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REVIEW ON THE SUSTAINABILITY OF SOME REGENERATIVE AGRICULTURE PRACTICES FOR ORGANIC VEGETABLE GROWING

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Abstract

Both the dynamics of world geopolitics and the environmental challenges rises a series of concerns for agriculture, in general, and vegetable growing, in particular, especially regarding the price and the carbon footprint of the inputs that are used.

In this regard, the trend of applying technologies that promotes the existence of cohesion and harmony between the various technological links at farm level becomes obvious. Among these, especially in the last decade, a particular amplitude is manifested in terms of regenerative agriculture practices. The present paper aims to evaluate the degree of regenerative agriculture practices sustainability with direct applicability to the ecological vegetable cultivation, highlighting the analogy of the two agricultural systems. In this respect, a relevant number of studies that addressed the topics involved were assessed, trying to synthesize the conclusive results and also to draw some potential directions to be followed in the very near future.

***Key words**: regenerative agriculture; carbon footprint; vegetable cultivation; technological links; soil organic matter.*

INTRODUCTION

The very essence of regenerative agriculture is represented by the purpose of improving soil health and restoring the highly degraded land, simultaneously with an enhancement of water quality, vegetation and land-productivity. The Rodale Institute (2014) provides one of the most complex definitions of regenerative farming, considering it ”a long-term, holistic design that attempts to grow as much food using as few resources as possible in a way that revitalises the soil rather than depleting it, while offering a solution to carbon sequestration”. Shifting to regenerative agriculture practices also implies the uptake of a series of organic farming techniques designed to preserve and grow the quantity of soil organic matter, such as minimum tillage, cover crops and green manures cultivation, composting, mulching and crop rotation (Rhodes, 2017).

The awareness of a paradigm shift regarding conventional farming practices first occurred due to the event known in history as the Dust Bowl, generated by the land management practices deficiency in the US Great Plains region, enhancing its susceptibility before the 1930s drought. The extreme soil erosion emerged because of farmers abandoning soil conservation practices following the crop prices fall-off and high machinery costs, as well as turning into exploitation some inadequate lands for agriculture. Usually, the drought’s main effect is mentioned from an agricultural point of view. Several crops were affected by deficient rainfall, high temperatures and winds, insect infestations and dust storms. This situation facilitated the Great Depression’s bank closures, business losses, increased unemployment and other physical and emotional trauma. Moreover, the precipitation shortage would also have altered wildlife and plant life, generating water shortages for domestic needs.

A recent report on soil conservation, restoration, and improvement suggests taking a comprehensive approach to soil management known as Integrated Soil Fertility Management (ISFM). It involves incorporating organic matter such as crop residues and manure into the soil and cultivating legume crops like cowpeas that deposit nitrogen into the soil naturally.

Regenerative agriculture systems depend on the particularities of every socio-ecological and cultural context, where local and indigenous knowledge has a crucial function. In this approach, human beings are not detached from nature, and tending for the environment represents a precondition for people caring (Anderson and Rivera-Ferre, 2021).

MATERIALS AND METHODS

Data source and selection criteria

Data were gathered from a comprehensive selection of scientific studies, primarily from the past two decades, that examined the benefits of implementing regenerative agricultural practices for organic vegetable cultivation. A total of 345 relevant papers were identified from databases such as Google Academic, ScienceDirect, and Springer.com, using search terms like "regenerative agriculture" "organic farming" and "recommended management practices". Only studies that met specific criteria were included in the analysis, such as being recent and immediately applicable, providing detailed information on the advantages of regenerative agriculture in organic farming and having relevant and sufficient research to draw conclusions from.

RESULTS AND DISCUSSIONS

Assessing differences between main farming systems

Usually, when referring to sustainability, the farming systems are divided in: organic (OFSs), integrated (IFS) and conventional farming systems (CFSs). While organic farming can be defined as “the science or art of managing/keeping under control agricultural organisms and their living environment for the long benefit of nature and humanity” (Toncea, 2002), the integrated farming system refers to “a holistic pattern of land use which integrates natural regulation processes with farming activities in order to maximize off-farm inputs replacement and sustain farm profitability” (El Titi, 1992; Morris and Winter, 1999; Pacini et al., 2003). On the other hand, the significance of conventional farming is often used in the literature to group a variety of practices that can be either more or less intensive.

Anderson & Rivera-Ferre (2021) provide a new perspective on the problem, labelling the agricultural systems on outcomes rather than practices, as follows: extractive and regenerative. Thus, a full comprehension of their characteristics would be obtained as opposed to a large debatable division in: sustainable agriculture, regenerative agriculture, climate-smart agriculture or agroecology, which retrives multiple forms of human and material capital in its focus on yields and profits (Gutierrez-Montes et al., 2009). Apart from providing food for human use, regenerative agricultural systems also sequester carbon, sustains biodiversity, offers diverse diets for malnutrition control, increases community well-being by maintaining farming livelihoods, support the dignity and autonomy of the person and mitigates external inputs and knowledge reliance (Anderson & Rivera-Ferre, 2021).

Finally, as shown in Table 1, Neiger (2019) proposes the following classification of agricultural system function dependent:

Table 1. Different types of agricultural systems (by Neiger, 2019)

Agricultural system type	Characteristics
SUSTAINABLE	It functions at a regular state without decreasing its long term capacity to operate
RESILIENT	It is able to regain its key functions after a disruption.
REGENERATIVE	It is flexible and increases operational capacity overtime; it has a positive effect on other systems

(https://www.regenerativedesigngroup.com/restoring-land-with-regenerative-agriculture/)

Carbon sequestration and GHG mitigation potential of some regenerative farming methods

Carbon stockpiled at soil level represents the largest terrestrial carbon pool. It is also 3.3 times the size of the atmospheric pool (760 Gt) and 4.5 times the size of the biotic one (560 Gt). The predominant range of soil organic carbon pool to 1 m depth is between 50 and 150 tons/ha, representing a dynamic equilibrium of gains and losses (Lal, 2004). A negligible change in soil C content can disrupt the global climate (Luo et al., 2010; IPCC, 2014). Vegetable cultivated soils are usually characterized by low soil organic carbon compared to permanent plant cover ones, where the values are significant higher. Thus, Jarecki and Lal (2003) showed that over the past 200 years, reconverting the natural land to agricultural use generated a loss between 50-100 Pg of soil organic carbon worldwide.

Similarly, Gelaw et al. (2014) and Wang et al. (2016) highlighted that land use/cover changes, especially agricultural activities, significantly affect ecosystem services including soil organic carbon (SOC) storage. At least temporarily, by the means of some recommended management practices, carbon stocks of these soils can be restored, thus removing CO_2 from the atmosphere. Nonetheless, up-to-date estimations of the actual soil C sink capacity are only 50-66% of the cumulative historic C loss (Lal, 2004).

An accurate description of the Carbon sequestration potential in world soils by adopting regenerative farming practices is presented in Table 2.

Even though the potential of SOC sequestration is finite (Lal, 2004b), it still has the capacity to offset between 5 and 15% of the global fossil-fuel emission (Kauppi and Sedjo, 2001; Lal, 2004b).

Stockmann et al. (2013) emphasizes the importance of the C dynamics understanding within agro-ecosystems and identification of appropriate farming practices in order to protect soil resources and provide adequate food and fiber for an ever-increasing population.

Therefore, soil represents a major influencer of the global carbon and nutrient cycle, holding more carbon than all terrestrial vegetation combined. Kopittke et al. (2019) showed that the use of soils for food production causes 30-60% of carbon loss, triggering the soil functionality decline. A global soil organic carbon map is presented in Figure 1.

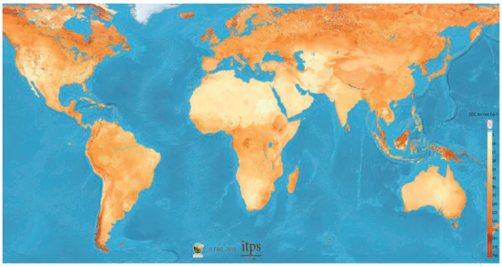

Figure 1. Global Soil organic Carbon Map (Scale 5-750 tons*ha^{-1}) (GLOSIS - GSOCmap ©FAO 2018, http://54.229.242.119/GSOCmap/)

Furthermore, the difference between the two layers (the one formed by areas where soil organic carbon is dominant and the one formed by the areas where biomass carbon is proeminent) is presented in Figure 2.

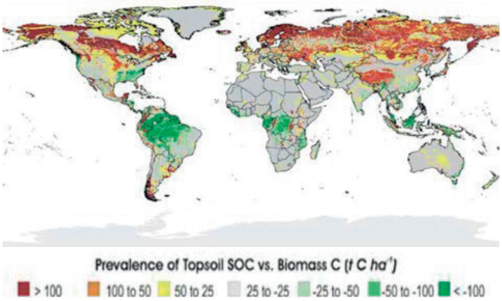

Figure 2. Prevalence of carbon in the topsoil or biomasshttps://www.fao.org/3/i5199e/i5199e.pdf

The assessment of agricultural impact on soil carbon sequestration emphasizes the carbon restore especially through animal manure recycling (Smith et al., 2001; Freibauer et al., 2004). While passing the digestive tract, manure is enriched in more sturdy compounds that can persist as stable soil organic matter in association with clay and silt particles. Above all, the application of composted manure has further advantages induced by the aerobic decomposition, where less CH_4 develops compared to stacked manure (Davis et al., 2002).

Several studies have evaluated the influence that irrigation (Houlbrooke et al., 2008; Kelliher et al., 2012), fertilization (Lemke et al., 2012; Yan et al., 2012), tillage (West and Post, 2002; Franzluebbers and Steiner, 2016) or land use change (Venkanna et al., 2014; Wiesmeier et al., 2015) has on soil organic carbon content and stocks in agricultural soils. Organic fertilizers substantially enhance soil C content as opposed to the chemical ones (Leifeld et al., 2009; Brar et al., 2013).

Regarding organic vegetable cultivation, Lal (2004), Liao et al. (2015) or Matsuura et al. (2018) emphasized the great potential of its practices to increase C stocks at soil level. By contrast, Leifeld and Fuhrer (2010) pointed out that the positive effects of organic system on SOC might be caused by the exceedingly applications of organic fertilizer compared with conventional system. In this respect, Powlson et al. (2011) consider that SOC increase due to organic fertilizer does not represent a genuine C sequestration.

As for agricultural GHG mitigation efforts, organic farming systems may be of paramount importance, because it uses less energy and stores more C per hectare than conventional system (Larsen et al., 2014; Reganold and Wachter, 2016). Meanwhile, on a production unit basis, both energy use and carbon footprint do not always favor organic (Meier et al., 2015; Reganold and Wachter, 2016).

Lal (2004) highlights the fact that beside increasing food security, carbon sequestration has the capability to offset fossil-fuel emissions by 0.4 to 1.2 gigatons of carbon per year, or 5 to 15% of the global fossil-fuel emissions (Lal, 2004). In this sense, the restoration of degraded soils and ecosystems whose resilience capacity is intact becomes essential (Silver et al., 2000).

Table 2. Potential of Carbon Sequestration in World Soils by adopting regenerative farming practices (Lal, 2004)

Cropland Soils: 1350 Mha [0.4 to 0.8 Gt C/yr]	**Irrigated Soils: 275 Mha [0.01 to 0.03 Gt C/yr]***	**Range Lands and Grass Lands: [0.01 to 0.3 Gt C/yr?]***	**Restoration of Degraded and Desertified Soils: 1.1 billion ha [0.2 to 0.4 Gt C/yr]**
Conservation tillage (100-1000)	Using drip/sub-irrigation	3.7 billion ha in semi-arid and sub-humid regions	Erosion control by water (100-200)
Cover crops (50-250)	Providing drainage (100-200)	Grazing management (50-150)	Erosion control by wind (50-100)
Manuring and Integrated Nutrient Management (50-150)	Controlling salinity (60-200)	Improved species (50-100)	Afforestation on marginal lands (50-300)
Diverse cropping systems (50-250)	Enhancing water use efficiency/water conservation (100-200)	Fire management (50-100)	Water conservation/harvesting (100-200)
Mixed farming (50-200)	Both soil organic and inorganic Carbon are sequestered	Nutrient managemen	
Agroforestry (100-200)		Both soil organic and inorganic Carbon are sequestered	
High potential for about 250 Mha in South America of acid savana soils			

Going regenerative in "4 per 1000" initiative context

The "4 per 1000" (4p1000) initiative has been launched during the COP 21 in Paris in 2015 and was based on transposing the science of soil carbon sequestration into action at the global scale. According to Lal (2020), the initiative represents an example of a broader set of negative emission technologies. The main features of the initiative are presented in table 3.

Better management practices have the ability of transforming agriculture from a net source of GHGs to an intense sink of atmospheric CO2 (Lal et al., 2018). By adopting this recommended management practices (RMPs) in a cost-effective manner, soil and biomass-C stocks and emission reductions can be measure and monitor. De Pinto et al. (2010) outlined the industry role in developing mechanisms in order to gather farmers in rural communities and design markets and contracts.

Furthermore, a 2018 study emphasized the role of governments and markets that needs to establish a baseline price levels and develop a methodology for carbon permits allocation and carbon finance initiatives to operate in a fair, just and transparent manner (BWP, 2018).

In order for carbon farming to be successful, carbon gains in agro-ecosystems (soil and biomass) through improved management must exceed the erosion, decomposition and harvest losses (Carbon Cycle Institut, 2020).

Also, the key of the 4p1000 initiative is represented by the creation and operationalization of carbon trading markets.

By the implementation of the essentially regenerative RMP (Recommended management practices) that sequester SOC and mitigate emissions, carbon markets can offer a new source of income for farmers (Koper, 2014; Gustin, 2017). Being scale-neutral, carbon farming feasibility for both small-scale and large-scale commercial farms is certain. Becker et al. (2013) emphasizes the prospect of climate change mitigation in hot and dry areas by adopting regenerative practice to sequester carbon at soil level.

Table 3. `4 Per 1000 Initiative` - the core of regenerative movement for the years to come

`4 Per 1000 Initiative`			
History	**Signification**	**Main implementation methods**	**Literature**
- has been drafted at 2015 Climate summit held in Paris with the 21st Session of the Conference of the Parties and the 11th Session of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol	- an annual soil carbon content increase of 0.4 percent on a 30-40 cm depth that will determine a major balance of the CO_2 triggered by human activities	- intercropping	Corbeels et al. (2018); Mikula et al. (2020)
		- improved crop rotations	Francaviglia et al. (2019); Wiesmeier et al. (2020); Bruni et al. (2021)
		- organic farming	Leu (2017); Garcia-Palacios et al. (2018); Keel et al. (2019); Wiesmeier et al. (2020)
		- agroforestry – woody plants (tree or shrubs) are mixed with vegetable crops	Arango-Quiroga (2019); Cardenas et al. (2017); Wiesmeier et al. (2020)
		- conversion of arable land to grassland	Soussana,et al. (2017); Rodrigues et al. (2021)

Best of regenerative farming practices to adopt in organic vegetable cultivation

Some of the best regenerative farming practices that are suitable for organic vegetable growing are presented in Table 4.

Using catch crops/cover crops will generate a permanent vegetal cover for land, extending the carbon assimilation period whilst preventing soil erosion, weeds infestation and nitrate losses (Poeplau and Don, 2015; Kanders et al., 2017; Strickland et al., 2019; Chahal et al., 2020). Legume varieties, several grasses and some cruciferous species are usually sown after the harvest of the main crop or undersown in/with main crops, being used as fodder crops for ruminants or as green manure, with soil improvement role (Lawson et al., 2015; Bleuler et al., 2017; Koehler-Cole and Elmore, 2020). Tiefenbacher et al. (2021) underline the positive soil organic carbon balance of utilizing catch crops in rotations.

Typically, the carbon sequestration potential of an annual catch crops cultivation was of 403 ± 142 kg C ha^{-1} y^{-1} in agricultural topsoils (0-25/30 cm) (Chambers et al., 2016; Bleuler et al., 2017; Jian et al., 2020). Likewise, Hu et al. (2018) emphasized an increase in topsoil organic carbon stocks (0-25 cm) of 210 kg C ha^{-1} y^{-1} due to the catch crops introduction into rotation. Furthermore, Jian et al. (2020)`s meta-analysis of 131 studies across the globe highlighted a mean carbon sequestration rate of 560 kg C ha^{-1} y^{-1}. Similarly, Bleuler et al. (2017) assessed cover cropping influence under permanent crops at a rate of 550 kg C ha^{-1} y^{-1}.

In organic vegetable fields, crop diversity can be enhanced on a temporal (crop rotation, catch crops) or spatial scale (several plant species at the same time, cover crop mixture). The variety of crop rotation and organic fertilizers/ amendments usage and/or perennial cropping systems have the capability of a better soil organic carbon storage compared with conventional (single) cropping systems (Minasny et al., 2017; Don et al., 2018), simultaneously enhancing soil microbial diversity, soil aggregate stability and subsoil organic carbon due to deep-rooting crops (Tiemann et al., 2015; Finney and Kaye, 2017). In terms of soil organic carbon storage, deep-rooting crops are determined, since roots retention is up to 2.3 times higher than the aboveground biomass (Kätterer et al., 2011; Gherardi and Sala, 2020). The positive effect prevails in the topsoil and declines with soil depth (Kaiser and Kalbitz, 2012). Börjesson et al. (2018) outline an enhancement of carbon sequestration potential by 360 and 590 kg C ha^{-1} y^{-1} in the topsoil (0-20 cm) at clay and, respectively, loam texture sites due to incorporating legumes in the rotation for 35 years.

Sokol et al. (2019) emphasize the deep-rooting crop species and varieties role of transferring carbon into the subsurface (where a high carbon sequestration potential exists) through root exudates (sugars, amino acids and other organic acids), particularly when organic substances are protected in organo-mineral aggregates (Paustian et al., 2016).

The deep-rooting crops cultivation can deliver a sequestration of 374 ± 117 kg C ha^{-1} y^{-1} (Börjesson et al., 2018; Poulton et al., 2018; Poffenbarger et al., 2020).

On the other hand, Lugato et al. (2018) highlight that carbon sequestration via N-fixing crops is limited to the first 20 years, thereafter, N_2O emissions exceeding the ability of these crops to mitigate CO_2 emissions.

Some extra benefits of deep-rooting crops are represented by their ability to use resources such as water and nutrients from the subsurface horizon, preventing nitrogen leaching and assuring a better plant resiliance to drought (Hansen et al., 2019). Also, they enhance deep infiltration and improve the pore connectivity of soils (Freibauer et al., 2004), augmenting the subsequent crops expansion throughout biopores.

Natural farming is another low-input regenerative method that uses weed residue mulching as an unique form of agroecosystem management to continuously increase soil carbon sequestration. Ultimately, it also reduces soil bulk density and enhances soil quality. Natural farming has the potential of making organic vegetable production compatible with environmental conservation. However, Dewi et al. (2022) warn about the importance of nutrient balance during long-term management in order to ensure that the necessary nutrients are available.

A series of authors emphasizes the use of biochar as an example of carbon farming solution to anthropogenic climate change, being an important negative emission technology (Smith, 2016; Jackson et al., 2017; Alcalde et al., 2018). It relies on implementing known and proven land use and soil management practices.

Organic matter ties the soil particles into aggregates, improving soil structure and infiltration rates while reducing compaction. It also run as a nutrients and water sink in the soil, as well as heightening microbial biodiversity and activity (Xu et al., 2022).

Usually, adding organic amendments or using them alongside cover cropping in mixtures could represent a feasible alternative for vegetable growers since these treatments showed beneficial effects on soil health (Baffaut et al., 2020; Conway et al., 2020; Xu et al., 2022).

Montgomery et al. (2022) highlighted that regenerative farm had almost three to four times the soil organic matter and a soil health score three to seven times higher compared to conventional farm.

Regarding the quality of the crop, cabbage grown in regenerative system had higher values for vitamin K (46%), vitamin E (31%), vitamin B_1 (33%), vitamin B3 (60%), vitamin B5 (23%), calcium (41%), potassium (22%) and less than a third of the sodium, 35% more carotenoids and 74% more phytosterols compared to cabbage from a regularly tilled organic field.

In addition, regenerative cultivated spinach presented a total phenolic content about 4 times higher compared to conventional system yield. Similarly, regenerative carrots had 60% to 70% more total phenolic content compared to conventional ones (Chun et al., 2005).

Table 4. Regenerative farming practices suitable for organic vegetable growing

Regenerative farming practices	Main features
Conservation cover	- a permanent vegetative cover; - plants that generates high volumes of organic matter in order to sequester carbon and enhance soil health are suitable;
Conservation crop rotation	- growing crops in a planned sequence on the same field over time;
Residue and Tillage Management, No-Till	- maintaining the preceding crop waste throughout the year and planting the subsequent crop directly into it;
Residue and Tillage Management, Reduced Till	- it limits soil-disturbing operations, expanding soil-carbon stocks and intensifying plant-available moisture;
Contour Buffer Strips	- narrow strips of continuous, herbaceous vegetative cover set on sloping cropland;

	- major role in reducing soil erosion and improvement of water quality and infiltration along with a stronger soil health;
Cover crops	- are set for a seasonal vegetative cover and consist of either legumes or grasses; - they lacks the cash crop role, being accountable for building soil structure and health by increasing organic matter and carbon stocks;
Field border	- a strip of permanent vegetation that encircles a cropland or it is placed at its edge;
Filter strips	- herbaceous vegetation with contaminants removal role from overland flow
Grassed waterways	- channels planted with grass and other suitable vegetation in order to reduce the water runoff speed;
Mulching	- use of plant waste or other materials to the land's surface; - enhances soil carbon sequestration and moisture management and reduces erosion;
Stripcropping	- use of a systematic arrangement of planned rotation crops that are erosion-resistant and erosion- susceptible on a cropland field
Vegetative barriers	- permanent strips of dense vegetation set in flow areas
Herbaceous wind barriers	- herbaceous vegetation set in narrow strips with role in wind speed and erosion mitigation

Permaculture - a state of the art way of growing organic vegetables by embracing regenerative principles

Permaculture is a low impact agricultural method that uses perennial cultivation methods to produce food crops through a series of principles that are in harmony with nature (Mollison & Jeeves, 1988; Holmgren, 2002; Rhodes, 2017). Land use in permaculture is closely linked with agroecology, agroforestry and traditional and indigenous practices. Two broad criteria are at the core of permaculture view: ecosystem mimicry and system optimization. Thus, it promotes some pragmatic methodological principles in order to develop resilient, autonomous and equitable living spaces. Both biodiversity and agrobiodiversity are valued for their positive effect on resilience: high-energy foods should consist in cereal crops, root vegetables and fruits from mini-orchards. Also, Morel et al. (2019) outline that the same element must fulfil multiple functions: e.g. a legume supplies of protein and improves the soil fertility. Therefore, the key principle of permaculture is the maximization of desirable connections between elements in order to achieve their best synergy and optimal design.

Another fundamental principle of permaculture is that the entity is more important than the sum of its parts. It requires an integrated 'systems thinking'. Permaculture design objective is to minimise waste, human labour and inputs of energy and other resources, establishing maximal benefits systems in order to fulfil a high level of holistic integrity and resilience. Hence, permaculture designs are 'organic' and grow over time according to the interplay of these relationships and elements having the potential to become extremely complex systems, able to produce a high density of food and materials with minimal input. Falk (2013) shows that a regenerative farm based on permaculture principles will develop an evolving ecological structure and biological production that increases in its complexity with time. Moreover, the overall biological yields will continue to grow, while the external inputs will decrease.

Rhodes (2017) outlines three ethical principles of permaculture design that are briefly presented in table 5.

Furthermore, Holmgren (2002) has identified twelve principles of permaculture design: (1) observe and interact, (2) catch and store energy, (3) obtain a yield, (4) apply self-regulation and accept feedback, (5) use and value renewable resources and services, (6) produce no waste, (7) design from patterns to details, (8) integrate rather than segregate, (9) use small and slow solutions, (10) use and value diversity, (11) use edges and value the marginal, (12) creatively use and respond to change.

Most of the goals of agricultural permaculture align with the aspirations and objectives of organic agriculture. However, unlike permaculture, the organic system adheres to well-defined regulations that enable expansion and replication. These rules are understandable to consumers. Conversely, several aspects of permaculture, such as the management of animal farming amendments or the usage of plant protection items, like neem oil or copper products, lack regulation, including related maximum restrictions. It is important to openly discuss with consumers, who expect safe products with clear knowledge of their origin and production methods, whether commercial permaculture is viable without organic agriculture standards. As long as there are no consistent and obligatory standards for permaculture, its implementation in commercial environments will likely remain debatable (Fiebrig et al., 2020).

The primary considerations for designing agroecosystems using permaculture techniques are (i) site characteristics; (ii) the interplay between various components across multiple levels, such as mixed crop cultivation at the plot level and diverse land utilization at the agro-ecosystem level; and (iii) the spatial configuration of the elements as crucial factors that impact multiple functions (Ferguson & Lovell, 2014; Holmgren, 2002). Permaculture has not originated most of the approaches it employs. Instead, it can be viewed as a conceptual framework for assessing and integrating pre-existing methods (Krebs & Bach, 2018).

Similar to organic and biodynamic agriculture, permaculture places significant emphasis on soil fertility. Permaculture shares many similarities with traditional organic farming, agroecology and biodynamic farming, in that all of these approaches advocate for a harmonious and respectful coexistence of humans and nature. However, biodynamic farming historically evolved from spiritual concerns (theosophy), while organic farming and agroecology are more closely linked to the collective and political struggles of peasants who fight for their autonomy. In contrast, permaculture emerged to support self-sufficient initiatives at an individual and community level, in preparation for a world less reliant on petrol.

As organic and biodynamic farming, permaculture attaches a great attention to soil fertility. Permaculture has much in common with traditional organic farming, agroecology, and biodynamic farming, in the sense that all these approaches promote a harmonious and respectful integration of human beings in nature. However, biodynamic farming has a historical association with spiritual concerns (theosophy), while organic farming and agroecology have stronger ties to peasant’s movements collectively and politically fighting for their sovereignty, whereas permaculture was born to support individual and community-scale self-sufficiency initiatives in preparation for a post-petrol world.

The combination of management practices and the consequent characteristics of agroecosystems observed in permaculture farms are associated with a wide range of ecosystem functions and services (Hathaway, 2015; Krebs and Bach, 2018). Firstly, current research on perennialization indicates that the deliberate integration of perennial species can promote provisioning (agricultural yields), regulating (pest control, hydrological cycles, water quality, carbon sequestration, and storage), and supporting (soil quality, pollination) ecosystem services (Asbjornsen et al., 2013; Corry, 2016). Secondly, permaculture's emphasis on not just biodiversity but also enhancing yield through beneficial interactions may have anticipated the growth of the functional diversity field; modern ecologists refer to this as overyielding driven by complementarity or facilitation (Hooper et al., 2005; Szumigalski and Van Acker, 2005).

Ultimately, permaculture's groundbreaking idea that agricultural landscapes should strive to be diverse, varied, and incorporate areas for conservation (Mollison and Holmgren, 1978) anticipates modern wildlife-friendly matrix and agricultural mosaic models (Tscharntke et al., 2005; Kremen, 2015). Due to the uniform interpretation and implementation of permaculture principles among independent adopters and its extensive global recognition, permaculture is in a favorable position to impact the provision of numerous agroecosystem services.

In contrast, Ferguson & Lovell (2014) highlighted the downside of permaculture movement by the fact that starting from the founding parents, who had a solid, academic scientific background, here named Mollison, followed by his apprentice, Holmgren, gradually, the movement has become isolated from the scientific side, acquiring a pronounced empirical character In this regard, both Scott (2010) and Chalker-Scott (2010) emphasizes that Most permaculture texts do not refer to contemporary scientific research.

Table 5. Key ethics of permaculture (by Rhodes, 2017)

Permaculture ethics	Features
'Earth Care' (take care of the Earth)	Provision for all life systems to continue and proliferate.
	Work with nature
	Act to prevent damage and destruction
	Consider the choices we make
	Aim for minimal environmental impact
	Design healthy systems to meet our needs
'People Care' (take care of the people)	Supplying people`s access to the necessary resources for their existence
	Look after ourselves and others
	Working together
	Assist those in need of food and clean water
	Develop environmentally friendly lifestyles
	Design sustainable/regenerative systems
'Fair Shares' (share the surplus)	Healthy natural systems use outputs from each element to sustain others.
	Resources are limited and only by consumption mitigation durability should be achived
	Build economic alternative
	Develop a common unity
	Modify our way of life now in order to become part of the solution and not of the problem.
	Need to become reconnected with the natural world: shift in thinking and being.

CONCLUSIONS

Regenerative agriculture systems promote nutritious food, carbon sequestration, biodiversity conservation, community welfare improvement, and uphold human dignity and autonomy, while reducing reliance on external inputs and knowledge.

Recommended management practices for regenerative agriculture have the ability to convert agriculture from a net emitter of greenhouse gases to a strong absorber of atmospheric CO_2.

The regenerative agriculture techniques appropriate for cultivating organic vegetables include incorporating catch crops/cover crops, crop rotation and intercropping, natural farming techniques, mulching, and implementing reduced or no-till systems.

The utilization of land in permaculture is strongly associated with agroecology, agroforestry and traditional and indigenous methods, with the goal of enhancing its intricacy over time.

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