Regenerative agriculture: its meaning, rationale, prospective benefits and relation to policy

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Abstract

A critical narrative review is conducted of "regenerative agriculture" literature. An outcome-oriented definition, aiming beyond sustainability, is defended as consistent with evidence of regenerative farmers' usage. It is partly a response to problems of soil degradation and has scientific rationale in contemporary understandings of soil formation and soil ecology. Potential benefits include input reduction enabled by an enhanced soil microbiome, improvements to farming livelihoods, farmscape ecosystems, health and wider environmental public goods. Research at a systems level is lacking, however; and scale of adoption is contingent on the business and policy environment.

Keywords: regenerative agriculture, agricultural systems, soil health

Introduction

"Regenerative agriculture" (RA), is an alternative farming movement currently gaining traction, with potential to address degradation of soils on agricultural land. Some striking claims have been made in its name, but the term has only recently gained widespread currency among either farmers or researchers. Its definition is contested, and it is born into a policy environment evolved around distinct approaches. The review contextualises RA by outlining the need for improved soil health. It then argues for a particular definition, covers some central scientific aspects, reviews key practices and their benefits, considers the policy landscape in relation to RA and identifies some priority areas and challenges for research.

The approach taken to sampling the literature is *purposeful* rather than comprehensive or statistically representative, aiming to collate the most relevant and informative studies for the purpose at hand (Luke, 2025). The review draws on literature searches conducted via *ISI web of knowledge* for co-occurrence of terms *regenerative* and *agriculture*, and cognate expressions. In addition, it covers literature encountered *inter alia* by attending relevant academic and agricultural events in the UK and Ireland since 2010, that was judged to be substantively significant. It is a critical narrative review in the sense described by Hammersley (2001) as involving "… judging the validity of the findings and conclusions of particular studies and how these relate to one another, and how their interrelations can be used to illuminate the field under investigation."

Depletion and degradation of soils have reached an alarming level, such that the FAO has reported that there is only 60 years of harvesting left (Arsenault, 2014). A recent study suggests that 90% of conventionally farmed soils are thinning, with many soils facing complete exhaustion within 100 years, including the UK's and China's (Evans *et al*., 2020). Such estimates imply that the current agricultural system cannot "feed the world" in the long run; it can only do so temporarily at the expense of future harvests. It is also uncontroversial among climate scientists that this system is a huge net contributor to greenhouse gas emissions, and therefore anthropogenic climate change (IPCC, 2019), which is itself an existential threat.

Degraded soils are also plausibly linked to adverse human health outcomes. The "one health" proposition, "healthy soils, healthy food, healthy people" was originally postulated by extrapolation (Balfour, 1943), from animal feeding trials linking dietary quality to health, and contentions of organic agriculture pioneers linking soil conditions to dietary quality (Matless, 2001). Relevant animal studies since then have studied organic or biodynamic versus agrichemical fertilization or feeds, often reporting supportive results on animal health (Velimirov *et al*., 2010). Soil properties tend not to be directly manipulated or measured in these studies; however, see Takahashi *et al*. (2018) for evidence that higher soil organic matter increases livestock growth. Soil degradation provides a candidate explanation for much of the ongoing deterioration of the measured nutritional content of foods, documented for example by Thomas (2007).

In addition to regulating the incidence of soil-borne pathogens (Samaddar *et al*., 2021), modern research outlines plausible

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biological mechanisms for potential positive soil influences on human health. These include phytochemical and nutritional effects via crops, and effects of direct exposure, impacting for example the immune and digestive systems (Reeve *et al*., 2016, Brevik *et al*., 2020; Blum *et al*., 2019; Hirt, 2020; Montgomery and Biklé, 2022; Oliver and Brevik, 2024). Effects of "healthy soils" may have a role to play in alleviating many health problems facing modern societies (Miller, 2013). This is because, for example, the human gut microbiome is linked to cancer risk (Davis and Milner, 2009) and incidence of allergies (Dotterund *et al*., 2010; Aguilera *et al*., 2020) and obesity (Ley, 2010). Soil health has been variously defined, but biologically involves having an abundance and diversity of soil bacteria and fungi supporting higher level microorganisms (Lehmann *et al*., 2020). Conversely, degraded soils with a paucity of microbiological life plausibly contribute to the generation of such problems.

What is regenerative agriculture?

Paradigm shifts, occurring partly in reaction to soil degradation, and aligned with scientific developments outlined below, include one from conservation- and sustainability-oriented agricultural practices to "regenerative" practices (Perkins, 2020). The term RA has a long history, dating back at least to the 1970s (Giller *et al*., 2021), but the currently fast-growing movement through which it has become widespread terminology is relatively recent and farmer-led (Newton *et al*., 2020; Wilson *et al*., 2024).

Studies of its meaning have generally proceeded via analysis of either academic or organisational descriptions and definitions (Schreefel *et al*., 2020; Newton *et al*., 2020), or via stakeholder interviews (Wilson *et al*., 2022), but have produced different results. Newton *et al*. (2020) emphasise definitional diversity, and posit a classification of "outcome-based" definitions, centering on what RA is supposed to achieve, "process-based" definitions, which outline practices constitutive of RA, and ones with both elements. They point out that the definitions are inconsistent but conclude that none are to be preferred. Wilson *et al*. (2022) in contrast emphasise commonality of understanding between interviewees, who are reported to share an outcome-based understanding of the term, and one that goes beyond sustainability. A problem with process-based definitions of RA is that the list of potentially regenerative practices, key examples of which are considered in the next section, is large, evolving and context-sensitive (Newton *et al*., 2020).

More attention should perhaps be paid to the nature of language in this debate, in particular the insight that "the meaning of a word in its use in the language" (Wittgenstein, 1953). A definition is not a use of a word but a mention, purporting to clarify use. Such clarification is often a non-trivial task, and it would be surprising if independently-formulated definitions (of almost anything), coincided. Arguably, therefore, it would be useful to have more discursive attempts to clarify usage conducted with RA farmers as the linguistic group of primary relevance. Wilson *et al*. (2022, 2024) appear to be an exception in conducting interviews with self-identifying RA farmers to clarify usage, but only report 4–5 in their sample of 19 "practitioners", which also included researchers, company and NGO staff. Alexanderson *et al*. (2024) work with a larger Australian sample of self-identifying RA farmers, but use survey methods. Their conclusions coincide with Wilson *et al*. (2022) in terms of an outcome-oriented definition going beyond sustainability, though the eventual definition is described as "inspired by" the survey results, rendering its status unclear.

On the basis of the foregoing, the following definition is proposed, tentatively, as consistent with the available evidence of usage by RA farmers. RA can be defined as farming which is geared towards working with and enhancing natural nutrient, carbon, and hydrological cycles for agricultural benefit. Those cycles work through soils, hence the centrality of soils and "soil carbon" noted by Schreefel *et al*. (2020). This specific formulation paraphrases material from UK RA farmer interviews conducted by the author (work in progress).

The outcomes mentioned are broad since the natural cycles are multi-faceted, defying reduction to specific metrics. The hypothesised definition would not exclude purely plant-based intervention, given the soil-plant nexus noted in the previous section, for example via foliar sprays of aerated compost tea (Ingham, 2005) or of mineral solutions designed to enhance photosynthesis (Kempf, 2020, 2024). It will not satisfy all critics, particularly those inclined to include social factors, or to acknowledge the contribution of indigenous practices in its definition (Sands *et al*., 2023). There are also farmers who would argue that a *truly* regenerative approach entails eschewing agrichemical inputs entirely, and actors who want certain processes or specific outcome measures to become definitive (Wilson *et al*., 2024). These contentions can be taken as pleas to broaden the agenda or to reform usage of terms, respectively, and as such do not necessarily contradict any characterisation of current usage.

The UK RA conference Groundswell has proposed a still more open definition, as "any form of farming which at the same time improves the environment" (Groundswell, 2024). This furthers an inclusive event, but taken literally would for example include setting aside less profitable land on conventional agrichemical farms in order to capture subsidies. It would also obviate any distinction between traditional- and regenerative-organic agriculture, as insisted on for example by the Rodale Institute (Rodale, 2019) and associated farmers (Gordon *et al*., 2023). This example illustrates the problem with relying on published organisational definitions, which often reflect goals beyond clarifying use of terms in natural language.

Emergent understanding of soil formation and functioning

In practice, RA involves trending techniques in biological agriculture believed to improve soils with knock-on benefits. Though many of these are anticipated by examples of traditional or indigenous practices (Sands *et al*., 2023), they can be understood in relation to developments in modern soil science. Key among these is the microbial pathway for the formation of soils, which may actually account for most soil formation, recently demonstrated by Kallenbach *et al.* (2016). The researchers created soil over 15 months *in vitro* by inoculating inert sand and minerals, then feeding the microbes synthetic root exudates. Thus, soils can be formed via microbial activity fed by plants, and microbial necromass. This is a discovery of profound significance since it was previously believed that soil formation takes place principally via slow geophysical weathering of rock and incorporation of litter. *In vivo*, soil fungi and bacteria make diverse nutrients available to plants, including via root ingestion of microbes (Paungfoo-Lonhienne *et al*., 2010), and the plants, in turn, feed the soil microbiota via root exudates, driven by photosynthesis. New soil organic matter results from the process via new microbial mass and microbial residues. An upshot for farmers is that plants contribute to both soil formation and soil health. Another is potential for rapid regeneration of soils and additions to soil organic matter, reflected for example in the concept of "soil carbon farming".

This scientific development complements an evolving understanding of the complex ecosystem known as the "soil food web" dating back more than 40 years and ongoing (Hunt *et al*., 1987; Moore and Hunt, 1988). A key role is afforded to fungi and predominantly aerobic bacteria in soils. These form the trophic base of a system of mutually-interdependent soil-based life forms, extending from protozoa, nematodes and micro-arthropods to macrobiota such as earthworms, in symbiosis with plants (e.g. Hendricks *et al*., 1998; Ingham and Slaughter, 2004; Wagg *et al*., 2019). Beneficial effects for plants grown in microbe-rich soils include enhanced nutrient availability, stress- pest- and disease-resistance (e.g. White *et al*., 2018, 2019), but it is important to realise that it is the entire web, including non-living elements such as water and minerals from rocks and stones that is involved in nutrient cycling and soil health. Consequences of improved understanding of the soil food web include proposed biomarkers for healthy soils, awareness of effects of tillage on soil biology, and an expanded view of the potential for natural processes of the farm ecosystem to substitute for synthetic inputs (Perkins, 2020). Scientifically, there is now an increased role afforded to plant root exudation and root zone interactions in driving soil food web processes generally (Bradford, 2016), an understanding that underpins RA practices to be outlined below.

Regenerative practices and benefits

Given our treatment of its meaning, specific practices involved in RA should be seen as operationalisations, rather than definitive. Indeed the diversity of practices considered regenerative (e.g. Wilson *et al*., 2022) is not surprising, as appropriate realisations may vary from place to place, and over time as knowledge progresses. Various interventions and practices are held to align with the microbial pathway to soil formation, to restore soil microbiota and / or boost the plants' photosynthetic ability to feed microbes, with potential to rebuild depleted agricultural soils and pastures. These are often grouped under "principles" of RA or soil health, including diversity of cropping, keeping soil covered, integrating livestock, keeping roots in the ground, and minimising disturbance, including agrichemical inputs and tillage (Brown, 2018). While results of specific practices will vary from context to context, and RA practised as a system needs to be sensitive to this, extensive research exists on individual practices (Khangura *et al*., 2023), which can only be briefly summarised here.

The first benefits to be considered are those of increasing plant diversity. This has been observed to increase both soil formation and plant productivity (Chen *et al*., 2019; Prommer *et al*., 2020), with some results apparently challenging conventional wisdom that soil organic matter reaches saturation at relatively low levels. The effects of increased plant diversity on soils are exploited in RA via multispecies swards, crop and cover crop diversity via polycultures and varietal mixes.

Secondly, appropriately managed livestock grazing can restore and build soils either in integrated crop-livestock systems (Prairie *et al*., 2023) or livestock farming (Savory and Parsons, 1980; Wilson *et al*., 2018; Gillmulina *et al*., 2020). This is hypothesised on grounds that the biome of the grazing animals and that of soils is intimately connected. Many studies report that as part of "holistic" agricultural management (that is, with the agricultural enterprise and production system proactively and adaptively managed as a whole; Savory and Butterfield, 1999), rotational grazing systems can be operated to restore soils such that pastures become a significant net carbon sink, notwithstanding enteric emissions of methane (Follett *et al*., 2001, Ch. 16; Teague *et al*., 2011; Machmuller *et al*., 2015; Wang *et al*., 2015; Rowntree *et al*., 2016; Teague *et al*., 2016; Stanley *et al*., 2018; Gosnell *et al*., 2020).

Such evidence has been controversial, perhaps because holistic and adaptive management systems do not lend themselves to evaluation methods designed for single-point interventions (Teague *et al*., 2008, 2013; Gosnell *et al*., 2020). Since agricultural context is multidimensional and highly variable from site to site, it is necessarily not "exactly the same" intervention that is repeatedly observed across sites, and adaptive management implies making changes to the system in the course of observation. Such variations are anathema to many experimentalists who would regard them as confounding. A high degree of adherence to these methods by adopting farmers (Stinner *et al*., 1997; Sherren *et al*., 2012; Mann and Sherren, 2018; Gosnell *et al*., 2020, Gosnell, 2022) seems by comparison uncontested. The research literature on holistic management, sometimes referred to as adaptive multi-paddock grazing, mostly covers rangelands in the USA and Africa, reflecting its origin and early uptake there in response to desertification. More research is needed to quantify carbon sequestration potential across contexts, which should be possible with adoption proceeding elsewhere. There are currently 50 Savory Institute "Hubs" teaching holistic management for example, in 30 countries spanning 6 continents. A Rothamstead trial reports positive interim results from intensive rotational grazing trials in the UK (Rivero *et al*., 2023), but does not report *net* sequestration potential or apply holistic management in full.

Thirdly, traditional tillage has been shown to damage soil structure and soil organic matter formation. Minimum-till and no-till techniques have been developed and taken up worldwide, for example as part of conservation agriculture, that have demonstrated positive effects on soil carbon formation and retention (Kassam, 2019), albeit dependent on context (Khangura *et al*., 2023). At the moment, no-till is frequently practised with herbicides such as glyphosate to terminate cover crops.

As noted above, the restoration of soils sequesters carbon, with potential contribution towards climate change mitigation. Since root systems can extend deep into healthy soil, well below the 30 cm depth regarded as labile, there may be potential for stable forms of carbon sequestration, stability increasing with depth. Mineral-associated organic matter is more stable than particulate organic matter, and has been found to respond positively to RA, particularly when livestock are integrated with zero tillage and intensive forms of regenerative cropping (Prairie *et al*., 2023).

Improvements to soil health can also be expected to boost biodiversity since soil microorganisms lie at the trophic base of the farmscape ecosystem. One indicator of this in RA is an increase in density of earthworms (e.g. Daverkosen *et al*., 2022), commonly classified by ecologists as a keystone species. Abundance and diversity of soil microorganisms can be expected to reduce risk from plant pathogens since other microorganisms compete with them for resources, among other mechanisms (CPM, 2021; Singh *et al*., 2025). They also imply changes to soil structure and moisture retention (Duerer *et al*., 2009), with broader social benefits such as reducing flood risk, and damage when floodwater is heavy with soil particles.

The business and policy environment

If abundant and diverse populations of soil microorganisms work in place of artificial inputs to produce healthy crops and animals, RA has potential to restore prosperity to farmers by reducing their input costs (Perkins, 2020), and related labour and capital costs. Potentially reduced inputs include fuel for tillage, artificial fertilisers, fungicides and insecticides, and mineral additives. However, there are significant transition costs to overcome in terms of learning and new equipment, most obviously for min-till and no-till cropping (Chatterjee and Acharya, 2021). It is, therefore, arguable that significant government support should be given to farmers to take up RA farming methods, to maximise adoption. Benefits discussed above extend to significant public good provision in the economic sense of nonexcludable and nonrival benefits, as a by-product of input substitution.

There has been support among sections of the UK policy community for paying farmers to produce public goods in addition to food production. This led to the evolving Environmental Land Management Scheme framework in the UK (DEFRA, 2024), operating through agreements with farms to adopt new practices. However, its Sustainable Farm Incentive (SFI) pilot scheme is now closed to new applicants with uncertainty over its future (Impey, 2025). SFI does not explicitly encompass RA, but covers some relevant practices, including agroforestry, cover crops and companion crops.

Policies could alternatively take the form of rewarding farmers for measurable positive ecological outcomes (Herzon *et al*., 2018). This contrasts with rewarding departures from hypothetical baselines or by carbon trading, which notoriously generate opportunities for fraud (e.g. Cavanagh and Benjaminsen, 2014; Badgley *et al*., 2022; Trencher *et al*., 2024). An example of public sector payment for measured soil carbon sequestration is provided by the Australian Government's Emission Reduction Fund, which since March 2019 has been paying for measured carbon sequestration on agricultural land (Calver, 2019). This currently has 602 agricultural carbon sequestration projects registered from 2237 projects (Australian Government, 2025), though roughly twice as many schemes are registered for vegetation management measures. However, some RA farmers express scepticism about payment for carbon sequestration (e.g. Snorek *et al*., 2024) on several grounds, including that this can be gamed, for example by timing and location of sampling. Another problem is that different soils have different capacity for adding soil organic matter depending on local geology (Vos *et al*., 2019). Having several feet of sandy loam affords more potential to increase soil organic matter than a thin layer of topsoil over chalk, for example. Payment by results could therefore be inherently inequitable, in contrast to support for adoption of particular practices.

In addition to encouraging adoption of RA, research and development arguably need funding in priority areas, including organic no-till arable farming (Godwin, 2014). This is challenging since tillage in organic systems has been the main form of weed control. Other mechanical methods such as roller crimpers can be used to terminate cover crops, with seeds drilled into residues, and a variety of crimping equipment is now available (e.g. Hill, 2022). However, in many contexts there may be significant regrowth of "volunteer" plants competing with food crops, requiring further weed suppression (Price *et al*., 2019; Alonso-Ayuso *et al*., 2020).

Certification of RA could bolster consumer confidence and invites comparison to the organic sector with which there is long experience (Elrick *et al*., 2022; Gordon *et al*., 2024). The outcome-oriented nature of RA seems at odds with practice-based certification (the basis of organic certification) because of the consequent diversity of practices (Bless *et al.*, 2023). It seems, therefore, that certification needs to be based at least partly on ecological outcomes, particularly in soils. Notable examples of such certification include that by the Savory Institute (2024), which covers systems involving at least some livestock, and by Regenified™ (Regenified, 2024). It remains to be seen whether consumers are willing to pay a premium for products of certified RA.

The relationship between RA and a farm's surrounding community also merits consideration. Perkins (2020) observes that consumers may need to be familiarised with a more diverse output of crops, and advocates farm open days during which produce can be sampled. As an alternative or complement to certification, this may also help build confidence in claimed ecological practices on a local basis. Participatory guarantee schemes are sometimes operated for organic agriculture and if adopted for RA might also fulfil some of the functions of certification locally (Elrick *et al*., 2022).

Relatedly, both researchers and farmers have already raised concerns about corporate cooptation of the label "regenerative" and greenwashing (Gordon *et al*., 2024; Wilson *et al*., 2024). For example, corporate accounts of RA seem often to omit the goal of low-to-no synthetic inputs, particularly if they produce such inputs themselves (Bless, 2024), which seems a dilution of the approach. The emphasis on integration of livestock under RA may also risk misuse to justify conventional practices with high environmental impact. Certification could counteract free use of the term for greenwashing but brings its own challenges in terms of either measurement or inclusion / exclusion of specific practices, flexibility and costs to the farmer. Finally, several studies have noted positive effects of RA adoption on farmers themselves, which could act counter to commercial cooptation and greenwashing. These include a shift in self-perception to being "good" farmers (Miller-Klugesherz and Sanderson, 2023), an enhanced sense of self-efficacy (Brown *et al*., 2022), a shift in understanding and ethos towards holism and non-instrumental environmental values respectively, and an associated positive kinship amongst RA practitioners (Gosnell, 2022; Seymour and Connelly, 2023).

Concluding thoughts

This review has covered the rationale and definition of regenerative agriculture, highlighting its coherence with significant developments in soil science and its "beyond sustainability" aspiration. Evidence is mounting for diverse potential environmental benefits of RA practices. Whether benefits can be secured at scale depends on the business and policy environment, however.

As RA is a relatively new movement, many key research questions seem ripe for addressing, several of which are noted above. Analyses of the farm economics of RA also seem scarce and would be timely. Economically, RA has not been premised on increases in yield, rather reductions in increasingly costly inputs. It would be surprising if conventionally-measured yields were higher than under traditional agrichemical management, though Jordon *et al*. (2022) claim that key elements of RA can be adopted without yield loss. However, it is sometimes claimed (e.g. Brown, 2024) that land under RA can be in production longer, for example because of integration of cropping with livestock farming, which normal yield metrics do not take into account. This proposition invites assessment across different farming contexts.

Potential benefits to human health from RA could be substantial given the issues noted in the Introduction, but have yet to be conclusively demonstrated given the long and complex causal chains involved (Montgomery and Biklé, 2022). Research is still needed, that is, to test the organicists' "One Health" proposition (Balfour, 1943). Since this concerns soil health rather than organic agriculture *per se*, it could be addressed by tracking effects of RA from farm-soil to fork, to health outcomes. RA is a systemic approach, however, and experimental studies of RA practised as a system, rather than of component practices seem lacking (Khangura *et al*., 2023). RA farmers have complained about widespread epistemic resistance to compound experimental interventions in academia (Wilson *et al*., 2024), mirroring the issue that has arisen with research on holistic management. If rejecting research that does not provide epistemic certainty is a matter of chosen priorities, this contradicts the idea of "value-free science" that many researchers may associate it with. "Value-laden science" has been inferred from the fact that conventional hypothesis testing comes at the expense of the precautionary principle in environmental studies (Welin and Buhl-Mortensen, 1998; Steel, 2015, Ch.7). This point may extend to an insistence on within-study demonstrative power regarding specific mechanisms, at the expense of practical relevance and openness to new ideas. Research funding regimes seem problematic though, if long-term, whole agricultural systems research is needed (Silva and Tchamitchian, 2018), notwithstanding official injunctions to researchers to achieve practical "impact".

CONFLICT OF INTEREST

The author has no conflicts of interest to declare.

ETHICS STATEMENT

The author confirm that the research meets any required ethical guidelines, including adherence to the legal requirements of the study country.

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AUTHOR CONTRIBUTIONS

Not applicable as this is a single authored paper.

DATA AVAILABILITY

Interview material referred to as work in progress will be made available on reasonable request, upon completion.

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