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Review

Unravelling Regenerative Agriculture's Sustainability Benefits and Outcomes: A Scoping Review

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Abstract: Regenerative Agriculture (RA) has emerged as an environment-centric agriculture that prioritises reducing synthetic inputs, emphasising holistic management focussed on sustainability. However, evidence linking RA practices to desired sustainable outcomes remains inconclusive, and today's modern conventional agriculture (MCA) prioritises similar aspects. This scoping review explores RA's origins and how its proponents perceive sustainable outcomes. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses—extension for Scoping Reviews guidelines, our review searched peer-reviewed articles from Scopus and Web of Science, along with a Google Scholar snowball search, up to July 2024. Of the 71 articles reviewed in detail, 46 explicitly discussed RA, and 25 addressed sustainability or holistic management relevant to RA. Key research gaps identified include: (1) Despite varying definitions and uncertain outcomes, growing interest in RA warrants further research into farmers' preferences for RA over MCA. (2) There is insufficient evidence on how farmers balance the interconnected elements in the economic, social, and environmental domains for sustainable outcomes. (3) RA practices are often unclear and overlap with other production methods, necessitating clearer definitions of input systems and strategies used to comprehend RA's biophysical and economic outcomes. A conceptual framework is proposed to guide future research and inform agricultural sustainability programmes.

Keywords: sustainable; biodiversity; farming practices; motivation and values; farmers

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1. Introduction

Agricultural revolutions have played significant roles in evolving the current food system addressing food security for the ever-growing world population [1]. Specifically, in the aftermath of World War II, agricultural industrialisation benefitted humankind across the world [2]. The successes of the green revolution witnessed a significant increase in food and fibre production, wherein crop and livestock productivity increased and saved many lives [3]. The approach that led to achieving these successes is attributed to "conventional agriculture" or "the industrial agriculture" of the 1950s to the 1970s (hereafter as Early-CA) [4,5]. Beus and Dunlap [6,7] defined Early-CA as capital-intensive, often monocultured, highly mechanised, with excessive use of synthetic fertilisers, weedicides, and pesticides, and with intensive animal use. Simply put, some describe it as an open farming system where external inputs are used to produce food and fibre with little sensitivity to soil erosion [4].

While this approach ensured food security, achievements were not without cost. Kim et al. [8] suggested that achieving higher agricultural productivity for sustaining humankind sometimes led to the overuse of external agricultural inputs, intensive farm mechanisation and grazing systems, and utilisation of finite natural resource bases amongst Early-CA advocates. It is argued that the over-use of inputs has led to decreased ecological and biological resilience across agricultural systems, causing adverse environmental, social, and economic impacts, hence, limiting farmers' livelihoods [5,9].

Of the 38% of the earth's surface that is dedicated to the agricultural sector, 25% of the world's productive land is degraded, and 24 billion tons of fertile topsoil is lost every year [10,11]. Assuming soil with a bulk density of 3 tons per cubic metre, 24 billion tons equals eight cubic kilometres of irreplaceable soil loss each year. It is argued that the rate of soil erosion is higher than the known soil formation rates [12]. Thus, in the minds of many, the current global food system is considered to have impacted the environment, rendering more harm than good [13,14]. Furthermore, agriculture is also known to emit various greenhouse gases (GHGs) such as methane, nitrous oxides, and carbon dioxide, which are considered to contribute to climate change.

Early-CA, which was embraced as an innovative agricultural production system and underpinned achieving food security in the past [1,6,14,15]) is no longer regarded as a viable option for food production as it is believed to pose threats to long-term sustainability [16]. Through such narratives, Early-CA is seen as a production system that is short-term profit-oriented and "views farms as factories and considers fields, plants and animals just as production units" [17]. It is therefore considered an unsustainable production system today [1,18,19]. Due to the growth of such apprehensions and uncertainties associated with Early-CA, modern societies desire eco-friendlier production systems for long-term sustainability [20,21]. Thus, consideration of agricultural systems that are deemed economically viable, socially acceptable, and environmentally friendlier were felt appropriate to adapt and adopt for food and fibre production across the world [22,23]. As a result, farming communities including academia, policymakers, and relevant stakeholders have explored and adopted various new agricultural models that are believed to be more sustainable in nature [24,25].

1.1. Sustainability and Alternative Agriculture

Rachel Carson's Silent Spring (1962) awakened people to the environmental damages already done by pesticides and other chemicals; sparking the modern environmental movement which has stopped the use of many of the most dangerous materials [26]. In concurrence with such concerns, the concept of sustainability emerged mainly due to increasing global environmental problems and unsustainable production systems [27–29]. The sustainability concept was endorsed by the World Commission on Environment and Development through the "common future" of the 1987 Brundtland report and adopted by over 180 countries at the Rio Summit in 1992 [30]. The report defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs". Similarly, the UN [31], asserts that "to be sustainable, it is crucial to harmonise the three core elements of economic growth, social inclusion and environmental protection suggesting improvement in economic and social quality of life, while limiting impacts on the environment". These elements are understood to be interconnected and essential for the overall wellbeing of individuals and societies as a whole [32].

Nowadays, sustainability is often used interchangeably as the triple Ps (profit, people, and planet), or the three Es (efficiency, equity and environment) commonly referred to as the "Triple Bottom Line" (TBL) [17,33,34]. It aims to ensure continuity through a harmonious approach prioritising balanced consideration of economic, social and environmental concerns [35]. Although the concept of sustainability might have evolved long before the formal Brundtland report [36], it gained momentum since then, while at the same time, there was a paradigm shift toward alternative agricultures [17], resulting in the emergence of several alternate farming approaches based on these very ideas of sustainability. Modern conventional agriculture (MCA) has been quick to evolve on similar lines with the expansion of international scientific collaboration through the Consultative Group for International Agricultural Research (CGIAR), the Food and Agriculture Organisation (FAO) of the UN, and national agricultural research such as the Australian Centre for International Agricultural Research (ACIAR) working in many countries, each coordinated with university research and extension efforts. The Brundtland Commission confirmed the need for, and further strengthened the support of, international collaboration already established.

Alternative Agriculture and Its Narratives

Several alternative agricultures emerged aiming to achieve long-term sustainability [37]. Alternative agriculture can be broadly described as the production systems that do not use conventional methods [15,38], and often refrain from or discourage use of synthetically manufactured inputs like fertilisers, pesticides, supplements, and sometimes heavy farm machinery [39]. Alternative agriculture may also encourage using locally available inputs [15,39,40]. An agricultural system that is considered sustainable must maintain farm productivity, be useful to farmers and create enabling avenues to enhance the life quality of farmers and society indefinitely [17]. Farming systems that fail to conserve the natural resource base will eventually lose their productivity, resulting in more harm than good, and ultimately lose their value to society as they can fail in sustaining social or environmental or economic imparatives [41].

Some of the alternative agricultures currently practised around the world include "Sustainable Agriculture", "Organic Agriculture", "Conservation Agriculture" or "Permaculture" [42–46]. There exist subtle differences in the methods and practices of these approaches; however, they nonetheless share much in common in their philosophies, concepts, beliefs, and values, which consider the three main pillars of sustainability (the social, economic, and environmental) and primarily focus on resource stewardship [47]. For example, proponents of alternative agriculture seek to improve their overall quality of life by ensuring farm profitability through upholding, managing, and expressing reverence to the environment and its people (society) [15,40]. This type of sustainability-oriented paradigm in agriculture "treats the farm like an organism consisting of many complex, interrelated suborganisms, all of which have distinct biological functions and limits", which enable achieving desired farm outputs [48,49].

In recent years, the concept of regenerative agriculture (RA) has surfaced as an alternative agriculture, which is held by adherents to be environmentally friendlier, economically viable, and socially acceptable [5,50]. RA has been gaining momentum in agricultural spheres in recent years [51], and sustainability is highly prioritised by the RA proponents [52]. Apart from the calls of sustainability goals, RA has emerged out of multifaceted discussions and criticisms of the past agricultural and food production systems [53]. However, the main motivating factors for the adoption of RA, and underlying reasons for its gaining popularity in recent years, have largely remained unknown; and thus, calls for examination, especially when the claimed outcomes achieved by RA adherents have often remained contentious [51,54,55]. In addition, the interactions between the interlinked economic, social, and environmental pillars to achieve sustainability outcomes are currently least addressed. Thus, the review not only examined the origins of RA but also studied its interconnected economic, social, and environmental pillars within the RA framework.

To this end, this scoping review was conducted with an overall objective of understanding what RA is, identifying potential evidence gaps linked to the sustainability objectives, and propose a relevant framework that addresses the identified gaps by asking:

1. What is RA, and what are the explanations for its rising growth?
2. What are RA's major principles, practices, claimed benefits, and outcomes?
3. How do RA adherents perceive the sustainability benefits and outcomes?
4. What are the evidence gaps hindering the achievement of RA's sustainability outcomes?

2. Materials and Methods

A scoping review was undertaken to examine the existing peer-reviewed articles instead of a systematic review. This is because, unlike systematic reviews which focus on specific research questions, scoping reviews are designed to explore and address broader questions on the subject of interest, provide an overview of existing evidence, and identify potential research gaps [56,57]. Scoping reviews are also commonly used over systematic reviews for emerging subjects such as RA [58]. Only peer-reviewed articles were considered for this scoping review because they carry more weight in terms of information reliability over grey literature [59].

2.1. Data Sources and Search

This scoping review adhered to the methods developed by the Joanna Briggs Institute (JBI) [60], supported by a widely used methodological framework known as Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocol (PRISMA-P) developed and proposed by Page et al. [61]. This framework was later embedded by the JBI and used as PRISMA-ScR, an extension for scoping reviews [57,62]. Authors have extensively used the PRISMA-P framework for both scoping and systematic reviews; e.g., Hargreaves-Mendez and Hotzel [63] and Voisin et al. [58]. Two widely used databases, Web of Science (WoS) and Scopus, were used to find peer-reviewed articles because they provided a comparatively higher number of papers on RA relative to other databases. To avoid missing any articles, a snowball search using Google Scholar was also used iteratively (Figure 1).

Owing to the broader objectives of this review to trace the origin and evolution of RA, we used an unrestricted timeframe to trace all the possible existing peer-reviewed articles. We used the broad term 'regenerative agriculture' to capture all articles that mentioned RA. Similarly to the key words used by Hargreaves-Mendez and Hotzel [63] and Schreefel et al. [64], the keywords were expanded as '(['regenerative agri*' OR 'regenerative farm*'] AND ['sustainability'] AND ['holis* AND manage*'])'. "Holistic management" was included because farmers dealing with livestock farming often identify themselves as holistic practitioners of RA [65]. Screening eligibility criteria for inclusion and exclusion are shown in Table 1.

2.2. Data Extraction (Charting) and Analysis

Following the PRISMA process (Figure 1), extracted articles were broadly categorised into articles substantially on (1) RA, (2) sustainability linked to RA, and (3) holistic management linked to RA. The search yielded 617 articles from the Scopus and WoS databases combined. After removing duplicates (n = 33 articles), 584 articles were left. Then, the primary screening process based on the titles and abstracts resulted in the exclusion of 485 articles. The secondary screening of full texts, abstracts, and keywords eliminated 33 papers that did not explicitly discuss RA, sustainability, or holistic management, such as mentioning RA in the abstract, conclusion, or recommendations only. In total, 66 articles remained. An additional 5 out of the 15 articles identified from a snowball search on Google Scholar were included in the final review. Altogether, 71 articles were reviewed in detail.

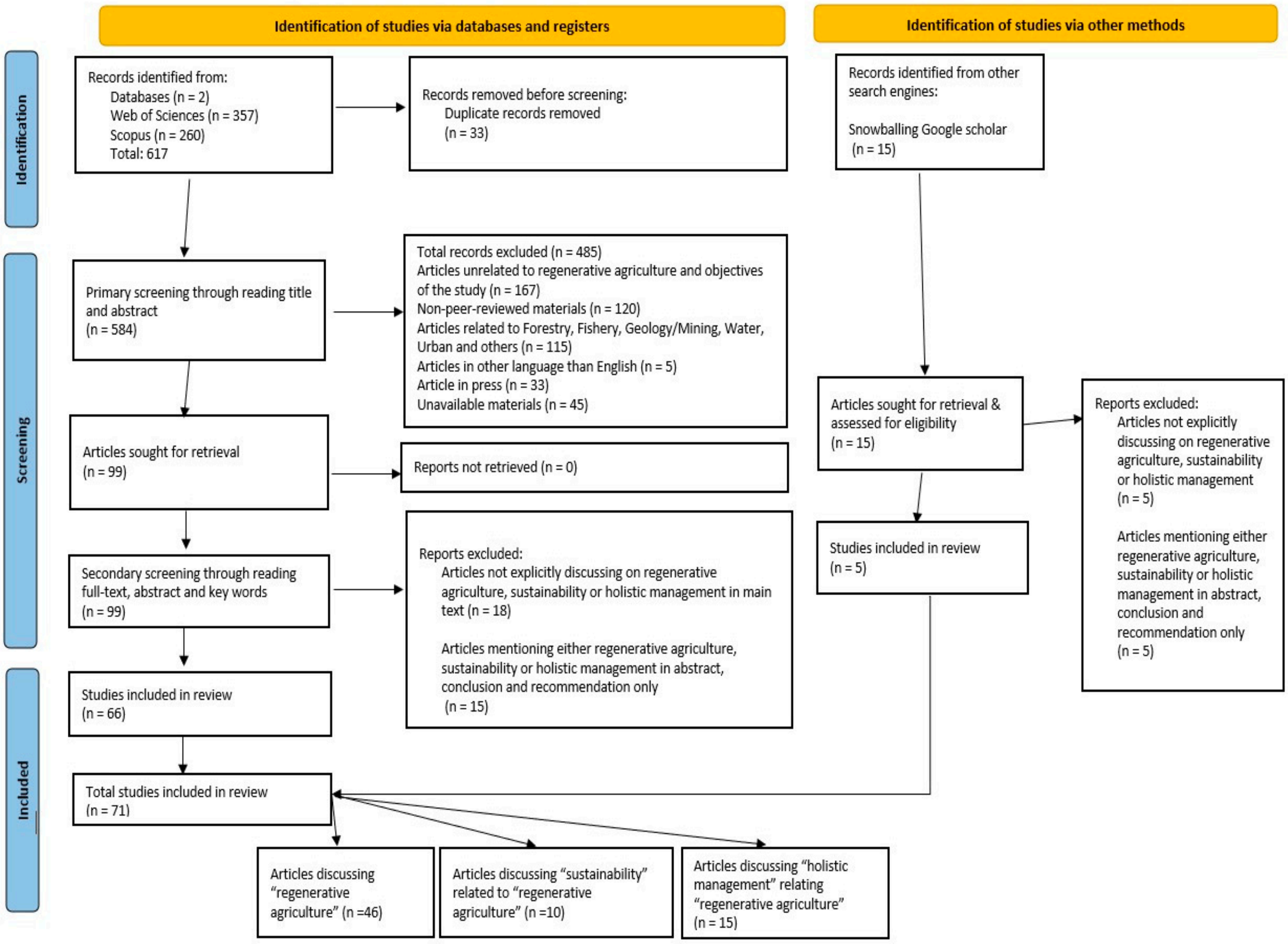

Figure 1. PRISMA flow chart for the identification of studies via databases and records. Authors' own work adapted to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses-Extension Scoping Reviews), and the checklist from Tricco et al. [62]. For more information, visit: http://www.prisma-statement.org/ (accessed on 10 July 2024).

Table 1. Screening criteria for the literature search.

Inclusion	Exclusion
- Only published peer-reviewed articles - Quantitative and qualitative or both (mixed) articles - Only papers written in English - Subject area: agricultural sciences, environmental, economic, and social sciences	- Grey literature (e.g., non-peer-reviewed articles, practitioners' websites, etc.) - Papers in languages other than English - Subjects other than agricultural sciences, environmental, economic, and social sciences - RA found only in the abstract, keywords, conclusion, or recommendations - Articles not relating to research questions/objectives

There was a mix of qualitative (n = 39) and quantitative (n = 30) articles. Two articles were a mix of both. Most articles explicitly discussed RA (n = 46), while some discussed sustainability (n = 10) and holistic management (n = 15) relevant to RA (Figure 1). The majority of the papers were based in the USA (30.4%), followed by Australia and the UK (10.6%) and Brazil (10%). Few originated from Canada (7.9%), Germany (7.0%), China (7.0%), Netherlands (6.7%), Spain (6.4%), and Italy (4.6%).

3. Results and Discussion

3.1. The Rise of Regenerative Agriculture

The earliest peer-reviewed article we found that mentioned RA was published in 1983 (Figure 2). Publications increased but remained less than ten articles per year until 2018. In 2019, publications more than doubled. The trend increased, reaching 73 and 61 publications by mid-2024 for Scopus and WoS, respectively. By July 2024, there were 617 peer-reviewed articles, with 260 articles from Scopus and 357 from WoS. Citations followed a similar pattern, with very few in the 1980s and 1990s, to as high as 1114 citations for Scopus and 1138 for WoS in the 2020s. Total citations were 4570 for Scopus and 6792 for WoS. The increasing trend of citations and publications indicated that RA was an emerging subject that has gained traction over the years. As such, specific underlying reasons for the sharp rise in RA since the year 2019 could not be traced. However, most discussions in these articles revolved around climate and vulnerability smart agriculture focussing environment-centric principles and practices that have potentials to lower greenhouse gas emissions, improve soil health, and provide economic stability and social wellbeing. Perhaps because of these compelling calls, due to degradations posed by mainstream agriculture, RA seems to have gained momentum in recent years, led by farmers as a social movement [66], with increasing interest from both the public and private sectors with a promise to offer better and sustainable ways of farming in the future.

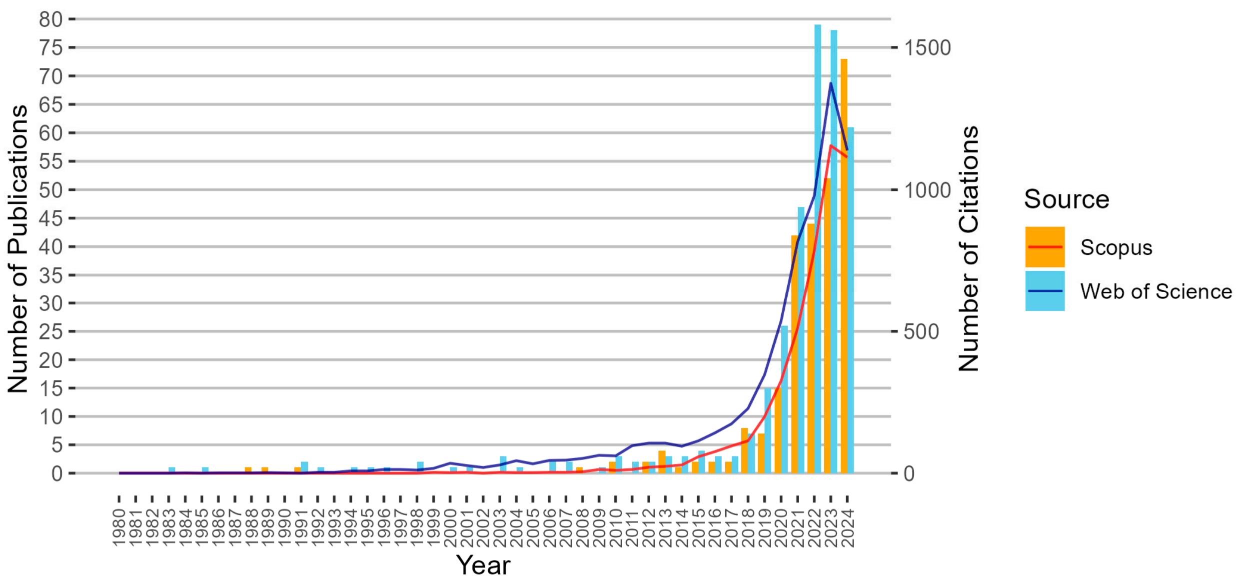

Figure 2. Trends in the number of publications (bars) and citations (lines) over the years, depicting the rising traction of regenerative agriculture.

3.2. Tracing the Origin and Evolution of RA's Concept

RA has been considered the latest paradigm in the sustainable agricultural movement [16]. The origin of the principles and practices that are aligned and promoted today with RA are reported to have long been practised by indigenous Black, Latinx, and Asian farmers [16,67]. Francis et al. [68], pointed out that Gabel [69] conceptualised and proposed RA as an alternative agricultural model that was subsequently elaborated and articulated by Rodale [70].

Sustainability has been central to RA, and adherents of RA emphasise meeting the collective objectives of economic, social, and environmental outcomes through the implementation of RA farm principles and practices [65,71]. Rodale [70] proposed a definition of RA as "one that, at increasing levels of productivity, increases our land and soil biological production base. It has a high level of built-in economic and biological stability. It has minimal to no impact on the environment beyond the farm or field boundaries. It produces foodstuffs free from biocides. It provides for the productive contribution of increasingly large numbers of people during a transition to minimal reliance on non-renewable resources".

3.3. Evolving Variations in Definitions and Narratives of RA

There are varied and inconsistent definitions used to describe RA. Gosnell [50] saw RA as an alternate option that has the objectives of providing not only social benefits but also economic and environmental gains, prioritising the sustainability of farming landscapes. White [72], described RA as both an attitude and a suite of practices aimed at restoring losses due to environmental deterioration. Delving further, this review indicated the emergence of diverging thoughts among theorists and academia. For instance, Giller et al. [51] argued that RA is merely "an addition of an adjective to describe agriculture to suit their own interests and gains". Given the diverse range of ways in which the term RA has been defined and described, Newton et al. [55] cautioned against advocating for any specific definition and avoiding privileging definitions over others as more correct or better, and suggested that users of the term RA ought to define it cautiously for any given use and context. Page and Witt [5] opined that RA has not matured sufficiently to have a clear definition that recognises its credentials in terms of the claimed benefits and outcomes. Others have argued that, due to the involvement of the industrial agri-food industry, RA is being "greenwashed" to improve the sustainability image of the industry [58]. In addition, critics argue that RA is merely used as a "buzzword" to mobilise more resilient food systems [53] and may entail both positive and negative connotations. For example, Wilson et al. [53] suggested that "No one really agrees on what "regenerative agriculture" means, or what it should accomplish, let alone how those benefits should be quantified. Even as "regenerative" becomes increasingly hyped as a transformative solution, the fundamentals are still being negotiated". On the other hand, it is equally argued that RA is more than a "buzzword" and in fact, growing numbers of agri-food companies have undertaken several RA initiatives and calls for agencies to verify whether or not these companies are sustainability-oriented [73].

Due to these inconsistencies in describing RA, there is wide miscommunication, not only with the opposite camp (conventional agriculture), but also among RA proponents [65].

Unlike other alternative agricultures, it is pointed out that the term RA is ambiguous, and there has not been a universally accepted definition in the scientific domains to date [5,64,74]. In a similar tone, others were unclear and claimed that RA cannot be defined at all. RA proponents may not be keen to define themselves or associate with either of the clusters (i.e., alternative or conventional) [55]. This lack of an agreed definition of RA to distinguish itself from alternative agricultures could hinder implementation [55]. Despite this, there has been an increasing trend of interest in RA over time (Figure 2). Examined closely, it seems RA adherents perceive and view RA as a systems thinking paradigm [75] and not just a set of principles and practices that are linked to the narratives of past alternative agricultural models [76].

3.3.1. RA as a System Thinking Model

Systems thinking can be understood as a process or a discipline by which people see and recognise wholes rather than parts and understand the interconnectedness of these parts and patterns of the larger whole system (farming), which gives living systems their unique character [77,78]. In this context, RA proponents visualise farming through the lens of holism, rather than as an individual enterprise through reductionist approaches. For example, sustainability is highly prioritised, and RA adherents desire to achieve their overall social, economic, and environmental goals. It is argued that RA's principles and practices (Figure 3), accompanied by careful planning, aim to achieve the desired outcomes of long-term farm sustainability rather than the short-term gains sought by conventional agriculture proponents [16,71]. In essence, these principles are considered appropriate by being sensible in their intent and objectives. Accordingly, they are inclined to employ environment-centric farming practices to create harmonious living landscapes and provide healthier food production alternatives than conventional practices [50,71,75,79].

Using systems thinking, RA adherents employ principles and practices based on their values, influenced by their inner belief systems, motivations, and a desire for change [50,75,80]. It is evident though that many of these practices employed and advocated by RA proponents are not new [17], and RA shares foundational principles with earlier alternative agricultural systems. For example, Bless et al. [76] argued that practices employed by RA proponents are similar and, indeed, many overlap with the practices of past alternative agricultures (Figure 3). Moreover, unlike Early-CA, the agriculture of today, which can be described as "Modern Conventional Agriculture" (MCA), is concerned about sustainability and avoids environmental degradation, similarly to RA. Thus, practitioners of MCA adjust their farm production practices to minimise environmental degradation [81]. Against such complexities, there is a need to distinguish between the two approaches if differences exist in the farming practices they employ, and their possible outcomes. Nonetheless, it is argued that RA is not only about implementing farm practices but is also to do with the decision-making abilities of the RA farmers to achieve what they want, which is inherently influenced by considering farms as a whole system, and identifying the practices that work best for them [22,82]. Importantly, RA is the shift from a deductive mindset to holistic thinking anticipating desired outcomes [83]. Thus, among RA practitioners, there is a sense of renewed hope and aspirations to be resilient especially to counteract adversaries such as combating climate change impacts. Among other principles and practices employed by RA proponents (Figure 3), this review identified holistic management (HM) as notably important and popularly practised by RA farmers, especially for livestock farming.

3.3.2. What Is Holistic Management?

"Holistic Management" (HM) practitioners believe in regenerating soil through integrating sustainable livestock production systems, mainly focussing on pasture-grazing management [50,65,82,84,85]. Savory [86] suggested that the problems are due to "our inability to address complexity" which is sometimes understood as the "wicked problems" of systems. The central idea that gave rise to the concept of HM was to confront the negative trends of environmental degradation, such as the problems of desertification, biodiversity loss, over-stocking, and soil and climate impacts [87]. Allan Savory developed HM as a decision-making framework in the 1980s to deal with environmental degradations caused by intense and sustained overgrazing, and inappropriate cultivation practices [88]. His aim was to help farmers/graziers understand how their quality of life, influenced by their social, environmental, and economic wellbeing, was inextricably linked to the health of the land [65]. Savory believed that farmers' decisions must consider both short- and long-term ecological, economic, and social/personal wellbeing implications [87]. Subsequently, Savory observed this as "the critical factor missing in conventional decision-making while pursuing their intended goals" [65,88]. It is emphasised that the adoption of HM requires a shift from reductionist thinking to a holistic view of the world wherein behaviour is aligned with values and involves a fundamental paradigm shift in the land steward's approach to land management [65,85].

HM is based on the four key insights [88], adapted in domestic grazing systems to minimise environmental degradation [89]: (1) "the world functions in wholes and should be managed as such"; (2) "environments exist on a scale of brittleness, from very brittle (dry, with uneven and erratic rainfall patterns throughout the year) to non-brittle (humid year-round)"; (3) "brittle environments evolved with large herds of grazing animals concentrated and forced to move by pack-hunting predators, which maintains and improves the health of the land"; and (4) "overgrazing which is not just related to the number of animals, as conventionally thought, but to the amount of time when the land is exposed to animals and the time given for recovery" [82,85]. HM has been practised as regenerative grazing (RG), where short periods of intense grazing are followed by pasture rest periods to support vegetative recovery. It has also been practised as strategic rest [90], Voisin rational grazing [91], rotational grazing [92], time-controlled grazing [93], short-duration rotational grazing [94], holistic planned grazing [86], and mob and adaptive multi-paddock grazing [95].

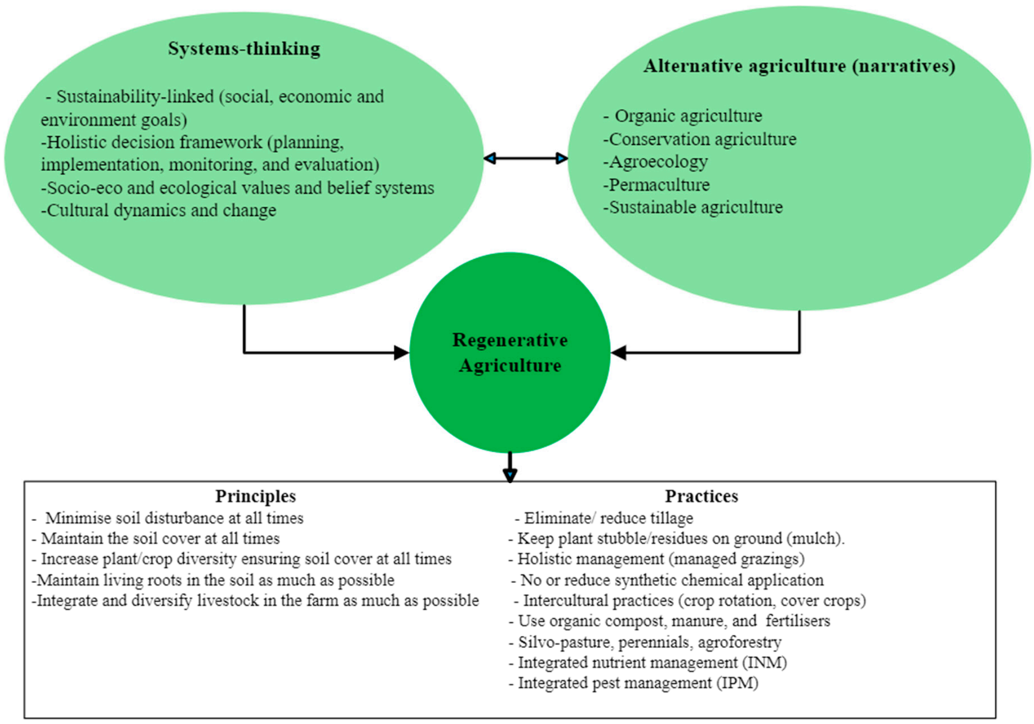

Figure 3. The authors' identified key themes, principles, and practices based on the cited works in the text (in particular Bless et al. [76]; Briske, Derner [92]; Brown et al. [75]; Gosnell et al. [65]; Khangura et al. [96]; Lal [23]; Mann and Sherren [82]; O'Donoghue et al. [38]; and Teague and Kreuter [95]).

3.4. Analysis of Key Benefits and Outcomes of RA

3.4.1. Economic Benefits

Our review revealed varied economic benefits and financial wellbeing achieved as a result of implementing RA farm principles and practices (Figure 4). For example, O'Donoghue et al. [38] reported that RA corn farms in the U.S. were more profitable compared to conventional farms by approximately 80%. Similarly, Torsten et al. [97] showed increased profit by 60% in Germany. However, authors have not spelled out the detailed economic operations and interactions (e.g., input costs, prevailing prices, etc.) to support the claims. Detailed financial interactions incurred in farm operations that could determine (e.g., showing net present values, gross margins, debts, etc.) could have explained this better to ascertain the claims for the general audience. In addition, farms are context- and site-specific and, therefore, outputs are often influenced by the environmental factors in which the farm is operated. Thus, for instance, through agronomic perspectives, farm productivity and economic outputs vary from one farm to another to realise the economic benefits [96]. Generally, higher economic returns (profit) generated by RA adherents mostly centred around the idea of reducing or avoiding external inputs (synthetic fertilisers, herbicides, etc.). However, past studies have not explained the types and quantities of the inputs used, nor have the detailed costings incurred for using alternative input systems to manage the productivity been explicated. In addition, Francis and Holmes [98] observed that some authors were dismissive of credible methods to assess farm profitability. Taking these current scenarios into account, while claims may hold true, it does not suffice to ascertain the economic benefits. Further, there are good cases for better dialogue between RA advocates and modern standard soil science [99].

In continuation, the upfront investments incurred for transitioning to RA had made some reluctant to invest without assured economic gains [100]. It is argued that, at times, rather than achieving financial security, farmers were reported to have experienced increased stress due to uncertain farm returns [96]. Currently, there are no assured markets, premium prices, or accreditations to provide legitimacy for the claimed better quality of RA produce compared to that conventionally grown [96,101]. Exceptions to this may be found in certified organic production where known demand can evolve. Perhaps due to such uncertainties, and apprehension about the efficacy of RA currently [51], this review could not trace evidence that discussed opportunities for economic scalability. Although the trend in terms of publications (Figure 2) showed increasing numbers over the years, real-world data pertaining to economic policy supports were limited, probably indicating immaturity and the need for in-depth scientific queries to support the claims of RA's outcomes. Therefore, there is scope to further explore and expedite RA by embracing and practising more science-driven technologies backed by strong evidence claiming the outcomes for long-term sustainability. Nonetheless, critics have argued that there are indeed several untapped economic opportunities to expand and achieve better economic sustainability in RA as opposed to MCA [102,103]. These converging and diverging views have currently spurred mixed reactions among farmers and scholars alike [98,99].

3.4.2. Environmental Benefits

The fundamental idea of RA is implementing environment-centric principles and practices [104]. Several multi-dimensional environmental benefits are reported to have been obtained by employing RA's farm principles and practices. For example, benefits have ranged from enhancing overall soil conditions (fertility, microbial activities, farm biodiversity, etc.) and increasing carbon sequestration to reducing GHG emissions (Figure 4) [64,105,106]. Implementing practices such as cover cropping, retaining crop stubble, and avoiding soil disturbances, Khangura et al. [96] noted a significant increase in soil carbon stocks, nutrient and water cycling, and the filtration and mineralisation of the soil in Australia. As a result, farmers were able to achieve biodiversity-rich farmland, which is not only resilient to external shocks (e.g., dry spells), but is also considered to be more productive [65,105]. In concurrence, Schulte et al. [107] reported similar findings with increased soil fertility. Sheep farming in Spain reported RA's rotational grazing achieved 30% higher springtime grass production and 3.6% higher topsoil carbon storage than conventional grazing systems [108]. Likewise, Schreefel et al. [64,109] emphasised that RA prioritises environmental landscapes of sustainability with a focus on soil improvement. Further, Gosnell et al. [104] considered RA to be climate-smart farming that helps counteract climate change impacts.

These assessments hold true, but it can also be similar for MCA. This is because unlike Early-CA, MCA's production systems of today can also be considered equally environment-centric because they adjust their production systems and are cautious about environmental degradation (e.g., soil depletion, fertility loss, etc.) [81]. MCA proponents may apply synthetically manufactured fertilisers and pesticides and practice tillage, but they do this with much consideration and care for safety [4]. Currently, there is less clarity that RA's practices are distinctive from those of its counterpart, MCA [110]. For instance, the grazing systems employed by RA are common, if not overlapping, with MCA and other alternative agricultures [76,111]. Although RA's motives may not be to distinguish its practices from MCA's, the claimed environmental outcomes have generally lacked evidence [105]. There seem to be uncertainties associated with some of RA's claimed environmental benefits which, therefore, could be misleading [112]. For example, authors have argued that the practices are being applied without in-depth understanding of the agro-ecosystem and whether they are suitable for the unique context of a given specific farm [51]. Although these facts exist, they are seldom highlighted [51].

3.4.3. Social Benefits

Brown et al. [113] highlighted that one of the primary objectives of RA is to increase and improve the overall social wellbeing of farmers (Figure 4). Mann et al. [85] argued that RA farmers consider their farms as holistic entities, constituents of diverse living organisms (flora and fauna) that can improve not only farm productivity but also overall farming landscapes. This is because RA farmers avoid or minimise synthetically manufactured inputs, keeping the environment pristine while judiciously harnessing the economic benefits [50]. RA farmers continuously crave to live in agreement with nature, making close observations on their farms (what needs to be done) along with their crops and livestock [104,114]. In doing so, RA farmers ask themselves "what is missing in their lives and what do they want to achieve?". Thus, they constantly remind themselves whether they will be able to meet their set objectives and adjust accordingly to achieve their goals [82]. Authors have argued that RA farmers are more aligned toward achieving harmonious living surroundings that can enhance a better and healthier life [113,115]. Perhaps due to such outlooks among RA farmers, they were known to regularly reflect and seek to improve their quality of life by spending more time with their family, building community relations, and rewarding themselves with enhanced wellbeing [50]. While RA farmers do consider farm profitability, their personal wellbeing (e.g., life–work balance) is equally thought out [82,85]. Similarly, RA farmers have been reported to be more considerate regarding animal welfare and ensure animals are treated with utmost care [63]. Further, one of the other main reasons for farmers transitioning to RA is believed to be due to experiencing negative feelings associated with handling agrochemicals as do MCA farmers [50]. There are, in fact, some requirements that must be legally observed in the use of agrochemicals; certified training in safe handling, storage, measuring, and mixing water and ingredients, the calibration of spray rates to avoid over or under application, personal protection requirements, allowable wind speeds, safe washing of equipment, disposal of chemical wastes, etc. In other words, these are significant obstacles legally in place in Australia, such that it is easier, safer, and smarter for untrained small holders to avoid these chemicals.

Conversely, critics argue that the social benefits of RA are often "overstated" and have lacked adequate evidence to support the claims [53,96]. Brown et al. [113] explored the association between personal relationships and RA practices but could not significantly decipher the relationships indicating how and why RA farmers' wellbeing was enhanced as a result of RA practices. Similarly, Ogilvy and Heagney [115] argued that RA graziers experienced enhanced life satisfaction after their transition to RA. But, at the same time, they also reported feeling a sense of an "unsecured future" due to the uncertain environmental and economic outcomes associated with RA. Importantly, irrespective of RA farmers or otherwise, striving to achieve wellbeing is universal [116]. Understanding the interactions between the economic, social, and environmental pillars is essential to comprehending overall sustainability benefits. At this juncture, apprehensions have largely remained unaddressed, and it might warrant further queries to arrive at a comprehensive conclusion.

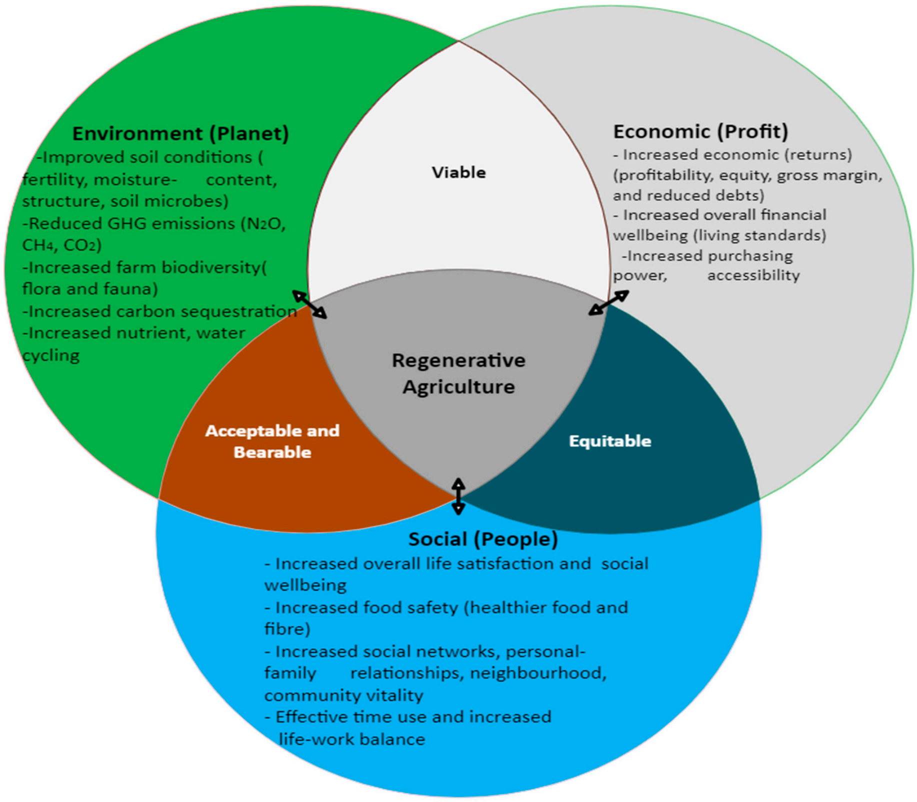

Figure 4. Benefits and outcomes of regenerative agriculture. The authors' own work based on Bless et al. [76]; Brown et al. [75]; Gosnell et al. [65]; Khangura et al. [96]; Mann and Sherren [82]; O'Donoghue et al. [38]; and Ogilvy and Heagney [115].

3.5. Identified Evidence Gaps for Future Research

This scoping review points out that RA proponents have highly prioritised sustainability. However, achieving sustainability is not as linear as it may seem. This is because farm sustainability lies in the subtle interactions between social, economic, and environmental factors, which are often complex to balance in perpetuity [117]. For instance, a particular choice and emphasis on one domain (e.g., environment) may significantly impact the other domains (e.g., the economic or social) and vice versa [118]. On the other hand, these domains may sometimes be complementary, or, at the same time, contradictory to each other [119]. In other words, farm sustainability depends on the ways farms are managed to render economic, social, and environmental functionalities throughout time [27,119]. Regardless of farming types (RA or MCA), farm sustainability is observed to be influenced by the viability of the farm that can generate outputs [120]. For example, if farms are commercially oriented and do not generate profits for producers (farmers), farming will not be economically sustainable and is likely to disappear [121]. This is perhaps more likely to occur in RA because its proponents tend to significantly reduce the use of synthetically manufactured inputs [104]. Unless required soil nutrients are replenished and managed adequately, farm productivity will decline, and so will returns. Significant challenges arise to balance sustainability. Critics question whether it is possible to balance the three domains of the economic, social, and environmental at all [122]. Thus, this review could not identify significant and actionable evidence relating to RA meeting sustainability objectives which are essential to persuade the general populace regarding the claimed benefits of RA.

Against these complex perspectives, despite the dearth of an agreed common definition of RA, the trend in RA is rising. Therefore, it might be relevant to understand farmers' motivating factors that trigger them to adopt RA over MCA and why RA matters to them. Thus, this calls for a closer examination, identifying a definition of RA that describes famers' desire and context-specific practices. Similarly, sustainability is clearly central to RA proponents, but how they would prefer to make choices between the interlinked economic, social, and environmental domains while aiming to achieve their desired outcomes is largely unknown, unlike in MCA. Finally, the input systems used by RA proponents to achieve their desired outcomes are not clearly laid out. Thus, the biophysical and economic outcomes achieved by RA adherents are mostly undervalued [4,51]. Therefore, it is warranted to define and assess the input systems and strategies used by RA proponents to realise the outcomes achieved by implementing RA as opposed to MCA practices at a given farm.

In view of these research gaps, we suggest a conceptual framework (Figure 5) that allows researchers to capture the overall picture of the identified knowledge gaps and address them. Further, the framework will enable researchers to delve into understanding the motivating factors and values associated with farmers that trigger them to adopt RA over MCA. Similarly, farmers' preferences and choices, including trade-offs, could be understood by exploring the overarching sustainability framework. Lastly, the framework will enable us to define and identify the input systems used by RA farmers and assess their outcomes compared to MCA.

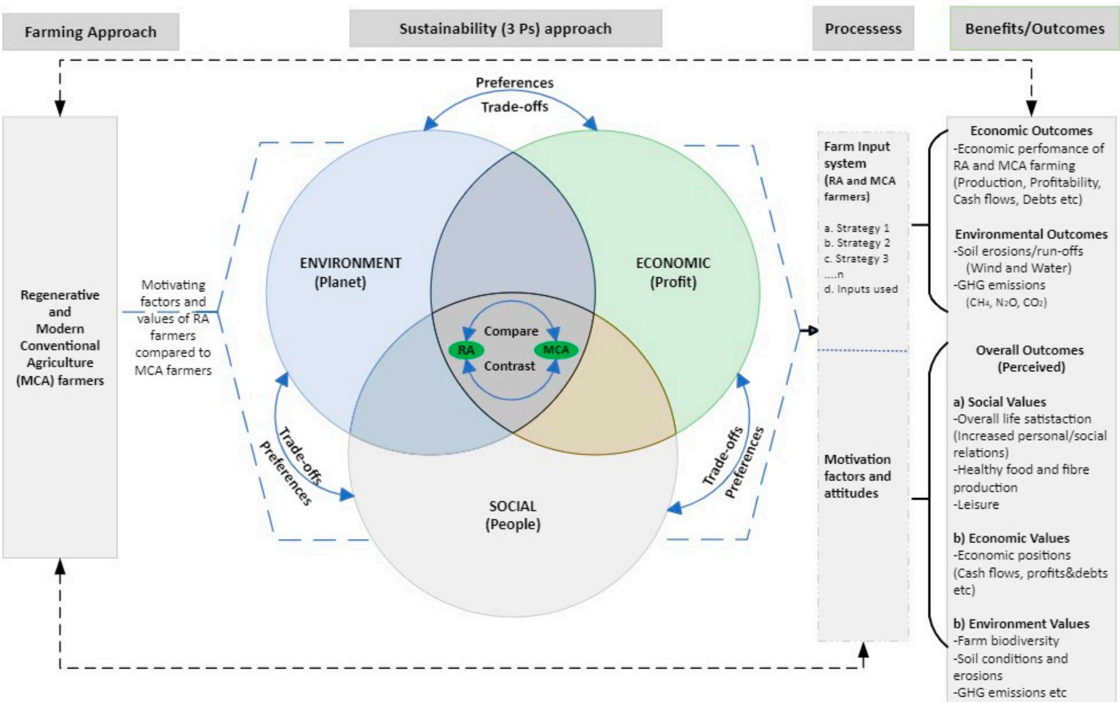

Figure 5. Conceptual framework for investigating the identified evidence gaps. The authors' own work, based on Bachev [27]; Arowoshegbe [28]; Pannell et al. [29]; and Smith [27–30].

4. Conclusions

This scoping review was conducted with the objective of identifying the potential research gaps by understanding what RA is, and what are the benefits and outcomes linked to sustainability. The review rationalised how RA emerged and discussed the interlinked economic, social, and environmental domains, which are an essential fabric of sustainability. As highlighted, the environmental degradations posed by the mainstream Early-CA have led to the emergence of several alternative agricultures in the past. In recent years, RA has emerged as an alternative agricultural paradigm, and is gaining momentum in agricultural spheres. The goals of RA might be innovative, novel, and may pave new directions toward environment-friendly farming in the future, particularly at a time when agricultural production systems are highly criticised for the effects of climate change. However, the outcomes achieved by applying RA's concepts and practices, which are generally unassessed, have led to ambiguous conclusions, especially in academic spheres around the world, including in Australia.

To this end, a new conceptual framework (Figure 5) is proposed that enables researchers to address the identified knowledge gaps and may facilitate the design of better policies and programmes to provide support for greater agricultural sustainability. Thus, further research is needed to operationalise each of the concepts in the framework so that data can be collected to test how it works. Specifically, to determine if RA farmers have a different farming approach (e.g., in terms of the input systems used) and different preferences compared to MCA farmers, as well as how they balance environmental, economic, and social preferences. As a result, the outcomes of RA and MCA farming in terms of biophysical and economic outcomes, including the associated social, economic, and environmental values, can be compared in order to better understand the impact of these preferences and trade-offs.

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