Regenerative Agriculture the Veganic Way: A Seven-year Research Study in Increasing Soil Organic Matter (SOM) and Crop Yields

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Abstract

Agriculture is a major contributor to greenhouse gas (GHG) emissions and biodiversity loss, mostly through deforestation for the cultivation of animal feeds; enteric fermentation from ruminants like cattle, fertilizers and manure; and soil degradation from intensive farming practices. There is currently a push to transform our farming systems to attempt to alleviate the almost-assured catastrophic burden of increasing amounts of atmospheric carbon. Many forms of agriculture claim they have evolved to follow a more regenerative form of agriculture by increasing soil organic matter (SOM), thus capturing said carbon in their soils. This study reports SOM results from one veganic agriculture (VA) farm from a study period of seven years. There was an observed increase of SOM from 5.2% to 7.2%, equating to an increase of 38.46% over the study's duration, suggesting that VA is an effective farming mechanism for increasing soil organic matter utilizing 100% plant-based regenerative practices and materials to nourish the soil. The VA farm also realized respectable yields per hectare, reporting a 46% increase in total crop production. This was all achieved by growing a diversity of plant-based crops, implementing four-year crop rotations, building soil fertility through plant-based inputs, cover cropping, and leaving the farm's fields covered as often as possible. Additionally, by its processes, the VA farm fully eliminated the industrial chain of animal agriculture and associated land use and methane emissions, suggesting VA to be a holistically regenerative form of agriculture, in comparison to animal-based forms of any other system.

Key words

Veganic, Vegan Organic, Regenerative Agriculture, Organic Agriculture

Introduction

A clear pattern in the scientific evidence documents that the earth is warming, that warming is largely anthropogenic, that warming is causing important changes in climate, and that rapid and potentially catastrophic changes in the near future are very possible (Thompson 2010; Lynas, Houlton & Perry 2021). Agriculture is a major contributor to greenhouse gas (GHG) emissions, mostly through deforestation, enteric fermentation from ruminants like cattle, fertilizers, manure, and soil degradation. These sources altogether account for at least one-third of total anthropogenic GHG emissions (Valin et al. 2013; Crippa et al. 2021).

Interest in regenerative agriculture has surged in light of agriculture's role in global warming and other environmental impacts (Giller et al. 2021). There are many goals and practices attached to regenerative agriculture, including carbon sequestration, improved soil health, and biodiversity enhancement; and cover cropping, livestock integration, and tillage reduction (Newton et al. 2020). For instance, Rhodes (2017) writes that at its core, regenerative agriculture focuses on improving soil health, incorporating practices such as growing green manures, minimizing tillage, and crop rotation that aim to preserve or build soil organic matter (SOM). Healthy soils then enhance water quality, vegetation, and productivity.

The urgency of shifting our farming systems to attempt to alleviate the almost-assured catastrophic burdens of global warming (Ripple et al. 2022) is clear. This article presents results from a seven-year research study that was designed to examine the performance of regenerative veganic – or entirely plant-based organic – techniques in terms of SOM levels and crop yields.

An overview of veganic performance relative to SOM levels and productivity is followed by a description of the study farm and methodological approaches. The discussion first contextualizes the study results in other veganic field experiments to demonstrate the value of veganic approaches to carbon assimilation as well as the viability of veganic agriculture. It then delves into the meaning of "regenerative," with consideration of all components within farming systems (e.g., inputs, land-use, animal production), and asserts that veganic agriculture is a truly regenerative method as it is the only form of agriculture that eliminates the use of animals and their inputs in the growing system.

Veganic agriculture (VA)

Veganic agriculture is described at the most basic level as organic agriculture that eschews animal products. The Veganic Agriculture Network (VAN), a core promoter in North America, defines veganic agriculture as, "an approach to growing plant foods that encompasses a respect for animals, the environment, and human health…this is a form of agriculture that goes further than organic standards, by eliminating the use of products that are derived from confined animals and by encouraging the presence of wild native animals on the farmland" (VAN n.d.). Another description is offered by the North American Veganic Certification Standard (NAVCS), which articulates that veganic gardening and farming is "the cultivation and production of food and fiber crops with a minimal amount of exploitation to all animal and plant species. Veganic growing methods use no animal products or by-products, such as blood meal, bone meal, manure, urea, fish meal, fish emulsion or any other animal originated matter, because the production of these products either harms animals specifically or is connected with the exploitation and subsequent suffering of those beings. Furthermore, while 'organic' cultivation allows for the use of organo-pesticides and organo-fungicides veganic agriculture would not, as spraying highly disrupts the native floral and faunal balance of the farming and gardening systems" (NAVCS 2022).

Several field trials have demonstrated that agricultural approaches consistent with veganic principles demonstrate some ability to maintain or increase soil carbon (C) or soil organic matter (SOM), as well as produce adequate yields. Design of a stockless organic system in the United Kingdom (UK) consisted of a rotation of potatoes, winter wheat, spring beans, and spring wheat, incorporating undersown red clover, red clover mulch, and turnip cover crop. The soil was a silty clay loam and had been cropped in an arable rotation for at least several decades before the study began. SOM was 2-2.5% before conversion. By six years into the trial, four years after the conversion period ended, SOM reached and remained at around 2.5% in all plots. A large increase in SOM was not anticipated due to the only substantial increase in OM input to the soil being from red clover and chopped wheat straw (Cormack 1999). At the end of the 10-year study period, winter wheat, spring wheat, and spring bean yields were all above average for organic production in the UK (averaging 7.3, 4.1, and 3.6 t ha^{-1} respectively). Potato yield was the most variable, due to rainfall, pests, and disease, though still similar to the UK organic average (Cormack 2006).

Another stockless organic experiment in the UK took place on clay loam soil and involved three rotations of red clover with winter wheat, spring oats, potatoes, winter oats, winter beans, and/or spring beans, sometimes incorporating a turnip cover crop. This eleven-year experiment demonstrated a drop in SOM levels from 3.2% to around 2.5%. However, this decrease is likely due to the experiment following a long-term grass ley; the increased intensity of cultivation mineralized the organic matter (Welsh et al. 2002). Philipps et al. (1999) observed that yields from the experiment were comparable with, though typically below, organic averages.

The Rodale Institute Farming Systems Trial (FST) in the United States (US) is the longest-running side-by-side comparison of organic and conventional grain cropping systems in North America. It features two organic systems – one deriving its fertility solely from leguminous cover crops, and one incorporating cattle manure and leguminous cover crops for fertility – as well as a conventional/chemical-based system. Both organic systems consistently outperformed the conventional system in soil health metrics (Rodale Institute n.d.). At the beginning of the FST, which is run on a silt loam soil, there was no significant difference in soil C levels between the three systems (Pimentel et al. 2005). Focusing in on the two organic systems, 15 years into the experiment, soil C levels in both the manure- and legume-based systems were significantly higher than they were at the beginning of the trial, with a greater increase reported for the manure-based system (Drinkwater et al. 1998). Around 20 years in, soil C levels in the organic legume and organic manure systems were almost equivalent (2.4% and 2.5%, respectively) (Pimentel et al. 2005; Hepperly et al. 2006). Hepperly et al. (2006) suggest that because the organic manure and organic legume systems showed similar soil C improvements, rotation and cover cropping outweigh the importance of manure additions for achieving gains in soil C. At the 35-year mark, SOM levels for the organic legume and organic manure systems were similar (4.2% and 4.4%, respectively, from starting levels of 3.5% and 3.3%, respectively), after some fluctuations in the legume system in the latter years of the trial (Rodale Institute n.d.).

Both organic systems were found to be competitive with conventional yields after an initial 5-year transition period (Rodale Institute n.d.). During this period, corn grain yields averaged 4,743 kilograms per hectare for the legume-based system and 4,222 kilograms per hectare for the organic animal system. Around 20 years in, corn and soybean yields were similar for all systems, with the conventional system performing more strongly than the manure-based system, which outperformed the organic legume system (Pimentel et al. 2005). At 35 years into the trial, the organic legume systems (till and no-till) produced an annual corn yield of about 160 bushels per acre, and the organic manure systems produced 175-200 bushels per acre, substantially outperforming conventional systems (Rodale Institute n.d.).

A three-year Polish trial, on sandy loam soil with sweet pepper, compared red clover mulch, a red clover based organic fertilizer, a mineral fertilizer, and a non-fertilized control. All red clover fertilizer doses and the red clover mulch significantly increased soil C and SOM compared to the other two treatments. Red clover fertilizer and mulch achieved soil C levels of 1.52-1.72% and SOM levels of 2.77-3.13%. Sweet pepper yields were maximized via red clover mulch and the highest dosage of the red clover based fertilizer (approximately 41 t ha^{-1} and 38 t ha^{-1}, respectively); both treatments outperformed the mineral fertilizer (approximately 33 t ha^{-1}) (Kaniszewski et al. 2021). Based on data from working Japanese vegetable farms as well as vegetable system field trials, (Matsuura et al. 2018) modeled the ability of chemical- and animal-manure based, non-chemical animal manure-based, and green manure-based systems to sequester soil carbon over the next 20 years. Their results suggested that a no-till green manure system incorporating grass mulch possessed the highest carbon sink ability of the six systems assessed. The green manure systems did not perform strongly in terms of yield relative to the systems that incorporated chemical and/or animal inputs. The highest yield of the green manure systems was one-sixth of that of the chemical- and animal-manure based system, and roughly 20% of that of the organic animal manure-based system.

Research into biocyclic-vegan systems has demonstrated higher yields for produce grown in biocyclic humus soil spread atop the field soil, a treatment solely including materials of plant origin, than in clay loam soil plots treated with inorganic fertilizer. Average total sweet potato yields were 35.6 t/ha and 9.9 t/ha for treatments with humus soil and inorganic fertilizer respectively (Eisenbach et al. 2018). Yields for processing tomatoes were 116.8 t ha^{-1} in comparison to 80.6 t ha^{-1} for the inorganic fertilizer treatment, for a difference of 45% (Eisenbach et al. 2019). Both treatments outperformed the controls (untreated) in each experiment. The authors suggested that the compactness of the clay loam soil may have been an important factor in the sizable yield differences. A more extensive experiment on processing tomatoes tested five treatments of tomato pomace with biocyclic humus soil, tomato pomace with plant residues, tomato pomace with farmyard manure, nitrogen fertilizer, and an untreated control. Inorganic nitrogen fertilizer produced the highest yield (163.4 t ha^{-1}), followed by tomato pomace with biocyclic humus soil (150.7 t ha^{-1}) and tomato pomace with manure (approximately 143 t ha^{-1}) (Roussis et al. 2019).

Materials and Methods

The Veganic Farm Model

La Ferme de l'Aube is in Boileau, Québec, Canada (45.944837N, -74.805983 W). The hardiness zone of the farm site is a 4a, which correlates to the lowest temperatures of the winter (-25 to -30F; -31 to -34.5C). Average freeze dates are last freeze in the spring averaging May 21–30; first freeze in the fall September 11–20. The average frost-free growing season is 105–122 days. The farm site is situated on a space of less than one-half acre (.19 hectare), where the top 12 inches of topsoil had been previously scraped off prior to October 2014, leaving most of the area devoid of diverse plant life.

La Ferme de l'Aube was originally purchased in October 2014 by the current owners, James Videle and Mélanie Bernier with the intention of cultivating a small-scale (less than ½ acre) biointensive market farm using solely plant-based inputs. After the initial infrastructure was built in 2015 (i.e., greenhouses, caterpillar tunnels, packing house), garden construction began in 2016-2017 on land that had never been cultivated. Off farm inputs of chipped branch wood and veganic (live mulch) composts were incorporated. Practices of crop rotation, cover cropping, in-bed composting and on-site compost making were adhered to. The idea was to discontinue all brought-in garden inputs by 2021, all the while, hoping to increase soil fertility and health with decent crop production. The farm was certified organic with Ecocert in 2016 and certified vegan-organic with Stockfree Organic Services in the same year.

Methodology of Planting

The field research on SOM levels and crop productivity was planned to span 2016-2022, forming a seven-year study on the one-half acre of growing space. The initial preparation of the fields was as follows for 2016–2017: Black plastic sheeting (re-usable) was laid to begin the composting of any sparse native flora in the beds. After four weeks the plastic was removed, and a five-horsepower craftsman front-tine rototiller was passed to incorporate the decayed humus and break open the new soil. Beds were staked out at 2.5' x 50' (125 square feet per bed). A cover crop of buckwheat was immediately planted. When the cover crop reached appropriate height, it was cut with walking garden shears and an initial application of four wheelbarrows (24 cubic feet) of plant-based compost (a mixture of composted green grass and chipped branch wood) was spread per bed. The cover crop would grow back in the same year and would freeze covering the beds for the winter. Rotations of cover crops were planted after the buckwheat, utilizing annual clover and oats, depending on the harvestable crop to be planted after.

All plant detritus and plant materials (like cover crops) were left on the farm beds at the end of each season and covered with the annual snowpack. Where the ground was open from a harvested cultivar a cover crop was planted, either buckwheat, clover or oats, to attempt to keep all garden areas covered with plant materials as long as possible. A crop rotation was practiced so that no crop family would return to the same bed for at least four years. Other than compost (which decreased from four wheelbarrows per bed in 2016 to a maximum of one in 2022) the only other soil fertilization was with an annual application of on-farm produced wood ash at two cups per 50' bed to raise the pH level as each cultivar desired.

The plant-based compost (sometimes referred to as live mulch) was originally purchased from Savaria, Laval, QC in 2016 (roughly 120 km from the farm) and was then purchased from Biohorticentre, Gatineau, QC in 2018 at the same distance away. In 2018 the compost was mixed by 50% with a farm-made mix of chipped branch wood and indigenous hay (mix of legumes and grasses) that was co-created in Brébeuf, QC, 30 km away from the farm site, to procure materials closer. Some varieties, including *Cucurbitaceae*, fall planted garlic and strawberries enjoyed a dry straw or hay mulch that was procured in Brébeuf or Mont-Tremblant 30-35 km away. In 2021 no more compost of any kind was brought in; it was solely produced on the farm.

At the beginning of the trial, seeds were bought-in, and were almost entirely certified organic. Shortly after, in fall 2016, on-farm seed saving was implemented, when possible, for open-pollinated and heirloom varieties. Seeds were started in the on-farm greenhouse with a 100% plant-based potting soil developed by the farmers and were then transplanted into the fields. When seed starting inside was unnecessary, the seeds were seeded into the garden beds directly.

In 2016, edible fruits, vegetables, herbs and flowers were produced solely for farmer consumption; 2017 was the first year the same were produced for limited sales as well as farmer consumption on an area of about .32 of an acre (.13 hectare). The 2018 production year through 2021 saw the area increased to .46 of an acre (.19 hectare), its maximum capacity. In 2022 due to a catastrophic rain and wind event in late May, one section was closed to production, so the production area declined to .42 of an acre (.17 hectare).

Soil Testing

An initial soil test was taken on June 24, 2016, with samples taken from twenty-five locations across the cultivated area that were deemed to be the most infertile by the growers based on the abundance or lack thereof of wild flora. The tests were analyzed by A & L Canada Laboratories Inc. A second soil test was taken from approximately the same locations and analyzed by the same laboratory on June 9, 2022. The numbers revealed values for SOM, CEC (cation exchange to best illustrate ability for soil to hold nutrients), pH, and SOC (58% of SOM, based on averages from documented sources) (NDSU 2019).

Results

Soil Testing

The 2016 test revealed SOM of 5.2%. Cation exchange (CEC) was 12.7meq/100g. The power of Hydrogen (pH) was 5.1 (very acidic). SOC was 3.01%. The 2022 test revealed SOM of 7.2%, CEC of 16.0meq/100g, pH of 6.9 (neutral), and SOC of 4.18%. Thus, SOM increased 38.46% from 2016 to 2022. All values are shown in Table 1.

Table 1

SOM, CEC, PH and SOC from soil tests taken in 2016 and 2022

Year	SOM %	CEC	pH	SOC%
2016	5.2%	12.7meq/100g	5.1	3.01%

2022	7.2%	16.0meq/100g	6.9	4.18%

Yields

As a commercial production farm and to be in accordance with organic and veganic certification requirements it was necessary for the farmers to keep yield records. Harvesting, which occurred daily, was done by hand and brought to the packing facility where it was weighed and then itemized in a harvest log. All data was then compiled into an end of the year excel spreadsheet, organized by crop.

La Ferme de l'Aube expanded diversity to grow over 100 different vegetables, fruits, herbs and flowers in 2022 which included over 400 different varieties. The production area was .13 hectares in 2017, and .19 hectares for the years 2018-2021. In 2022 the total growing area was .42 of an acre (.17 hectare).

Because of the garden building year of 2016 production numbers are not included as many crops failed or produced poorly due to the very acid starting pH of 5.1. 2017 saw continued garden bed creation but was the first-year sales occurred and saw production of 1,227 kg. In 2018, the first full production year, total crop yield was 2,360 kg; production reached its maximum in 2021 with 2,781 kg. Due to the previously described catastrophic rain and wind event production fell in 2022 due to a loss of production growing area, yet that year still realized the second largest production when expressed in terms of production per hectare (see table 2). The total production gain from 2017 to 2022 was 46%.

Table 2

Total recorded production from 2017-2022 in kg, hectares farmed and an expression in kg/hectare

Year	Production	Hectares	Kg/Hectare
2017	1,227 kg	.13	9,440 kg/ha
2018	2,360 kg	.19	12,677.8 kg/ha
2019	2,379 kg	.19	12,779.9 kg/ha
2020	2,509 kg	.19	13,478.2 kg/ha
2021	2,781 kg	.19	14,939.4 kg/ha
2022	2,327 kg	.17	13,688.2 kg/ha

Yields for specific crops

On any farm there are certain crops that are more economically important than others. For the research farm there are ten highlighted in Table 3. Green beans, cabbage, carrots, lettuce, onions, potatoes, summer squash, tomatoes, winter squash are illustrated. Dry beans are included because they provide the main plant-based protein food source grown for the farmers' family. The six-year yield results are represented as well as the square footage (sq. ft) of planting space. There are fluctuations as the farmers grew or diminished space due to demand. A mean value for 2017-2022 was ascertained, as well as an expression of the mean value per hectare.

Table 3

Yields and planting area (sq. ft.) of 10 different crops, with means and an expression in kg/hectare from 2017-2022

Crop	2017	2018	2019	2020	2021	2022	Mean kg & sq. ft	Mean kg/ha
Beans, green	33.2 kg 275 sq. ft	51.5 kg 375 sq. ft	41.5 kg 438 sq. ft	61 kg 438 sq. ft	42.2kg 500 sq. ft	42kg 500 sq. ft	45.2 kg 421 sq. ft	11,557 kg/ha
Beans, dry	7.2 kg 375 sq.ft	17.5 kg 750 sq. ft	22 kg 825 sq. ft	4 kg 825 sq. ft	11 kg 690 sq. ft	13 kg 565 sq. ft	14.4 kg 792 sq. ft	1,957 kg/ha

Cabbage	34.1 kg 125 sq. ft	62 kg 225 sq. ft	81.4 kg 500 sq. ft	145 kg 500 sq. ft	131.4 kg 500 sq. ft	85 kg 415 sq. ft	103.5 kg 378 sq. ft	29,479 kg/ha
Carrots	122 kg 250 sq. ft	180.5 kg 375 sq. ft	358.9 kg 875 sq. ft	251 kg 750 sq. ft	226.4 kg 750 sq. ft	174.5 kg 625 sq. ft	218.9 kg 604 sq. ft	39,012 kg/ha
Lettuce (heads)	26.5 kg 163 sq. ft	76.5 kg 450 sq. ft	67.3 kg 500 sq. ft	24.8 kg 500 sq. ft	111.5 kg 565 sq. ft	101 kg 445 sq. ft	67.9 kg 437 sq. ft	16,724 kg/ha
Onions	71.4 kg 288 sq. ft	112 kg 375 sq. ft	159 kg 525 sq. ft	172 kg 560 sq. ft	213.5 kg 650 sq. ft	145.5 kg 565 sq. ft	145.5 kg 494 sq. ft	31,706 kg/ha
Potatoes	170 kg 750 sq. ft	355 kg 1250 sq. ft	285 kg 1500 sq. ft	410 kg 1500 sq. ft	343 kg 1500 sq. ft	225 kg 1375 sq. ft	298 kg 1313 sq. ft	24,430 kg/ha
Summer Squash/ Zucchini	27 kg 100 sq. ft	140.5 kg 313 sq. ft	82.8 kg 375 sq. ft	85 kg 313 sq. ft	74.5 kg 438 sq. ft	206.5 kg 375 sq. ft	102.7 kg 319 sq. ft	34,654 kg/ha
Tomatoes (Slicing and Paste)	181 kg 375 sq. ft	264 kg 375 sq. ft	256 kg 375 sq. ft	317 kg 375 sq. ft	363 kg 375 sq. ft	192 kg 375 sq. ft	262.2 kg 375 sq. ft	75,261 kg/ha
Winter Squash	32.5 kg 250 sq. ft	88 kg 315 sq. ft	57 kg 438 sq. ft	150 kg 688 sq. ft	88.4 kg 750 sq. ft	247 kg 575 sq. ft	110.5 kg 503 sq. ft	23,646 kg/ha

Discussion

Consistency of field trial results with previous studies

There is notable diversity in locations, land-use histories, soil types, fertility management plans, crops, and trial lengths in the small body of literature on veganic forms of agriculture and SOM. Across these differences, this study and most of those reviewed above point to the potential of veganic methods to maintain or increase SOM. La Ferme de l'Aube demonstrated the greatest increase in SOM amongst studies that reported initial and final SOM levels (Cormack 1999; Rodale Institute n.d.). The trial also demonstrated an increase in overall crop yield over the study period. This too is consistent with other studies that reported on yield over time in veganic systems, finding that veganic methods tended to maintain or increase production (Cormack 1999; Philipps 1999). These findings suggest veganic agriculture to be both regenerative and viable.

Regenerative agriculture the veganic way

Using regionally sourced plant-based materials for soil fertility, using methods of cover cropping and in-bed composting can generate sustained increases in soil organic matter levels. Using diverse cropping systems of only plants can realize high yields per hectare. Because of greater production capabilities, there is even a possibility to convert mono-cropped agriculture lands (corn and soybean), which are utilized to mostly feed animals. back to their natural state. While the transition would be complex, veganic agriculture could eliminate all animal exploitation in agriculture, raise SOM on agricultural lands necessary for human consumption, increase production per hectare over any animal-based system, and free up land to address the wild animal extinction crisis.

Even the best agricultural soils are still likely to store less carbon than wild native ecosystems (Lal 2010). And ultimately, agricultural soils would be more susceptible to reversing the carbon stored than wild untouched ecosystems. VA can offer both a model of high ecological stewardship and yield, while also working in tandem or assisting with rewilding and nature-based solutions. If ranching-focused agriculture increases in popularity, it may improve some overly grazed or intensively cropped areas but would mean a mass program of deforestation and wild ecosystem conversion to even come close to meeting current typical grazing and feedlot beef yields, all while likely increasing methane (Eisen & Brown 2022). Studies have shown that shifts to plant-based food systems, and rewilding; freeing up grazing and feed crop land, can draw down the equivalent of 9-16 years of fossil fuel emissions (Hayek et al. 2020).

Raising animals also requires the subsequent slaughtering of those animals. They are 'harvested' and require transport to a slaughtering facility, where immense fossil fuel resources are required. The 2016 National Beef Quality Audit (NBQA) showed that time transported ranged from 0.25

to 12 hours with distances ranging from 12.9 to 1400.1 kilometers. The animal's welfare was deemed to be jeopardized as they may be exposed to multiple stressors including noise, unfamiliar animals and humans, temperature extremes, temporary food/water deprivation and new pen conditions (Edwards-Callaway & Calvo-Lorenzo 2020).

All factors must be considered in the assessment of any system that is to be deemed regenerative. Two other forms of agriculture make claims to be regenerative in some capacity, regenerative agriculture (RA) and organic agriculture (OA). Here we will define each from the literature and show their published SOM percentages and yields where possible. Furthermore, in the RA section we will attempt to describe RA's reporting of carbon sequestration as it appears to be a major claim to the efficacy of this agricultural practice.

Regenerative agriculture (RA)

The concept of regenerative agriculture has been around for a while, but there has been a recent resurgence of interest in the topic in recent years. This is likely due to a combination of factors, including a popular TED talk by Allan Savory, significant investments from large food companies, and even attempts to offset carbon by oil and gas conglomerates (Savory 2013; Yu 2020; Carter et al. 2014; Wang et al. 2021).

Regenerative agriculture encompasses several farming practices like keeping crop residues, planting cover crops, limiting synthetic fertilizers and pesticides use, and reducing tillage. These methods are core to the well-established idea of quality conservation agriculture. Certain techniques like holistic grazing and incorporating ranching through mob grazing methods are less widely accepted and considered more specialized yet receiving significant attention. (Giller et al. 2021; Kassam et al. 2009). A review of 229 journal articles and 25 practitioner websites that characterized the term "regenerative agriculture" found that there were many definitions and descriptions of regenerative agriculture in usage. Some were based on processes like the use of cover crops, the integration of livestock, and no-tilling, while others were based on outcomes like improved soil health, sequestered carbon, or increased biodiversity (Newton et al. 2020). Many perceive RA differently, and a clear scientific definition is lacking (Schreefel et al. 2020; Giller et al. 2021). The goal of regenerative farming systems is to increase soil quality and biodiversity in farmland while still being able to operate the business profitably. Regenerative farming systems share common principles, including stopping tillage or reviving soil communities after tillage, covering soil to prevent bareness through cover crops, promoting plant diversity on the farm, and especially with increased funding, integrating livestock on the land (LaCanne & Lundgren 2018).

Project Drawdown claims that "regenerative agriculture enhances and sustains the health of the soil by restoring its carbon content, which in turn improves productivity—just the opposite of conventional agriculture," and estimates that regenerative annual cropping could reduce or sequester 14.5–22 gigatons of CO2 by 2050 (Eichler et al. 2021). The IPCC estimates that the world's agricultural soils can sequester 0.13-2.56 gigatons of carbon per year (Shukla et al. 2019). Far bolder claims from others like the Rodale Institute include that "regenerative agriculture… has the potential to reverse climate change" (Kastner 2016) and that "we could sequester more than 100% of current annual CO2 emissions with a switch to widely available and inexpensive organic management practices, which we term 'regenerative organic agriculture" (Rodale Institute 2014). The originator of these outlier claims, Robert Rodale (1983), defined regenerative agriculture as "one that, at increasing levels of productivity, 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" (Giller et al. 2021).

A recent study, adding to increasing consensus on the topic, showed that not tilling the land and using cover crops resulted in 86% less soil loss and erosion than conventional systems (Jacobs et al. 2022). There is little doubt that these practices are beneficial for reducing soil erosion and maintaining soil organic matter (SOM).

A widely cited study on regenerative agriculture by (Rowntree et al. 2020) highlights White Oak Pastures, a USDA certified organic farm in Clay County, Georgia, covering an area of 1,214 hectares. Annually WOP harvests 143,372 animal beings and produces on average 525 kg of flesh and eggs per hectare (Rowntree et al., 2020). According to the soil samples taken from the farm, SOM increased from 1.1% in year one to 5.2% in year 20. Questions remain whether this carbon storage has permanence, and if it resulted in significant carbon loss from elsewhere via nutrient transfers. Their linear regression, averaged instead of scatter plotted, also implicitly ignores carbon saturation that is widely recognized in the scientific literature (Godde et al. 2020). And most importantly, this style of regenerative agriculture uses 2.5 times more land than even conventional grazing, requiring several planets worth of land if we were to even partially attempt to scale this up.

This inability to scale was reflected as well in this meta-analysis on the topic of integrating livestock and grazing as a form of ecological practice concluded that "it would be physically impossible for the animal protein production produced today – about 27 g/person/day – to be supplied by grazing systems, at least without an unthinkably damaging program of forest clearance, which would vastly increase the livestock sector's already large contribution to global GHG emissions" (Garnett et al. 2017). In addition, they show: "Only under very specific conditions can [grazing] help sequester carbon. This sequestering of carbon is even then small, time-limited, reversible and substantially outweighed by the GHG emissions these grazing animals generate" (Garnett et al. 2017).

Integrating livestock as a part of regenerative agriculture, without a prerequisite of a major reduction in animal-sourced foods consumed, would increase agriculture land, beyond what's even available on Earth (Hayek & Garrett 2018; Loken et al. 2020). According to Lal (2010), all undisturbed natural ecosystems contain more soil organic carbon than their agricultural counterparts that, on average, sequester 25–75% less. Such natural ecosystems include forests, wetlands, and grasslands. All pasture or cropland was originally a type of natural ecosystem that has been converted to human use. Other studies show that "it is important to maintain SOC as high as practically possible in arable soils, but we conclude that in the vast majority of situations it is unrealistic to expect to maintain pre-clearance values" (Powlson et al. 2022). A meta-analysis of 109 independent studies on the response of animals or plants to livestock grazing versus exclusive and passive rewilding concluded that "across all animals, livestock exclusion increased abundance and diversity" (Filazzola et al. 2020).

Organic agriculture (OA)

As per the USDA study team on organic farming, "organic farming is a system which avoids or largely excludes the use of synthetic inputs (such as fertilizers, pesticides, hormones, feed additives etc.) and to the maximum extent feasible rely upon crop rotations, crop residues, animal manures, off-farm organic waste, mineral grade rock additives and biological system of nutrient mobilization and plant protection" (Meena et al. 2013). In another definition the FAO suggested that “Organic agriculture is a unique production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles and soil biological activity, and this is accomplished by using on-farm agronomic, biological and mechanical methods in exclusion of all synthetic off-farm inputs” (Meena et al. 2013).

OA relies heavily on industrial animal manures, if the animals are not exclusively exploited in the same farm system, which is allowed as part of the United States’ National Organic Program regimes (NOP 2000; COPS 2021). Heavy use of dried chicken manure from battery cage-kept, industrial systems of laying hens and slaughterhouse rendered products of blood, bone and feather meals are common as soil additives. Even the best grazing systems also displace countless wild animals and prevent rewilding and reforestation.

Organic agriculture is found to improve soil fertility by enhancing soil organic matter (SOM) content. A total of 68 data sets were analyzed from 32 peer-reviewed publications aiming to compare conventional with organic farming. The analysis revealed that after conversion, soil organic carbon (SOC) in organic systems increased annually by 2.2% on average, whereas in conventional systems SOC did not change significantly. However, in the few studies where crop rotation and fertilization were comparable in both systems no consistent difference in SOC was found. From this data analysis, the authors conclude that the claim for beneficial effects of organic farming on SOC is premature and that reported advantages of organic farming for SOC are largely determined by higher and often disproportionate application of organic fertilizer, mainly manures, compared to conventional farming (Leifeld & Fuhrer 2010).

The DOK field trial at Therwil (near Basel), Switzerland can be considered the world’s most significant long-term field trial comparing organic and conventional cropping systems. Initiated in 1978, the field experiment includes biodynamic, bio-organic farming systems that are based on organic principles and a conventional, manure-based system that additionally receives mineral fertilization and conventional plant protection (cover crops). Also being compared is a conventional system with mineral fertilization only, as well as one system remaining completely unfertilized. The current crop rotation, which has been used in all systems, is potato, winter wheat, soybeans, maize, winter wheat, followed by two years of grass clover, rounding out the seven-year rotation. The methods of cultivation were identical for all systems.

The highest levels of SOC were found in the biodynamic and bio-organic fields (Esperschutz et al. 2007). However, after 21 years it was determined that only the biodynamic field showed stability (neither rise nor loss in SOM). The conventional, manure-based system showed a 7% loss, and the bio-organic system showed a 9% loss. The conventional system with mineral fertilization yielded a 14% loss and the unfertilized system showed a 22% loss (Fliessbach et al. 2007). In relation to the crops grown (potatoes, wheat, soybeans and maize) over a 35-year period it was found that the organic plots yielded at a rate of 80% of the conventional plots. (IFOAM, Lang 2019).

In a meta-analysis of 362 published comparative organic-conventional crop yields, it was found that organic yields were 80% of conventional yields, which seems to compare quite identically to the DOK-field trial results and seems to be a consistent measure of organic vs. conventional crop yield performance. The meta-analysis resulted in the inclusion of 362 paired sets of organic-conventional yield data in the database. The data covers 43 countries worldwide, with the majority of data (85%) coming from Europe and North America. A total of 67 crops are represented. Cereals comprise 43% of all data, followed by vegetables, pulses, fodder crops, fruits, root and tuber crops, oilseed crops, and other food crops. 18% of all data were from long-term collection data (greater than five years) (Ponti et al. 2012).

The Rodale Institute Farming Systems Trial (FST) compares three forms of agriculture. Conventional agriculture is defined as, "...a system that represents a typical grain farm, relying on synthetic nitrogen fertilizer and weeds controlled by synthetic herbicides." Organic legume defined as, "...a system that represents a cash grain model, a rotation of annual grain and cover crops, where the sole source of fertility is leguminous cover crops." And an organic manure system, defined as, "...representing a diversified organic dairy or beef operation, that includes a rotation of annual feed grain crops and perennial forage crops. Fertility is provided by leguminous cover crops and periodic applications of composted livestock manure" (Rodale Institute n.d.).

The corn yield was averaged from a period of 13 years (2008-2020) and found that a full-tillage approach yielded the greatest production for all systems. The organic manure system averaged 8,000 kg/ha, the conventional system 7,500 kg/ha and the organic legume system averaged 6,000 kg/ha. Interestingly, for all three systems, a reduced tillage approach, which many would view as better for soil health and carbon storage, performed 6-15% less across all systems (Rodale Institute n.d.).

Conclusions

The La Ferme de l'Aube research farm and the nascent literature on veganic systems demonstrate the potential of veganic agriculture as an approach to farming that is regenerative as well as viable. The research farm utilized 100% regenerative practices and materials to nourish the soil and increase SOM. These included live mulching, hay and straw top dressing, cover cropping, in-bed plant detritus composting, vegetable-based composts, chipped branch wood and dried leaves–materials that are recurrent every year. Furthermore, the farm's avoidance of animal production and animal inputs eliminated completely the resource requirements and greenhouse gas emissions associated with animal-based agriculture. While animal-based regenerative and organic agricultural systems can show increases in SOM and crop yields over time, the veganic model is arguably more regenerative than farms incorporating animals and animal inputs.

As with all single-model studies, this study is limited by its regional nature and its relatively short duration. Its promising results relative to soil carbon storage and yield suggest the importance of further research on small-scale veganic agriculture to advance the exploration of this regenerative and productive model, particularly in light of the imperative to far more extensively implement sustainable, regenerative methods in our agricultural systems.

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