Environment and Ecology 40 (1) : 60—69, January—March 2022
ISSN 0970-0420

Permaculture for Sustainable Agriculture : A Review

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Received 28 September 2021, Accepted 28 December 2021, Published on 7 January 2022

ABSTRACT

Rapidly increasing human population coupled with escalating urbanization posed a threat to unsustainable anthropogenic activities. At the same time existing industrial agriculture required for feeding this growing global population is primarily liable for adverse environmental impacts, such as biodiversity loss, soil deterioration and alteration of natural cycles or greenhouse gas emission. Thus there is a calling for substituting the existing forms of agriculture with a farming technology that addresses social, economic and environmental aspects of sustainability. Permaculture is a comprehensive layout that integrates sustainable agricultural practices with the potentiality of improving livelihoods. Permaculture purportedly offers a range of solutions to the negative facades that arises from the processes such as monoculture crop cultivation, industrialized food production and attempted to design and develop a sustainable community in harmony with natural ecosystems. It embraces solution oriented approaches to contemporary social and environmental problems. This review paper aims to discuss the processes used by permaculture practitioners that can lead to a sustainable development without compromise on the existing conditions and how permaculture can integrates landscape and society in providing their food, shelter and energy in a sustainable way.

Keywords Permaculture, Sustainable agriculture Farming technology, Environmental aspects.

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INTRODUCTION

In keeping tract with the present scenario it became clear that a more efficient agricultural system is needed to feed the rapidly increasing population. As agriculture serves as the main source of food

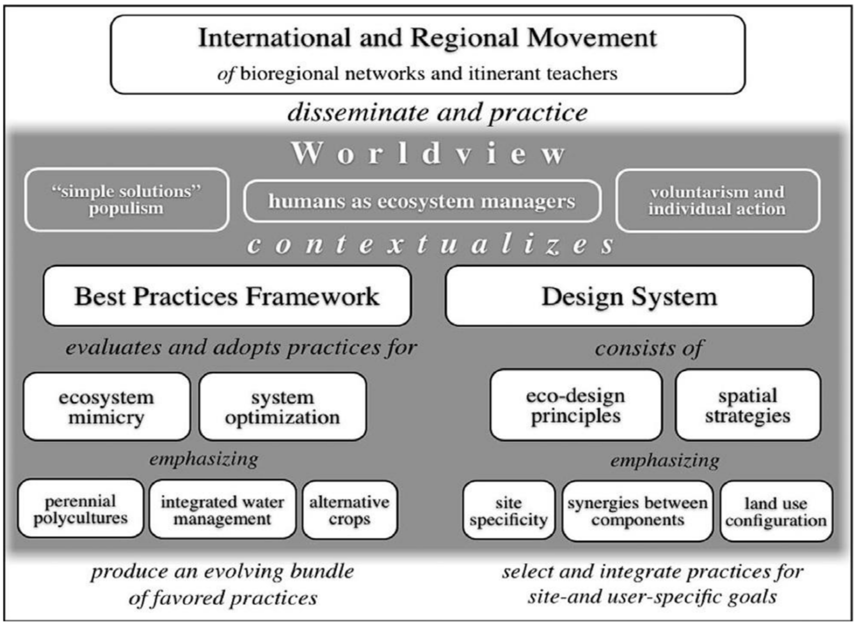

Fig. 1. Stratified definition of permaculture adapted from (Ferguson and Lovell, 2014).

however resource intensive farming practices have catastrophic impacts on the environment and societies at large (GEO-6, 2019, Gomiero *et al*. 2011, Wang 2013). Contemporary urbanization is also increasing in each year and it is expected that more than 60% of the world's population is residing in the urban areas (Verma and Tiwari 2020). This increasing pressure to sustain the masses, eventually leads to rampant usage of environmental resources, leading to their dearth and an introduction to a whole new set of risks and threats such as pollution, loss of diversity, species extinction and food insecurity. Many of the environmental issues faced by the humanity today are linked to the modern, industrial agriculture, which is based on the large-scale cultivation of monocultures using heavy machinery and a large amount of agricultural chemicals, such as synthetic fertilizers and pesticides (Matson 1997, Bennett *et al*. 2001, Zhang *et al.* 2007, Power 2010, Foley *et al.*2011). Also, the current land use change is pushing the earth's ecosystems to the limits of their capacity (Foley *et al*. 2005). Agriculture has a particularly strong impact on (a) eco-biodiversity (b) soil quality (c) water reservoirs (d) emission of greenhouse gases (e) the nutrients cycle.

A transition to sustainable agricultural systems is required for social and economic equity, food security, conservation of biodiversity and provision of ecosystem services (Wang 2013). Permaculture is an approach that could contribute to the sustainability of social and ecological systems (Gomiero *et al*. 2011). Its main aim is to minimize the basic necessary inputs in the form of natural resources; energy and any other fundamental material so as to uphold the system.

Permaculture

The term permaculture was defined by David Holmgren and Bill Mollison as an "Integrated, evolving system of perennial or self-perpetuating plant and animal species useful to man"(Holmgren 2002).They are considered to have coined the term permaculture in the 1970s as response to new design science which derived from the systems of nature like forests. It constitutes of 3 fundamental words - "permanent," "agriculture," and "culture" (Verma *et al.* 2020). Permaculture is the conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability and resilience of natural ecosystems. It is the harmonious integration of landscape and people providing their food, energy, shelter and other material and non-material needs in a sustainable way (Mollison 1979).

Permaculture definitions are broad and encompass different foci, but they universally emphasized the combined social and ecological dimensions of the concept (Fig. 1). As per the Permaculture Activist magazine permaculture is defined as a holistic system of design, based on direct observation of nature, learningfrom traditional knowledge and the findings of modern science. Embodying a philosophy of positive action and grassroots education, Permaculture aims to restructure society byreturning control of resources for living: food, water, shelter and the means of livelihood, to ordinary people in their communities, as the only antidote to centralized power' (Permaculture Activist 2004).

Permaculture is a process of living which teaches us how to get the most from our resources by minimizing waste and maximizing its output potential. Living in harmony with ecology doesn't mean giving everything up, rather it means realizing the importance of nature and understanding new ways of being physically fit, mentally sound, resourcefully sound and socially well-up. It is a conscious design of a routine which is highly productive and does not cause environmental damage while still meets the basic requirements and leaves the earth resourcefully wealthier than was found. Permaculture is a process of living which teaches us how to get the most from our resources by minimizing waste and maximizing its output potential. Living in harmony with ecology doesn't mean giving everything up, rather it means realizing the importance of nature and understanding new ways of being physically fit, mentally sound, resourcefully sound and socially well-up. It is a conscious design of a routine which is highly productive and does not cause environmental damage while still meets the basic requirements and leaves the earth resourcefully wealthier than was found.

Why Permaculture?

Ferguson and Lovell (2013) note that, while permaculture is probably the best known agroecological movement, it has been relatively neglected in scholarly circles. Permaculture, perhaps the most widely practiced form of agroecology, also provides an ethical framework and principles that serve as a basis for discerning actions that enable the design of diverse, sustainable systems suited to a wide variety of cultural and ecological contexts. Widespread adoption of agroecological methods and permaculture principles could significantly reduce energy, pesticide and freshwater usage while simultaneously restoring degraded soil, sequestering large quantities of carbon, creating more biodiverse agricultural systems and satisfying human needs for healthy, nutritious food. As well, engaging in ecological agriculture may encourage practitioners to develop genuinely ecological dispositions and worldviews that enable them to approach problems and discern actions from a perspective that systematically promotes sustainability and social justice. Alternative systems of agriculture, such as biodynamic agriculture, organic farming, pesticide-free farming, permaculture, and others (Satya *et al.* 2007), have been reported as sustainable, as well as pragmatic, solutions for tackling food safety and quality issues the world over.

Ethical and design principles of Permaculture (Fig. 2)

Permaculture includes a number of ethical and design principles that have made it flexible and adaptable to different environments and ecosystems (Pickerill 2013. Veteto and Lockyer 2008) A set of values, ethics and principles are included with sustainability at their core that can take shape and influence many factors of global society as well as agriculture (ibid).

Permaculture ethics

The word permaculture originally referred to permanent agriculture and was later developed to permanent culture to emphasize the significance of the social in achieving sustainable and regenerative systems. Hence,'permanency' is an integral aspect of permaculture and in order to achieve it an approach is required which 'addresses justice and sustainability holistically – not only in the ecological, but also in the economic, social and cultural dimensions' (Pyhälä 2013). It also advocates 'rapid regeneration and significant improvements of natural respire base and yields' by going beyond conservation and focusing on

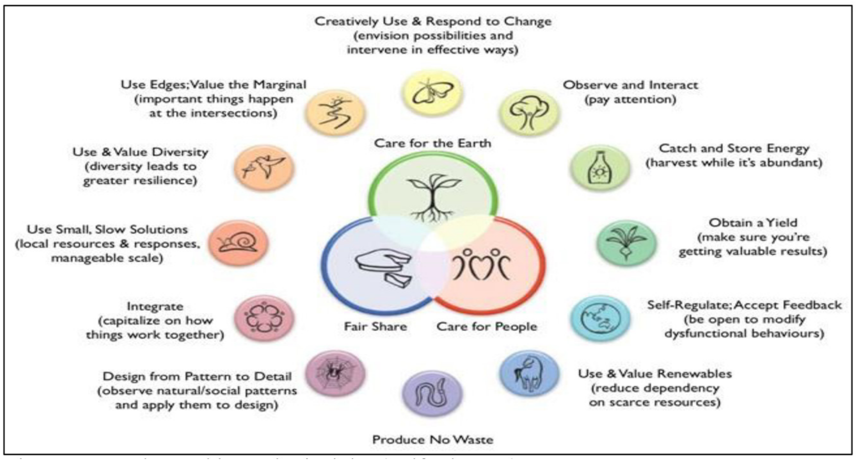

Fig. 2. Permaculture ethics and principles (Telford, 2015)

healing the damages which have been caused (Pyhälä 2013). Permaculture's emphasis on regeneration is based on the fact that sustainable solutions can become unsustainable over time. Therefore designing systems which are sustainable and regenerative at the same time, lies at the heart of permaculture philosophy. In a regenerative system output is greater than the input, it is resilient and adaptive. Moreover, a regenerative system does not only have the capacity to feed itself and constantly bring itself to existence, but it also has the capacity to restore and improve. Permaculture aims at restoring ecosystems and improving the human habitats and lives of communities around them. Therefore, permaculture should not only be seen as a food production system but a 'community planning philosophy' (Maye 2018) aimed at reconnecting humans with nature by regenerative means.

Permaculture is based on three ethical principles of: a) earth care b) people care and c) fair share.

a) Earth care emphasizes the significance of a healthy earth as the basis of our human wellbeing and healthy human environments.

b) People care highlights that people need to have access to the resources necessary for their wellbeing and basic needs. It emphasizes the significance of collaboration and companionship for achieving a healthy and flourishing life.

c) The ethic of fair share is about recognizing that limited resources should be distributed fairly among human beings, animals and plants as well as between the current and future generations. It suggests this will be achieved by setting limits to our consumption and population growth (Pickerill 2013, Suh 2014).

Design principles

Permaculture may be understood as both a movement and philosophy promoting design principles that can be applied beyond agriculture: The overall aim of these design principles is to develop closed-loop, symbiotic, self sustaining human habitats and production systems that do not result in ecological degradation or social injustice (Veteto and Lockyer 2008). The permaculture design system utilizes ecological and systems-thinking principles and spatial reasoning strategies, which are used to analyze site conditions, select practices and integrate them with site conditions and land use goals. The most distinctive aspects of the permaculture orientation toward agroecosystem design are its emphases on (1) site specificity, including attention to microclimate; (2) interaction between components at multiple scales, from field-scale poly cultures to agroecosystem-scale land use diversity; and (3) spatial configuration as a key driver of multiple functions. Permaculture then provides a set of twelve principles that create a framework for design while allowing for a wide range of methods applied in specific contexts (Holmgren 2002, McManus 2010). These principles form the basis of a reflective design process geared toward outcomes that align with the principles described above and the underlying ethical principles. These principles are:

(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.

Permaculture claims to be a concept for the design of sustainable socio-ecological land use systems, recognizing that land use systems are never separated from social systems. In the field of agricultural production, the practical implementation of permaculture shares many similarities with other alternative farming approaches such as organic farming, biodynamic farming, agroforestry or agroecology. All these movements have historically promoted the development of resource-efficient and pesticide-free agroecosystems favoring local nutrient cycling (e.g., using compost, green or animal manure) and favoring biological regulation by maintaining a high level of biodiversity to keep plants and animals healthy. Permaculture echoes agroecology and agroforestry for the central place given to spatial association of species (combination of trees, animals, crops, intercropping, diversified landscapes).

The most important aspects of permaculture for the planning of agroecosystems are (i) site characteristics; (ii) the interaction between individual elements on several levels, from mixed cultures at the field level to the diversity of land use at the level of the agro-ecosystem; and (iii) the spatial arrangement of the elements as decisive drivers for multiple functions (Mollison 1992, Ferguson and Lovell 2014, Holmgren 2002, Morel *et al.* 2018. This strengthens the natural processes and functions of the landscape (Mollison 1992).

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. Compared to other alternative farming approaches, one major specificity of permaculture is the central emphasis on the conscious global design of agroecosystems rather than focusing on specific techniques. Permaculturists tend to implement complex multistrata polycultures, intercropping, agroforestry (e.g., food forests) crop animal integration (e.g., silvopastoralism), and to promote a high diversity of habitats, integrating landscape features such as ponds and hedges. Soil tillage is often limited and soil is constantly covered by plants or organic mulch to favor the development of soil organisms that will work for humans and structure the soil (e.g., earthworms), store carbon and limit erosion. Trees and perennial plants often play a key role as they are considered energy accumulators (storing carbon and making nutrients available for other species).

The above mentioned 12 principles claim to provide a framework for the design of sustainable land use and a society within ecological boundaries (Holmgren 2002).

Principle I: Observe and interact

Permaculture is an adaptive management, which is a systematic approach for improving resource management by learning from management outcomes (Williams *et al.* 2007). Therefore, multiplemanagement options to reach specific management goals are implemented. The monitoring of system responses to management options gives decision guidance to adjust management practice (Westgate *et al.* 2013).

Principle II: Catch and store energy

Different sources of energy (e.g., solar energy, water, wind, living biomass and waste), shall be held within the system as long as possible. This is necessary to be able to use it as long and effectively as possible and to maintain their functions, such as buffering extreme events. The most important storages of future value are fertile soil with high humus content, perennial agroecosystems (especially trees), and water storages, such as groundwater and water bodies (Holmgren,2002).

Principle III: Obtain a yield

The (farming) systems designed and managed with permaculture have to obtain a sufficient yield and to supply humans with food, energy and resources. However, this principle also aims at the efficiency of production, as our “yield” is low if we have to put in a lot of effort, energy and resources to obtain it. Apart from that, this principle also calls for a more holistic understanding of yield, not only an economic one, but also ecologic and social yields (Holmgren 2002). This principle is especially crucial as it calls for a sufficient yield of agricultural products while-maintaining a high efficiency in terms of resource and energy consumption as well as ecological and social ‘yields’.

Principle IV: Apply self-regulation and accept feedback

The enhancement of regulating ecosystem services, such as natural pest control, pollination, nutrient cycling and soil and water quality regulation, are the most common applications of this principle. Strengthening of stabilizing feedbacks in ecological systems, such as those regulating ecosystem services, helps to maintain a favored and resilient regime of the ecosystem and increases robustness against external stress, e.g., climate change (Biggs *et al.* 2012).

The goal of permaculture is to create systems as self-sustaining and self-regulating as possible. Positive feedback accelerates growth and energy accumulation within the farming systems. This is best used in the early phase. Negative feedback, the more important one, protects the system fromi nstability or scarcity through miss- or over-usage. Additionally, each element within a land use system should be as self-reliant as possible to increase the resilience against disturbances (Holmgren 2002).

Principle V: Use and value renewable resources and services

The use of renewable resources and services is necessary to stop the exploitation of non-renewable resources, which, in the long run, undermines the functionality of the whole system. Plants might be used as an energy source, building material and soil improvers, while examples for animals are herding dogs, animals for soil cultivation and draught animals. This principle also covers the use of wild resources (fish, game, wood), which should be used sustainably to maintain the renewability of these resources. Overall, this principle focuses on maximizing the use and functioning of ecosystem services (Holmgren 2002).

Principle VI: Produce no waste

This principle aims at mimicking the natural pattern of exchange and cycling of matter and energy. In natural living systems, no waste occurs as every output of an element (a species) is used by another element. This is why waste could also be seen as an output, which is not used by the system. According to this, all waste should be seen as a resource that should be used to be as effective as possible (Holmgren 2002).

Principle VII: Design from patterns to details

Natural ecosystems should be used as patterns for sustainable land use as natural ecosystems evolved over a long period of time to function under certain environmental conditions (Holmgren 2002). Additionally, landscape patterns, such as geomorphology, catchments and methods, like zoning and sectors should be used in permaculture design for effective site planning (Holmgren 2002).

Principle VIII: Integrate rather than segregate

Biological interactions, especially mutual ones, should be used to increase the productivity and stability of the agroecosystem and to generate synergy effects. Integration of elements enables making use of the multifunctionality of elements, like chickens for pest control when integrated into an orchard system. Integration also allows sustaining important functions of a system through multiple elements, like chickens and fruit trees both covering the function of food production. This leads to higher stability of the agroecosystem through integrated pest control and higher economic resilience as the yield is distributed to two sources (Holmgren 2002) .

Principle IX: Use small and slow solutions

Functions are covered on the smallest possible level, while larger-scale functions are provided through replication and diversification. This principle includes the assumption that small-scale systems are potentially more intense and productive (such as marked gardening orgardening for self-sufficiency), while slow growing systems are potentially more stable and effective (such as tree-based systems) (Holmgren 2002).

Permaculture Principle X: Use and value diversity

This principle is based on the assumption that diversity is one of the foundations of adaptability and the stability of ecosystems. This is why, also in agroecosystems, the habitat and structural diversity should be maintained, as well as the age, species, variety, and genetic diversity (Holmgren 2002). Increasing biodiversity, in many cases of plant species, has positive effects on productivity in terms of producer and consumer abundance, on erosion control through increased plant root biomass, on nutrient cycling through increased mycorhizza abundance and decomposer activity and on ecosystem stability through increased consumption and in vasion resistance (Balvanera *et al.* 2006).

Principle XI: Use Edges and Value the Marginal:

Edges are potentially more diverse and productive, as resources and functions of both adjacent ecosystems are present. As in agroforestry systems, these edge zones can be increased on purpose totake advantage of this effect. Edge zones can also be planned as an appropriate separation of elements, such as woody strips in between meadows. This principle is also aimed at valuing margins for their often invisible advantages and functions instead of trying to minimize them (Holmgren 2002).

Principle XII: Creatively use and respond to change

Natural ecosystems are stable and resilient despite constant change and the influence of disturbances. The potential for evolutionary change is essential for the dynamic stability of ecosystems.That is why such systems should not be considered as being in a fixed state, but as an evolutionary process. The implications for agroecosystem design are to include flexibility to create resilience and to deliberately use natural change, such as succession (Holmgren 2002).

Permaculture and soil properties

Permaculture systems have largely been overlooked by soil scientists and have generally been ignored in scientific studies (Ferguson and Lovell 2014). Indeed, although there has been an increase in the number of

Table 1. OC concentrations and stocks in bulk soil (de Tombeur *et al.* 2018). Means with various letters are significantly different at the 95% confidence level (LSD Tukey); the error associated with the mean (n = 3) is given in parentheses (standard deviation). Corrected depth calculated as follows: Zcorrected sample = Zpasture * (δpasture / δsample), where Zpasture equals 10 cm and δ is soil bulk density in g cm^{-3}. Details can be found in section CStock Calculation.

Plot name	Total OC g kg^{-1}	Total N	C/N	Stone content %	Bulk density g cm^{-3}	Corrected depth cm	OC stock kg m^{-2}
Pasture	49.1(3.6)[c]	5.5 (0.4)[b]	8.9 (0.2)[c]	0.0 (0.0)	1.06 (0.11)	10.0 (0.0)	5.2 (0.4)[c]
Permaculture forest garden	60.3 (4.3)[b]	6.8 (0.3)[ab]	10.5 (0.5)[ab]	2.9 (0.4)	0.78 (0.15)	3.5 (0.4)	6.3 (0.5)[b]
Permaculture mounds	69.9 (0.2)[a]	6.2 (0.1)[a]	11.2(0.2)[a]	2.2 (0.1)	0.56 (10.7)	18.8 (5.8)	7.3 (0.0)[a]
Permaculture beds	73.0 (5.4)[a]	6.3 (0.1)[a]	11.5 (0.8)[a]	3.9 (1.7)	0.56 (0.12)	18.8 (6.2)	7.7 (0.6)[a]
Converntional agriculture	11.0 (0.9)[d]	1.1 (0.1)[c]	9.7 (0.2)[bc]	1.0 (1.7)	18 (0.22)	8.9 (3.5)	1.2 (0.1)[d]

Table 2. Soil bioavailable and exchangeable elements (de Tombeur *et al*. 2018). Means with various letters are significantly different at the 95% confidence level (LSD Tukey); errors associated with the mean (n = 3) given in parentheses (standard deviation).

Plote name	Bioavailable elements (mg 100 g $^{-1}$).				Exchange complex (cmol kg $^{-1}$)		
	P	K	Mg	Ca	CEC	Ca	Mg
Pasture	1.4 (0.3)^{b}	6.0 (1.1)^{b}	11.6 (1.2)^{c}	356.2(77.0)^{bc}	32.6 (2.5)^{a}	26.4 (8.9)^{a}	1.7 (1.4)^{ab}
Permaculture forest garden	45.4(18.6)^{a}	60.3 (9.0)^{a}	39.8 (7.9)^{ac}	877.4 (257.9)^{ab}	30.1(2.4)^{a}	30.1(2.6)^{a}	2.8 (1.0)^{a}
Permaculture mounds	23.1 (2.9)^{ab}	49.5 (3.1)^{ab}	32.8 (0.3)^{b}	796.4 (25.0)^{b}	32.4 (2.8)^{a}	35.2 (2.0)^{a}	2.7 (0.1)^{ab}
Permaculture beds	42.7 (9.0)^{a}	54.1 (36.0)^{a}	47.0 (2.3)^{a}	1346,6 (347.6)^{a}	33.4 (2.5)^{a}	35.3 (2.6)^{a}	3.4 (0.2)^{a}
Conventional agriculture	3.6 (0.6)^{b}	8.9 (0.7)^{b}	7.9 (0.9)^{c}	201.8 (57.9)^{c}	11.2 (0.6)^{b}	9.5 (1.7)^{b}	0.7 (0.1)^{b}

publications concerning permaculture since 2008, only 23.1% are about "life sciences" (Ferguson and Lovell 2014) and are even more rarely about soil science. Nevertheless, these systems have potentially limited impacts on ecosystems compared to conventional agriculture and have also proven to be economically viable in some cases (Morel *et al*. 2017).

Permaculture practices, characterized by significant and localized organic inputs, can sustain nutrient release (Kopittke *et al*. 2017, Sarker *et al.* 2018), while modifying OC stocks and distribution inaggregate-size fractions (Chenu *et al.* 2018). De Tombeur *et al*, (2018) observed that the permaculture practices largely increase nutrient bioavailability, as well as SOC stocks, in the surface layer of the soil. Soil Physical properties like aggregate-size distributions were modified by permaculture practices. Thus, permaculture practices enable the storage of additional C in soils which benefited soil physi-cochemical properties (essentially nutrient bioavailability and aggregation) (Tables 1 and 2).

Permaculture and livelihoods improvement

Didarali and Gambiza, (2019) highlighted that permaculture contributed over 40% to total income of permaculture practioner. However, permaculture was not the dominant source of income and periodically straddled multiple livelihood strategies. The main benefits of permaculture were identified as improved human health, increased resilience to environmental changes, and reduction of input costs. The key challenges included high labor input, infestation of pests and diseases, and lack of knowledge on permaculture practices. Although permaculture presents significant challenges, its integration with other forms of sustainable agricultural practices can contribute to improved rural livelihoods (Table 3).

Table 3. Benefits associated with permaculture for South African and Zimbabwean respondents (Didarali and Gambiza 2019).

Theme	Sub-theme	Description	South Africa (*n* =44)	Zimbabwe (*n* = 50)	X^3
Quality of life	Health	Eating more diverse foods, high nutritional intake	39	34	0.34
	Food security	Access to a variety of foods	27	27	0
	Well-being	Respect for nature and people	23	8	7.26**
Environmental	Long term sustainability	improves ability to address environmental problems : Increases resilience	33	33	0
		Use of local resources and reduced dependence on chemical input	18	26	1.45
Economics	Economic returns	Increased savings from reduced input	19	32	3.31
		High yields	11	14	0.36
		Affordable	6	2	0.08
		X^2	38.09***	39.51 ***	
		** p <0.01, ***p< 0.001			

Pros and Cons of Permaculture:

Pros	Cons
•Reduction in waste	Implementation of permaculture can be costly
•It can help to mitigate soil pollution	Short-term losses vs Long-term benefits
•Less air pollution	Farmers are not use to it
•Less groundwater pollution	Skepticism regarding this new concept
•Resources can be used quite efficiently	May conflicts with local customers
•Sustainable agricultural concept	Unwanted bacteria and pest may spread
•Self-production of energy	Religious concerns
•Use of renewable energy resources	Economic growth may be slow down
•Long-term process	Knowledge regarding permaculture is still rather limited
•Diversifying against risk	May not be sustainable for mass production
•Avoidance f chemical fertilizers and chemicals	Permaculture involves plenty of work
•Protection of natural habitats of animal and plants	May lead to unpleasant smell
•Mitigation of the endangered species problem	It takes time to see the benifits

CONCLUSION

Permaculture can be effective in supporting multiple objectives. It may help support livelihood activities and improve the ability of farmers to deal with environmental problems. It also holds the key to increasing dietary diversity within households and enhancing social and ecological resilience. Permaculture additionally includes principles to guide the design, implementation, and maintenance of resilient agroecological systems, such as observing and interacting to enable coping with change, using small and slow solutions and designing from patterns to details. This also shows that permaculture's central focus, in contrast to agroecology, is on the conscious design of agroecosystems, making it a possible link betweena groecological research and theory and practical implementation in agriculture. However, as with any agricultural system, it has its limitations. While permaculture on its own may not match the yields produced through conventional techniques, the prudent path towards reforming the global food system will require holistic approaches that have a neutral environmental effect and are economically viable. This implies a transition from conventional, monoculture-based and intensive production towards an array of sustainable regenerative production systems that improve productivity. Furthermore, shifting from a linear to a holistic approach in agricultural management is necessary. An approach that acknowledges the role of people as not mere producers of food, but also as managers of ecological systems that produce a suite of ecosystem services is needed.

REFERENCES

Balvanera P, Pfisterer AB, Buchmann N, He JS, Nakashizuka T, Raffaelli D, Schmid B (2006) Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecol. Lett. 9: 1146–1156.

Bennett EM, Carpenter SR, Caraco NF (2001) Human impact on erodable phosphorus and Eutrophication: A global perspective. *Bio Science* 51: 227–234.

Biggs R, Schlüter M, Biggs D, Bohensky EL, BurnSilver S, Cundill G, Dakos V, Daw TM, Evans LS, Kotschy K (2012) Toward principles for enhancing the resilience of ecosystem services. *Annu Rev Environ Resour* 37: 421–448.

Chenu C, Angers DA, Barré P, Derrien D, Arrouays D (2018) Increasing organic stocks in agricultural soils: Knowledge gaps and potential innovations. *Soil Tillage Res.* doi: 10.1016/j.still.2018.04.011. [Epub ahead of print].

De Tombeur F, Sohy V, Chenu C, Colinet G, Cornelis JT (2018) Effects of Permaculture Practices on Soil Physico-chemical Properties and Organic Matter Distribution in Aggregates: A Case Study of the Bec-Hellouin Farm (France). *Frontiers Environm Sci* 6. doi:10.3389/fenvs.2018.00116

Didarali Z, Gambiza J (2019). Permaculture: Challenges and Benefits in Improving Rural Livelihoods in South Africa and Zimbabwe.*Sustainability* 11(22): 19; doi:10.3390/su11082219 www.mdpi.com/journal/sustainability

Ferguson RS, Lovell ST (2014) Permaculture for agroecology: Design, movement, practice, and worldview. A review. Agronomy for Sustainable Development, 34: 251–274.

Ferguson RS, Lovell ST (2013) Permaculture for agroecology: Design, movement, practice and worldview. A review. *Agron Sustain Dev* 34 : (2):251–274. doi:10.1007/s13593-013-0181-6

Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, Mueller ND, O'Connell C, Ray DK, West PC (2011) Solutions for a cultivated planet. *Nature,* 478: 337–342.

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK (2005) Global consequences of land use. *Sci* 309, 570–574.

Gomiero T, Pimentel D, Paoletti, MG (2011) Is There a Need for a More Sustainable Agriculture? Crit. Rev. Plant Sci 30: 6–23.

Holmgren D (2002) Permaculture: Principles and pathways beyond sustainability. Hepburn, Vic: Holmgren Design Services.

Holmgren D (2002) Principles and pathways beyond sustainability. Holmgren Design Services, Hepburn, pp19

Kopittke PM, Dalal RC, Finn D, Menzies NW (2017) Global changes in soil stocks of carbon, nitrogen, phosphorus, and sulfur as influenced by long-term agricultural production. *Glob Chang Biol*. 23 : 2509–2519.doi: 10.1111/gcb.13513

Matson PA (1997) Agricultural Intensification and Ecosystem Properties. *Science* 277: 504–509.

Maye D (2018) Examining innovation for sustainability from the bottom up: An analysis of the permaculture community in England. *Sociologia Ruralis* 58 (2): 331–350.

McManus B (2010) An integral framework for permaculture. *J Sustain Dev* 3(3):162–174

Mollison B (1979) Permaculture two: Practical design for town and country in permanent agriculture. Tagari, Tasmania. Mollison BC, Permaculture: A Designers' Manual; Tagar iPubl: Tyalgum, Australia, 1992.

Morel K, San Cristobal M, Léger FG (2017). Small can bebeautiful for organic market gardens: an exploration of the eco nomic viability of French microfarms using MERLIN. Agric. Syst,. 158: 39–49.doi: 10.1016/j.agsy.2017.08.008

Morel K, Léger F, Ferguson RS (2018). Permaculture. Ref. Module Earth Syst. Environ. Sci. in press.

Pickerill J (2013). Permaculture in practice: Low impact develop ment in Britain. In J. Lockyer and J. Veteto (Eds.), Envi ronmental anthropology engaging ecotopia: Bioregionalism, permaculture, and ecovillage design for a sustainable future. pp. 180–194. Oxford, New York: Berghahn Books.

Permaculture Activist (2004) What is Permaculture? Permaculture Activist 53 (Autumn):3

Power AG (2010) Ecosystem services and agriculture: Tradeoffs and synergies. *Philos Trans R Soc Lond Ser B Biol Sci* 365: 2959–2971.

Pyhälä A (2013) In Search of Global Sustainability and Justice: How permaculture can contribute to development policy. In Lockyer J, Veteto J (eds). Environmental anthropology engaging ecotopia: Bioregionalism, permaculture, and ecovillage design for a sustainable future Oxford, New York: Berghahn Books, pp 195-212

Sarker JR, Singh BP, Dougherty WJ, Fang Y, Badgery W, Hoyle FC (2018). Impact of agricultural management practices on the nutrient supply potential of soil organic matter under long-term farming systems. *Soil Tillage Res.* 175: 71–81. doi: 10.1016/j.still.2017.08.005

Suh J (2014) Towards sustainable agricultural stewardship: Evolution and future directions of the permaculture concept. *Environm Values* 23(1): 75–98.

Telford R (2015) Permaculture principles poster. Permaculture Principles. http://permacultureprinciples.com/downloads/Pc_Principles_Poster_EN.pdf. Accessed 15 February

UN Environment (2019) Global Environment Outlook-6 (GEO-6). Healthy Planet, Healthy People 2019, 34–37.

Verma V, Tiwari P (2020) Permaculture: An approach to sustain ability in urban and rural context. *Res J Recent Sci* 9 (2):39-43.

Veteto JR, Lockyer J (2008) Environmental anthropology engaging permaculture: Moving theory and practice toward sustainabil ity. *Culture Agric Food Environ,* 30 (1-2): 47–58.

Wang HH (2013) Agricultural risks and risk management **in** the current context of Chinese economy. *Agric Financ Rev* 73: 245–254.

Whitefield P (2016) The Earth Care Manual: A Permaculture Handbook for Britain and Other Temperate Climates; Permanent Publications: East Meon, UK.

Williams BK, Szaro RC, Shapiro CD (2007) Adaptive Manage ment; US Department of the Interior, Adaptive Management Working Group: Washington, DC, USA

Zhang W, Ricketts TH, Kremen C, Carney K, Swinton SM (2007) Ecosystem services and dis-services to agriculture. *Ecol. Econ* 64: 253–260.