performed once, given the time since publication of the base set of reviews. Relevance and inclusion were determined according to items 2–4 above.

The literature review identified 189 relevant resources. Of these, 58 were classed as early, before 2010, and 131 were classed as current, after 2010. Within the current literature, 29 were from non-peer-reviewed sources, and 102 were peer-reviewed. Review of these resources based on item 4 (above) identified 63 peer-reviewed articles (52 from backwards and 11 from forwards snowballing), 7 corporate websites, 1 feature-length film, 4 academic and nongovernmental organization reports, and 18 popular or corporate publications, for inclusion in this study. Works by Massy [44], Brown [45], and Savory [46] were included within the popular publications. All included resources contributed to the following review, which maps the intentions and development of regenerative agriculture from concept to current day practice-in-action and the subsequent academic attempts to elucidate the mechanisms behind practitioner success.

## 3. Results

The early and current intentions of regenerative agriculture as a movement are presented below as are the five sources of potential as identified through the literature review: its public and farming following, an unconfirmed definition, an intention to innovate, an emerging certification-based consumer market, and a well-established link to ecosystem service markets.

### *3.1. Early Intentions*

Regenerative, the emotionally and spiritually charged word, was used as an adjective alongside agriculture twice—by Gabel [1] and Sampson [2]—before the term was picked up by Robert Rodale [37], of the eponymous institute, in an article in the Futurist in 1983 [3]. Rodale's became the original articulation of the term for many [8,37,47–50]. Gabel initially proposed the concept of a regenerative food system, within which regenerative agriculture was a major contributor [1,51]. Gabel went on to promote the need for regeneration more broadly across many sectors [52,53]. Sampson's article focused specifically on agriculture and the way current practices were using up/mining the resources it and humanity depend upon; particular focus was given to soil and the stability of rural communities [2]. Population/economic growth and the demands these imposed on the land needed to be countered by market systems that identified and rewarded farmers who applied appropriate conservation measures [2]. Rodale presented the concept as a goal for agriculturalists to iterate their systems towards, with the promise that once achieved, "farming would then change from a battle against nature into the art of encouraging nature to release the most benefits for human use with the least possible effort" [3]. Rodale postulated that by seeking solutions in complex systems, specifically by looking to nature for inspiration to problems in production, a regenerative agriculture could: improve the quality of life of farming families and their communities, safeguard production from externalities (peak oil and its role in urea production was a major concern of the time [47]), and repair the damage conventional agriculture had caused to the natural resources it depended on [3].

At the time, conventional agriculture in the USA, where Gabel, Sampson, and Rodale were writing, consisted of high input, high output, tillage-dominant systems [2,3]. Rodale saw these systems as reductive and as of direct descent from Jethro Tull's Horse Hoeing Husbandry (1730) [3]. Tull, and his eighteenth century "New Agriculture", introduced the seed drill, the concept of row crops, and championed tillage and bare soil as a means to maximize nutrition availability and eliminate crop competition [3,54]. Conversely, Rodale wrote from an organic farming heredity. After the American Dust Bowl (1930s) and the revelations on tillage that inspired the establishment of the Soil Conservation Service (1935), his father Jerome Irving Rodale established the Rodale Organic Gardening Experimental Farm in 1942 as a research station to promote and support organic methods of production [55]. In Sampson's 1982 article, he listed soil erosion, farmland conversion, soil quality, and plant-available water as the predominant and compounding resource concerns for U.S. agriculture and the targets for regeneration [2]. Thus, the risks associated with tillage and system simplification were ingrained. Robert Rodale intended his concept of a regenerative agriculture to overcome the shortcomings of organic agriculture [3], which relied heavily on tillage for weed control and seed bed preparation. However, the practical means to do so had not yet presented themselves [3,51].

Over the subsequent three decades, the concept of a regenerative agriculture received fleeting attention in academic circles (mentions of the term in academic journals infrequently exceeded five per year) [34,37]. Rodale Institute employees, Francis et al. in 1986, promoted four principle tools for regenerative systems: soil fertility, integrated pest management, advances in plant breeding, and integrated crop-animal systems [51]. In keeping with the original sentiments of the movement, many of these early writers put regenerative agriculture forward as necessary to reach a state in which a sustainable agriculture could be possible [47,50,51,56–58]. After all, Rodale's 1983 article was titled "Breaking new ground, the search for a sustainable agriculture". In these subsequent but early articulations of the term, the deterioration of soil, water, biodiversity, and human resources were the foci. Of these, soil was the lynch pin [2,3,50,51].

### 3.2. Current Popular Intentions

The 2010s saw enormous growth in the movement; academic and popular usage of the term dramatically increased particularly in the later part of the decade [34,37]. Much of the ground work for this popularity was laid by farmers [37,59,60]. During the later years, Charles Massy in Australia and Gabe Brown in the U.S., emerged as farmer figureheads. Both published popular books [44,45] that detail their own and others' transitions from conventional to regenerative practice. The common sequence of events sees a conventional farmer run out of options (financially, agronomically, and/or in terms of personal health) and seeking alternatives, ventures into more ecologically sensitive systems of management. Biodynamics, permaculture, agroecology, and holistic thinking play a significant role in influencing the systems these farmers develop [44,45]. Typically, within 5 to 15 years of conversion farm production, while potentially not meeting former or conventional yields for the region, is more consistent between years and more profitable yearly due to decreased costs [38,48,61]. Similar system transition timeframes have been reported for organic agriculture [9]. One study from the U.S. saw profitability increase for regenerative over conventional corn yields by almost 80% [49]. Invariably, practitioners also reported significant improvements in personal happiness [37,44,45], experiences that have been validated within the academic literature [48].

The innovations these farmers have developed have proven to be the missing link between the intentions of early writers and current farmer-reported performance. Some major practices are briefly described here. In regenerative pasture systems, holistic grazing is ubiquitous. The system, developed by Alan Savory in Zimbabwe [62], sees dense mobs of animals moved frequently between paddocks with long rest periods [46]. Management focus shifts from set stocking to adjusting livestock numbers to match feed availability and personal goals weigh heavily into system setup [48]. Cover cropping combined with minimized soil disturbance is the holistic grazing regenerative agriculture equivalent for crop systems. While also affiliated with other movements, almost poetically, it was the Rodale Institute that developed a chevron-blade roller-crimper [63], which excludes the need for herbicides or tillage in management of these systems. Reduced herbicide use sits well with regenerative practitioners and their drive for reduced input use, which also sees the adoption of organic forms of fertilization and pest management. With inspiration for the latter often being borrowed from agroecology and traditional systems. These methods of management have for many producers enabled or even defined regenerative agriculture [34]. What's more, regenerative practitioners claim to have put these and other practices in place and increased their profits [44,45,48,62]. A visual of the integration of some of these practices into a simplified farmscape is shown in Figure 1.

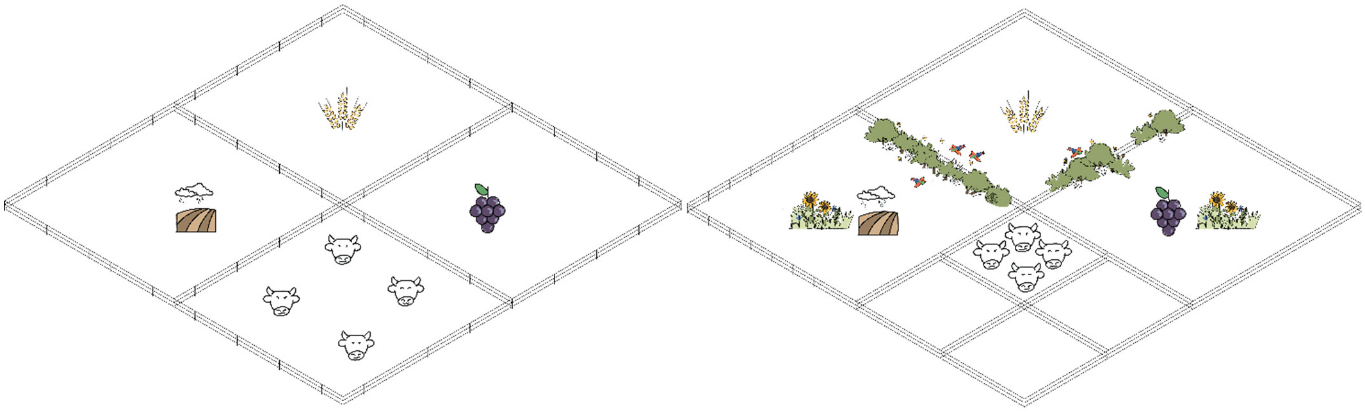


**Figure 1.** A typical conventional farmscape (**left**)—summer fallow, monoculture annual crop, monoculture perennial crop, and set stock grazing; contrasted with the same systems including "regenerative" practices (**right**)—a cover cropped fallow, nature refuges between fields, intercropping between perennial crop rows, and holistic grazing.

Given the movement's current farmer-led status and the prevalence of references to Massy and Brown's books within popular and academic literature [60,64–66], these texts give in-depth insight to the popular intentions of the movement not readily accessible elsewhere. Massy's central thesis, to restore the Earth and human health, revolves around encouraging five natural functions/cycles: solar-energy, water, soil-mineral, ecosystem-biodiversity, and the human-social [44,67]. Massy based these on Savory's four ecosystem processes [44]: Community (ecosystem) dynamics, water cycle, mineral cycle, energy flow (sunlight conversion) [68], and added a human element. This human element aligns well with the movement's early intentions [2,3]. Savory's work was not initially associated with regenerative agriculture. The holistic grazing method evolved out of personal experience in the Zimbabwean landscape as a game and national park manager and Jan Smuts' *Holism and Evolution* [69]. Savory and his institute's work is now heavily affiliated with regenerative agriculture (this will be discussed further later). The Massy–Savory functions are intended to guide farmer management decisions. Maximizing the capture, use, and support of available resources on the farm is intended to build resource availability, farm resilience, improve landscape function, and increase practitioner ecological literacy [44,46,68]. These functions are, for Massy, the guiding principles of regenerative agriculture. Brown, more practically, presents five principles to securing and improving the "health" of soil, the interface, of Massy's five functions/cycles; limit disturbance, armor (cover) the soil surface, build diversity, keep living roots in the soil, and integrate animals [45]. Brown's principles are also heavily influenced by holistic grazing and reflect Francis et al.'s (1986) principle tools: soil fertility, integrated pest management, advances in plant breeding, and integrated crop-animal systems [51].

### *3.3. Current Academic Intentions*

Academic support for the practices aligned with regenerative agriculture, e.g., holistic grazing, cover cropping, and limited soil disturbance, etc., have individually received inconsistent support. Holistic grazing has been heavily critiqued as rotational/crash grazing, although some suggest experimental applications do not reflect the practice of those trained in Savory's methods or managing their own farms [70,71]. Support for cover cropping is now well established with recent reviews identifying positive benefits for soil carbon [72], the soil microbiome [73], several physical properties [74], and weed suppression [75]. Limited soil disturbance has generally been embraced more widely, particularly for its affiliation with conservation agriculture. The same practices, under a regenerative banner, have received more criticism, although this has primarily focused on how practices and purported outcomes have been promoted in popular media with little regard for context and sometimes contempt for established science [34,37,76]; this is observed while noting that those same practices, in many contexts, form "part of the cannon of good agricultural practice" [37].

The recent surge of academic publications on regenerative agriculture have primarily sought to catalogue farmer perspectives and the necessity of full system, contextually relevant change rather than piecemeal practice change [38,48,49]. There are calls from both the scientific community and regenerative agriculture to assist one another in bringing these solutions to light [48,76,77].

To resolve some of the confusion surrounding regenerative agriculture, three recent reviews have sought to uncover: its central themes, Schreefel et al. [35]; existing definitions, Newton et al. [34]; and its agronomic role, Giller et al. [37]. Schreefel et al.'s review, the first systematic review of academic literature on regenerative agriculture, identified several dominant themes/intended outcomes; improving soil condition/health, sequestering carbon, increasing biodiversity, and stressing the importance of socioeconomic dimensions of food security; along with several practices theoretically capable of achieving these; minimizing tillage and external inputs, use of cover crops, and livestock-crop integration [35]. Curiously, holistic/rotational grazing was not featured. From 229 journal articles and 25 practitioner websites, Newton et al. (2020) extracted 121 and 22 definitions, respectively. These definitions were assessed for their focus on practices and/or outcomes. Academic offerings presented a spread of those based on practices (21%), outcomes (36%), and a combination of the two (43%). Practitioner definitions overwhelmingly relied on combined (68%) definitions. Giller et al. proposed that regenerative agriculture is seeking to solve agricultural crises for productivity, biodiversity, and soil health [78]. Schreefel et al. [35], from the themes present in the literature, proposed a provisional definition for regenerative agriculture 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.*

In light of the push towards an outcome-based definition, as identified by Newton et al. [34], quantifying performance through this definition is challenging. Which ecosystem services are included? How will they be monitored? The definition does, however, capture the early and current intentions of regenerative agriculture generally, while aligning these with global intentions for ecosystem renewal.

### *3.4. Public, Corporate, and Farming Following*

The movement has amassed a considerable public following [34,37,48,79], which is, in no doubt, attributable to the growing number of regenerative agriculture specific non-government organizations, e.g., Terra Genesis International, Regeneration International, The Real Organic Project, and Carbon Underground, among others, and the highly accessible promotional material that has been developed in partnership with the movement's farmer leaders, which includes a feature-length 2020 Netflix-produced documentary *Kiss the Ground* [80]. The number of popular science books on regenerative agriculture and its links to soil health and human health is extensive and growing (examples include [44,45,60,64,81,82]). The movement is also garnering a corporate response; major U.S. food producers Cargill and General Mills, in 2021, both announced a range of regenerative products and programs with the aim to safeguard their supply chains for the future [83,84]; Wrangler [85], Patagonia [86], and others, have followed suit; the Australian supermarket chain Harris Farm has also begun offering regenerative produce [87], and formal certification schemes have been launched in the U.S., which will enable smaller producers, the roots of regenerative agriculture, to enter consumer markets. These certification schemes are discussed further in the respective subsection below. For now, in terms of the movement's momentum, it is important to note that it is not just farmers who are interested; the nongovernment sector is looking to support change and regenerative-agriculture-specific consumer markets are operating. The movement's message is penetrating and resonating with food and fiber industries. In 2019, a round-table discussion involving stakeholders from across the south of the West Australian food system (including the public and media) declared the regenerative agriculture message integral to their future (Sambell et al., 2019)—an across-the-board snapshot of a very specific piece of the food puzzle.

### 3.5. Unconfirmed Definition

While some have claimed regenerative agriculture cannot be defined [88], attempts at definitions have been made, which were discussed previously, with both Schreefel et al. and Newtown et al. identifying key outcomes and practices as focal points for the current movement [34,35]. Drawbacks to definitions defined in terms of outcomes or practices alone were identified by Newton et al. [34]. Similar comments have been made of other practice and goal-oriented movements, such as organic agriculture [89] and sustainable intensification [8]. Where, by not specifying both a means and an ends led to undesirable outcomes and methods, respectively. These scenarios are elaborated on further in the discussion section. Nonetheless, with a definition still to be agreed upon, the potential to guide the movement and overcome the issues faced by others still exists.

### 3.6. An Intent to and History of Innovation

Another source of potential is the movement's modern foundation in innovation and collaboration. The original articulations of regenerative agriculture focused on a need to innovate and iterate towards sustainability [2,3,51]. The movement has put innovation into practice through the convergent development and adoption of holistic grazing, the innovations on cover crops from within regenerative agriculture, and integration of beneficial insect predation as inspired by agroecology and traditional/indigenous management practices. These innovations are shared within communities of practice, which exist at local and global levels [48]. These communities have, for many, provided a means to overcome negative attitudes from academics and agronomists/extension services [48]. Encouraging these communities and ensuring that they are based on data relevant to their audiences will support further innovation and acceptance by established science [76].

### 3.7. Consumer Markets and Existing Certification Schemes

As noted above, consumer demand exists and to meet it, regenerative products are being marketed [48]. In Australia, the supermarket chain Harris Farm provides regenerative products, with certification provided through multiple services [90]. U.S. food giants, Cargill and General Mills, present substantial promotional material detailing regenerative credentials and intentions [83,84]. For the most part these programs are practice based. The most prominent, formal, and transparent practice-based certification program was launched by the Regenerative Organic Alliance (ROA) in 2017, of which the Rodale Institute and Patagonia are key players. The alliance posed a Regenerative Organic Certification Policy as part of the 2018 U.S. Farm Bill [36]. The current iteration of this certification scheme [91] is based on three pillars of soil health, animal welfare, and social fairness. Compliance is transitionary, providing new adopters with the opportunity to increase conformity over time. This helps encourage change in practice by providing access to consumer markets earlier and overcoming the yield-penalty-during-transition barrier to entry. Compliance is governed through required and optional practices along with critical tolerances. Over time, many formally optional practices become requirements. Within this, different levels of practice are also rated – bronze, silver, or gold – for several requirements. For example, bronze crop systems have three crops in rotation while gold systems have seven; vegetation cover, and livestock feed sources have similar categorical levels of performance. A criticism of practice-based compliance certification would be the lack of inbuilt acknowledgement of contextual variability of practice performance. If future studies find performance is variable or lacking, system credibility will be lost, and momentum will suffer.

Conversely, the Savory Institute maintains a "Verified Regenerative Supplier Roster" for farms and ranches that are able to demonstrate positive performance trends for a range of in-house selected and monitored indicators as part of their Land to Market program [92]. The program focuses on grazed land and livestock-cropping systems; a standalone program for cropping is not yet offered, although such systems do not generally align well with the intentions of regenerative agriculture. The Land to Market program currently has over 1000 verified products, 70 member brands, and covers more than 2.5 million acres [93]. "Ecological Outcome Verification (EOV) is the 'science inside' [the] Savory Institute's Land to Market program" [92]. The program was initiated by one of the Savory Institute's U.S.-based regional hubs and Michigan State University. At five yearly intervals, biodiversity (flora), soil health, and ecosystem function (water infiltration) are quantified. Yearly inspections consider visual indicators, such as ground cover and type (living/non-living) and signs of erosion, to provide farmers with more regular performance updates. The program places a large emphasis on context, with indicators and benchmarks in the U.S. tailored to The Nature Conservancy's Bioregions. Locations outside of the U.S. are not as transparently described. Both indicators and benchmark observation locations are determined in-house by farmer hubs, local knowledge, and scientific consultation. An aggregation of indicator values and comparison with past performance then determines if the site is "regenerating", "degenerating", or "in a state of sustainability". In this framework, sustainability is seen as a "bridge" to the goal which is "regeneration" [94], a somewhat different perspective to what was described by early thinkers. The program promotes continuing innovation within farmer hubs, but the in-house process of indicator and benchmark selection and more qualitative rather than quantitative parameters are unlikely to deliver the full range of benefits possible from regular open monitoring of uniform indicators across regions, states, and continents.

### *3.8. Ecosystem Service Markets*

Scattered throughout the literature surveyed as part of this review are articulations of the potential benefits that financial incentives for conservation/regeneration efforts could bring to agricultural systems. The earliest is Sampson 1982 [2], and others include Newtown et al. [34] and Mitchel et al. [8]. Current trends towards commercializing ecosystem services have been developing formally since the turn of the millennium [95]. The most prominent ecosystem service market currently in operation for agriculture is carbon sequestration. The market is global and many projects have participated; above ground carbon is primarily the focus, but the push for soil carbon is palpable [96,97]. Almost all promotional material and many regenerative-agriculture-aligned non-government organizations focus on the need for and benefits of soil carbon sequestration, such as The Carbon Underground, Regeneration International, etc. As more ecosystem services become commercialized, an agricultural movement that is built around quantifying its impact on these, and elements of these services, will be adequately suited to easily transition into these markets. Markets which could exist for biodiversity, freshwater provisioning, agricultural worker welfare, etc.

The potential for additional ecosystem service markets can be demonstrated through existing nonregenerative-aligned consumer markets. Outside of IFMAO (organic) certification, GlobalG.A.P. certification and various certification schemes for tropical crops exist. These center around biodiversity, domestic animal, and worker/community welfare. Rainforest Alliance's Green Frog label, Fair Trade, and Smithsonian Bird Friendly now comprise between 12–38% of tea, palm oil, cocoa and coffee production [98]. Their existence shows certain industries have already attracted consumer support purely based on practice-oriented certifications. Quantified outcomes could substantially contribute to the further decommoditization of these and other agricultural products [99]. It would also enable standalone markets where credits could be traded as is currently being explored through carbon markets.

## 4. Discussion

### *4.1. 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.
- Rodale identified that progress towards regenerative practice would be iterative and be achieved through increased natural complexity.
- Sampson highlighted a role for financial motivators in this process.
- 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 [51].

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 [44,45,49,59]. 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 [38,48,49]. Critical work continues to call for greater consideration of context and a validation of claims from successful practitioners [37,76].

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.

### *4.2. 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 [34,66]. Although, there is pressure from academics and industry for a definition based on performance [48,79,83,100]. 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 [83,84]. With participation in carbon sequestration markets and other emerging ecosystem service markets (biodiversity [101]) 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 [102,103]. 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 [34,47]. This results in two questions.

1. How do we ensure performance?
2. How do we define regenerative agriculture?

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

*4.3. 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 [78]. 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% [104]. Both have intentions to conserve soil, improve on farm biodiversity, increase soil organic carbon, and improve farmers' socioeconomic outcomes [8,89]. Conservation agriculture also focuses on water-use efficiency [105] and quality [8], while organics place a high priority on aboveground biodiversity outside of commercial crops [55]. 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™), that provided an option for weed control aside from tillage in broadacre cropping [8,78]. Conservation agriculture has three principles: minimize soil disturbance, increase ground cover, and increase biodiversity through crop rotations [105]. 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 [78]. 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 [8,55]. Initially, organics focused on agricultural system design and then on the use of compost in place of synthetic fertilizers [47,89]. 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 [89]. 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) [106]. Several meta-analyses placed organic yields between 10–30% below conventional yields, depending on the crop [14,107–109]. 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 [28,110]. 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 [107] 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 [89].

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 [111]. Parallels are commonly drawn between regenerative agriculture and permaculture [68,112,113]. Syntropic agriculture shares principles with permaculture but enacts these through a focus on ecological succession [114,115]. 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 [116]. Agroforestry, more simply, is "the intentional integration of trees and shrubs into crop and animal production to create environmental, economic, and social benefits" [117]. 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 [118,119]. 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 [120], ecological intensification [121], 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 [120,121]. 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 [122]. 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 [120,121]. 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 [56] shortly after authoring *Regenerating Agriculture* [120]. In the 2010s, conservation agriculture was adopted in sustainable intensification's name [78], 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 [123], and conservation agriculture's focus on building soil organic matter [8]. The movement was embraced by the FAO as climate-smart agriculture [78] or a way to build climate-smart soils [124]. 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 [8,10,89,116,125]. 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 [34,79,112]. Similar observations have been made for conservation agriculture [8], sustainable intensification [10,120], and organic agriculture [3] recently [89], 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.

### *4.4. 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 [126,127], regenerative potential [100], 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 [128]. 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.

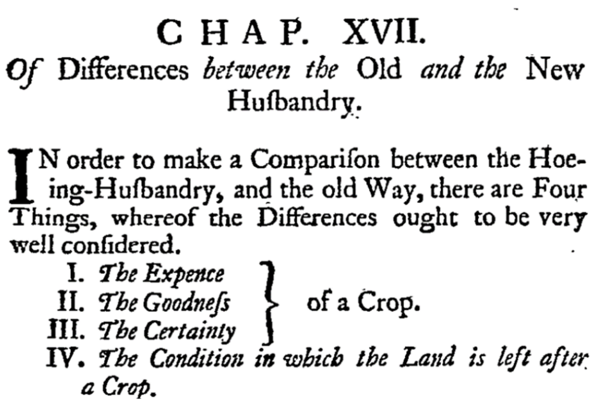
The Savory Institute's Ecological Outcome Verification (EOV) system does consider indicators and respects the variation in the inherent capacity of our farmscapes. Encouragingly, this system did not develop in a vacuum. Just as the Savory Institute stresses the need to measure biodiversity, infiltration, 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" [129]. 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 [130]. This work sought to build towards more sustainable rangeland management [131]. 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 [132]. 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 [133]. 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 [134].

Landscape ecology sees a landscape as an aggregation of similar spatial units or landscape elements [135]. 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 [136]. 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 [135]. 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. [132]. 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 [137]. An extract from the beginning of his chapter on the topic is shown below in Figure 2.



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 2.** 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" [137]. 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 3.

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 [138]. 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 [116].

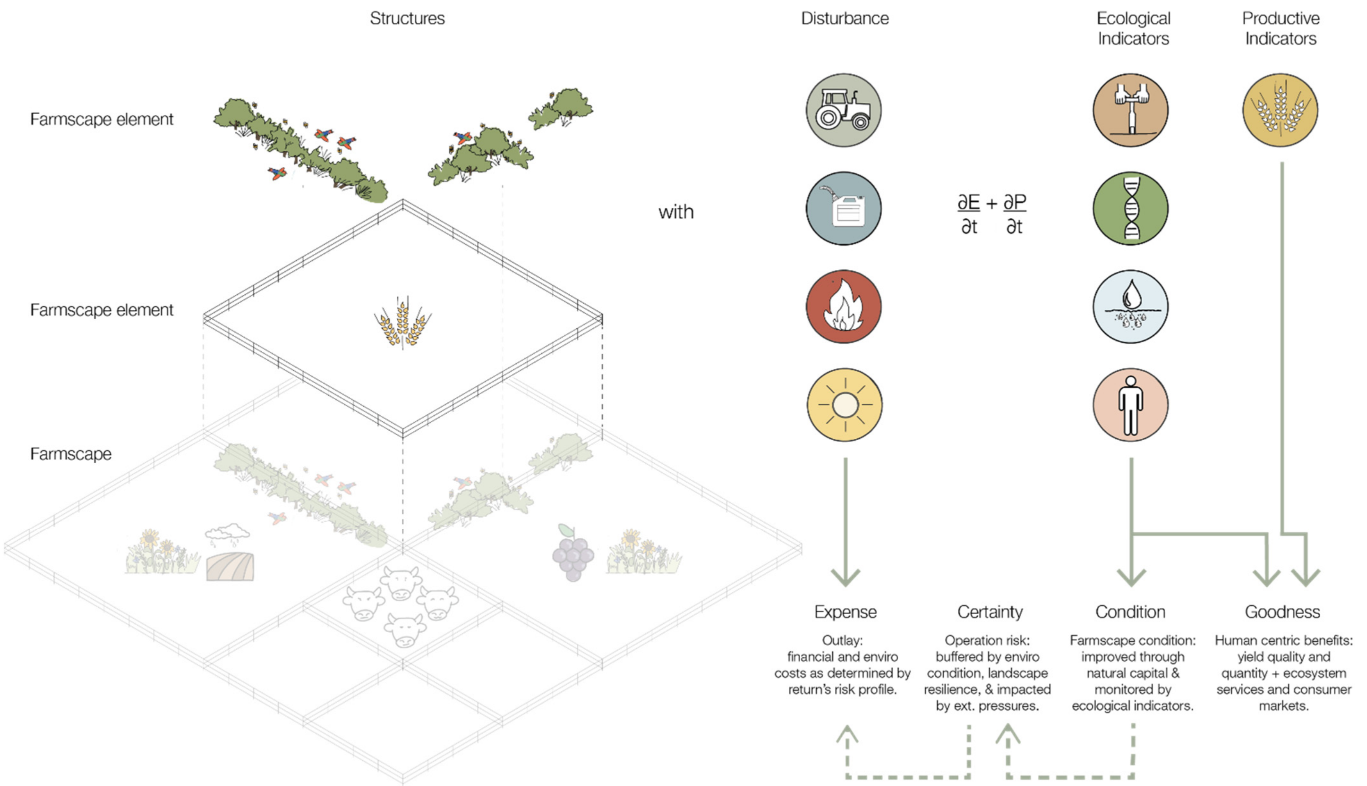



**Figure 3.** Farmscape Function framework, adapted from Jethro Tull's comparison of agricultural systems and landscape ecology. Within the framework, a farmscape will be divided into separate farmscape elements, based on (1) function; a hedgerow or field; and (2) history; time since establishment and 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.

### *4.5. Quantifying, Refining, and Iterating towards Higher Levels of Farmscape Function—The IPPI Mechanism*

The widescale monitoring of agricultural systems will provide a feedback on practices, indicators, and principles, thus providing a platform for further contextually relevant, data-backed innovation in practice and policy [35]. If widescale monitoring was implemented, where indicators of changeshow practices are not causing the desired effect:

(1) the practice can be adjusted according to the movement's principles,
(2) the principles the movement employs to achieve its intentions can be reassessed, or
(3) the indicator reviewed for its efficacy to quantify change.

An example of how this could work in practice can be given through conservation agriculture and the concerns surrounding its potential to increase soil organic carbon, as discussed previously in Section 4.3. Early reports of success were later revised, as initial increases in topsoil organic carbon were shown to have been accompanied by reductions in deeper soil organic carbon contents and increases in soil bulk density [78,110]. In this situation, both indicator and practice were inadequate. Early sampling programs did not consider deeper soil and reported on a percentage composition rather than a mass-area basis. Perhaps a practice change based on a stricter application of the principles of conservation agriculture, to include cover crops in the system, could have increased the depth and the proportion of the year that living roots are in the soil which may see soil carbon levels increase [105]. The mechanism demonstrated with this example is an iterative system for indicator, practice, and principal design to ensure incremental progress towards an intention, i.e., to increase soil organic carbon. The IPPI mechanism is intended to be used with multiple intentions to better consider systems, but application with a single intention as outlined will still be functional. A visualization of the IPPI mechanism is shown below in Figure 4. The central role of context in assessing indicator and principal performance is integral to the mechanism. **Context** here refers to the climatic, topographic, geological, biological, and socioeconomic peculiarities an agricultural system operates within. It is expected that the practices employed to achieve an agricultural movement's intentions will vary between contexts.

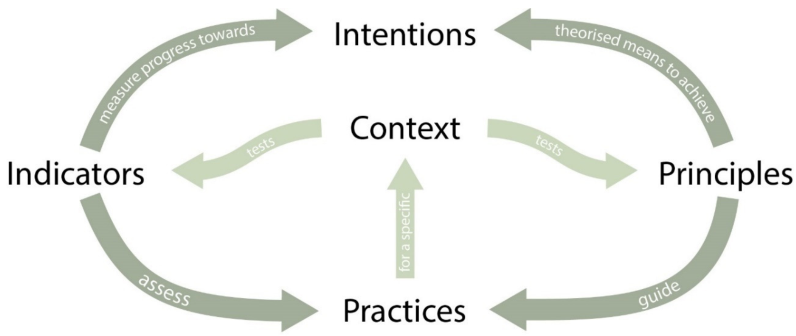



**Figure 4.** Intentions Principles Practices Indicators (IPPI) mechanism.

Within the IPPI mechanism, each element is relative. The mechanic is built to consider and refine an agricultural system's performance towards a set of intentions. As discussed in the introduction these intentions may be those of the agricultural movement being pursued, or to facilitate comparison between systems, those of another agricultural movement, or an overarching desired set of farmscape functions as defined by another means, i.e., the MEA's ecosystem functions or similar. Principles are provided by the agricultural movement. Practices are the application of those principles. While indicators will be reflective of the intentions being considered, for conservation agriculture, they would consider soil organic carbon, plant-available water, etc.; for organic agriculture, the indicators may also include measures of aboveground biodiversity. The specific methods by which these indicators are measured should be consistent between movements and contexts to assist with performance comparison [139].

Where the Farmscape Function framework is on-farm and change focused, the IPPI mechanism is focused on comparison, context, and iterative design. The framework and mechanism are interlinked through the data gathered through indicator measurement. Within both framework and mechanism, farmers or their advisors will ideally monitor their own indicators. Support need not be provided by an additional third party; sufficient global networks of extension agents and agronomists already have an understanding of farms and relationships with managers [2,140,141]. Widespread, farmer-enabled monitoring will provide many advantages.

(1) Farmers and their agents will be given the tools to quantitatively refine their own practice for their context.
(2) The contextually assigned data will contribute to refining indicators [142].
(3) The multitude of contexts covered will provide other farmers with highly tailored and accessible information for their system and context. Decoding contextually complex practices [50].
(4) Exemplary farmers will be identified [76].

(5) A common language will be provided through data for comparison by farmers, agronomists, and researchers to contribute towards realizing a systems agronomy [11,78].

All of these advantages will greatly assist with refining the pathway towards further innovation and improved farmscape function. Similar measures have been called for from across many agricultural movements: conservation agriculture and sustainable intensification [8,10], earlier regenerative work [58], current regenerative work [138], and agroecology [39].

Widespread monitoring of various landscape elements within a specific context will enable sigmoidal response curves to be built for specific indicators, such as water infiltration, soil carbon content, bird or species populations, etc. These response curves will identify natural limits for specific contexts (contextual capacities) and potentially limits for changes in management practice. Similar methodologies have been articulated for soil carbon content [143,144] and for multiple indicators in LFA and EFA [132]. Having lower and upper contextually relevant bounds for indicators and monitoring incremental change between those bounds will feed directly into ecosystem service markets, help balance certification schemes for consumer markets between contexts, and guide land managers with management change decisions. Of course, within a user-facilitated monitoring system, close monitoring of reported data will be necessary. Baselines will need to be established and incremental measurements will need to be validated through incrementally reported change over time and comparative assessments with farmers in contextually comparable systems. Unexplained outliers will require third-party validation to confirm results or clarify efficacy of indicators. The cost of additional monitoring, while providing certainty to current production through a greater understanding of current resource stock turnover, will be supported by access to new markets, be they traditional agricultural products or ecosystem service markets.

Selecting aspects of indicators to monitor will require a transdisciplinary effort in a space that has often been dominated by siloed solutions [145] to ensure a holistic solution is reached [31]. The process of indicator refinement, as outlined, will be iterative and rely on the IPPI mechanism. Respective disciplines will be best placed to determine indicators; collaboration between disciplines and other stakeholders will clarify these and identify crossover between parameters. A starting point for indicator targets is provided for regenerative agriculture in Table 1 below. While crop yield and quality will likely be industry-specific, soil, water and biota will be highly related [6,145]. Human parameters are likely to be at a higher level considering indicators of fair trade, human health, and the resilience of communities and regions. Energy will Involve a comparison of renewable inputs, including solar radiation, and non-renewable inputs.

**Table 1.** Dimensions of Regenerative Agriculture and Potential Indicator Targets for application with the Farmscape Function framework and the IPPI mechanic.

| Dimension | Potential Indicators |
|---|---|
| Soil | Organic matter, pH, bulk density, aggregate stability, ground cover, nutrient profiles. |
| Water | Soil infiltration, consistency of plant available water, stream flow consistency, stream flow quality. |
| Biota | Above and below ground flora and fauna diversity and abundance. |
| Human | Income, autonomy, quality of life, and community stability. |
| Crop | Quantity and quality. |
| Energy | Inputs: fossil fuels, renewably sourced energy, fertilizers, and incidence radiation capture. |

Potential indicators were compiled from [7,14,42,92,132,133,142,146] and are intended to represent dynamic rather than static parameters of farmscape elements. Static parameters will be established for each site at the outset and contribute to determining the farmscape element's context. Dynamic parameters will be used to monitor change.

### *4.6. A definition for Regenerative Agriculture*

Considering the above discussion, regenerative agriculture can be seen as a state rather than type of agriculture. In this light, the authors propose that a regenerative agriculture is

> ***Any system of crop and/or livestock production that, through natural complexity and with respect to its contextual capacity, increases the quality of the product and the availability of the resources agriculture depends upon; soil, water, biota, renewable energy and human endeavor.***

## 5. Conclusions

1. As a movement, regenerative agriculture has, since the 1980s, consistently focused on rebuilding or increasing the availability of the resources agriculture depends upon in the attempt to achieve a sustainable agriculture.
2. The movement has substantial support, consumer markets, interested corporate parties, and most importantly, farmers who claim to have provided the missing link between early conceptualization and current regenerative performance (claims which have been critiqued academically). However, an increased appreciation of system interaction is beginning to shift academic opinion.
3. Ensuring that regeneratively focused systems perform is essential in maintaining and building movement momentum. Herein, the authors have proposed a new Farmscape Function framework that will monitor change in agricultural resources over time and track relationships with system expenses, certainty, and land condition.
4. A new Intention, Principle, Practice, and Indicator (IPPI) mechanism will enable further data driven innovation within farms and across communities of practice.
5. Monitoring for the above framework and mechanism will be best undertaken by farmers and agronomist-extension workers and contribute towards establishing a systems agronomy.
6. These tools will quantify system performance and facilitate iteration to higher levels of function, enabling a situation where a regenerative agriculture can be confirmed as *any system of crop and/or livestock production that, through natural complexity and with respect to its contextual capacity, increases the quality of the product and the availability of the resources agriculture depends upon, soil, water, biota, renewable energy, and human endeavor.*
7. Future work will seek to identify regenerative systems by implementing the Farmscape Function framework and IPPI mechanism. Addressing limitations of communication, context determination, and cost-effective measurement of indicators will be major focus points. It is expected that digital agriculture will play a major role in overcoming these limitations. Collaborations will be sought with farming groups and academics within the fields encompassed by the dimensions of regenerative agriculture to assist in identifying and refining indicators.

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