Sidestepping the Climate Change Juggernaut

The potential for staple crop polycultures and passive solar greenhouse systems to safeguard food security

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ABSTRACT

Root vegetable polyculture growing practices used alongside permaculture design inspired passive solar greenhouses offer a novel methodology for ecologically benign, efficient staple food crop production. These systems have great potential to address the issue of food security in the face of abrupt climate change and can serve as a tool for magininalized groups such as indigenous peoples to maintain their food security and preserve their botanical heritage, and, in doing so, safeguard the genetic diversity of rare crop species. This paper outlines how these systems can be used for these purposes and advocates further research and field study trials to develop practical methodologies and further theoretical understanding of permaculture inspired polycultures.

Keywords: Climate change, permaculture, polyculture, greenhouse systems

Juggernaut

"A large powerful force or organization that cannot be stopped" (Cambridge University Press, 2021)

Climate change is sometimes described as being like a juggernaut, some great unstoppable monstrosity careening downhill towards us. While it may not be possible to stop it or outrun it entirely, it may be possible to sidestep some of its effects. Climate change is already causing a great deal of disruption in countries around the globe, with extreme weather events becoming more severe and frequent. Perhaps the most vulnerable aspect of society in the face of this though is food production.

Our current predicament and potential strategies for adaptation

Conventional growing methods of field crops are likely to face markedly reduced yields in many parts of the world with abrupt climate change and in many locations may become completely untenable. The current trajectory for emissions may well see a 4 degrees Celsius rise in global average temperature by the end of the century, which will have profound implications for agriculture globally (Raftery et al. 2017, p.639). In addition to temperature increases, this will lead to more erratic weather patterns with an increasing frequency and intensity of extreme weather events such as droughts, floods, and heatwaves which will substantially affect agricultural yields at a time when there is increasing global demand (The World Bank 2012, pp.43-46). These conditions pose a severe threat to food security globally as grain crops, which are typically grown in vast monocultures and provide a substantial proportion of human caloric needs, are very vulnerable to these changes (John, 2021). For example, 40 percent of global calorie demand is currently provided by only rice, wheat & maize (FAOa, 2018). Climate could lead to 'multiple breadbasket failures', a simultaneous failure of these staple crops in the main grain-growing regions of the world, primarily focused in a handful of nations in the mid-latitudes such as the United States, Russia, and China (Janetos et al., 2017). The risk is already rising year on year and could lead to global food shortages (Rivington et al., 2015).

The main alternative to grains as a plant staple in human diets are root vegetables and tubers (Jones, Martin, and Pilbeam 2007, p.374). Though they often store less well and have higher labor input requirements than grains, they can provide calories in a much more space-efficient way with substantial yield differences per hectare compared to grain crops (FAOb, 1990). Due to their high yield density, they are also easier to grow efficiently in polyculture systems. These systems typically offer greater resilience to pests & higher yields than monocultures (Bracken 2008, pp.2446-2449). There are also several productive root and tuber crops that have traditionally been grown by indigenous peoples (Plants for a Future, 2012) that are currently rarely grown but which have promise to be grown commercially (Neacsu, 2019).

A range of farming methods and new crop varieties such as breeding perennial grains and genetically engineering crops to withstand greater drought are currently being developed to address the risk that climate change poses to food security (Mbow et al. 2019, p.471, 504). One strategy that has been proposed is growing crops in controlled environments such as greenhouses and vertical farms as one of the means via which food production can be maintained efficiently in such an inhospitable future climate (Chang, 2019). While such techniques have value, they typically have high energy requirements and are used to grow luxury vegetable, fruit, or salad crops which are important for human health but only provide a small proportion of global caloric requirements (Chang, 2019).

However, the stable conditions provided by greenhouse agriculture may prove invaluable with declining yields from outdoor growing in many countries in a rapidly changing climate. If greenhouse production can be used with much lower energy requirements than most commercial systems they may also have scope to grow plant calorie crops in the form of root vegetables and tubers. These can be grown much more space-efficiently than grains, which have too low a yield per unit area to be practical to grow at sufficient scale within greenhouse conditions.

Optimal strategies for promoting food security and reducing the ecological impacts of agriculture in the face of climate change

Globally, agriculture is responsible for approximately 11% of the world's total carbon emissions (Center for Climate Solutions, 2019). A range of initiatives such as developing heat-tolerant crop varieties and utilizing no-till growing methods have been put forward to reduce the impacts of climate change on agriculture and reduce agricultural pollution while maximizing labor efficiency and improving yields (Immenschuh, 2014).

Whilst conventional agricultural practices are making progress in improving levels of efficiency and resource conservation while also improving yields (Ritchie and Roser, 2019), less progress is being made with regard to conserving biodiversity (Schwägerl, 2016). Global loss of biodiversity is arguably the other great crisis of our time, interplaying with the effects of climate change. Such losses weaken the resilience of ecosystems, leading to the loss of traditional lifeways and means of subsistence for indigenous peoples around the world and undermines the overall worldwide capacity for food production (Barnosky et al. 2012, p.57).

Alternative methods of agriculture have been developed that put biodiversity at the heart of the system, namely Agroecology; "the application of ecological concepts and principles to the design and management of sustainable agroecosystems" (Tallarico, 2019). There are a variety of methodologies within Agroecology, with the general aim to maintain the high yields necessary for a growing global population while conserving biodiversity alongside general resource conservation and pollution mitigation. 'Biointensive Agriculture', for example, has been shown to provide high yields on a small land area, including assessments within an enclosed environment (Ecology Action, 2010) but requires very high labour inputs to obtain sufficient yields (Nauta, 2012).

Permaculture is a movement that has developed in parallel to Agroecology as a design methodology predominantly focused on food production and can be viewed as a perspective on the design of agroecological systems (Tallarico, 2019). It is a conceptual framework for evaluating and adopting existing methods (Krebs & Bach 2018, p.5) and is a site-specific and context-based design system (Krebs & Bach 2018, p.9). Though currently less well represented in the scientific literature, there is scientific evidence to support the individual design principles in an agroecological context (Krebs & Bach 2018, p.3). It can be defined as "the conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability, and resilience of natural ecosystems" (Tallarico, 2019).

Permaculture is a design system that was developed emulating patterns and features observed in natural ecosystems; it is based on a series of design principles that provide an accessible methodology for communities to improve their food security (Althouse 2016, p.10). The permaculture concept was co-founded by David Holmgren and Bill Mollison, who put forward the principles in 1974; these were more clearly defined into 12 principles in 2002 by David Holmgren (Althouse 2016, p.12). David Holmgren's work was based mainly on the work of Howard T Odum, an ecologist whose work was grounded in systems theory (Holmgren, 2003).

The standard 12 design principles were further organized into a design process, initially developed by Althouse (2016) to provide a framework within which they could be implemented when creating design solutions (Althouse 2016, p.72). This framework has also been recommended for use in Moran (2019) and Mempouo & Moran (2019). This framework can be used as a template for creating design solutions and is outlined below:

Table 1: Design Process Using Permaculture Design Principles

Inventory & Analysis	Determine Needs	Functional Diagrams	Concept Design	Final Design
Observe & Interact	Catch & Store Energy	Design from Patterns to Details	Use Small & Slow Solutions	Creatively Use & Respond to Change
Apply Self-Regulation & Accept Feedback	Obtain a Yield	Integrate Rather than Segregate	Use & Value Diversity	
Use & Value Renewable Resources & Services	Produce no Waste		Use Edges & Value the Marginal	

(Althouse 2016, p.28)

Permaculture also has the potential to provide a framework that can be used in a complementary way to traditional ecological knowledge to provide communities with a toolkit from which they can design their systems. As advocated in McCleary & Moran (2019), permaculture guild food forests have the potential to improve the food security of indigenous people in a changing climate. Such techniques can also be used to create guilds in the form of root vegetable polycultures, as proposed in this paper for further research, utilizing ecological principles to maximize yield (Wooldridge, 2016). One such principle is the 'Edge Effect', an ecological principle where there is a "tendency to have greater variety and density of organisms in the boundary zone between communities" (Lawrence 2000, p.183). This principle is utilized in permaculture food forests which seek to mimic the ecological productivity of a forest edge with plants growing at every level from tree canopy to ground cover, maximizing photosynthetic efficiency and crop productivity per unit area (Crawford 2010, p.29). This principle is noted in the permaculture process's concept design stage above as 'Use Edges & Value the Marginal'.

Such a principle could be utilized for root vegetable polycultures, for example, with crops grown in rows in a semi-circular structure such as a polytunnel oriented for maximal sunlight depending on geographical location. In such a setup, the tallest crop could be grown in the central row, with successively shorter crops in rows on either side to maximize the photosynthetic and space efficiency of production per unit area and grow a healthy diversity of species to minimize pest problems. This approach could also be utilized with standard beneficial practices such as crop rotation with legume polycultures, cover cropping, and other methods to maintain soil fertility alongside rooftop rainwater collection, and other design methods to minimize input requirements. Detailed crop species-specific examples are provided in the 'Case Study Examples' section below. Such a setup could also be used in a triangular shape for a structure, such as the example passive solar greenhouse below in Figure 1:

Figure 1. Passive solar greenhouse (Crook, 2021)

While there are a range of types of greenhouses, they are generally assessed according to their utility as the most appropriate tool for a particular set of growing requirements rather than any one type necessarily being viewed as superior to others. The majority of commercial greenhouses, for example, are large glasshouses that can provide very high yields of commercial crops. They also tend to have high energy costs for heating and cooling them due to the relatively poor insulation values of glass or polycarbonate coverings (Awad, 2012) compared to materials such as earth or brick which are typically constructed with supplementary insulation or features such as internal air spaces (Archtoolbox, 2022). New innovative technologies such as seawater greenhouses are also being developed (Sundrop Farms, 2016).

Passive solar greenhouses also offer great promise as a system to grow food in an energy and space-efficient manner, particularly in the context of climate disruption. In contrast to typical commercial greenhouses in which the walls and roof of the structure are all made of a transparent material such as glass, passive solar greenhouses typically have one or more sides made from an insulator material such as brick (De Decker, 2015). Passive solar greenhouses only use the sun's energy and innovative design solutions to maintain consistent temperatures for plant growth rather than relying on external energy inputs in the case of most commercial greenhouses. As such, they are designed for maximal efficiency, with one famous design being the 'Chinese Solar Greenhouse'. This design has a single exposed side facing the sun and the other sides are made of an insulator material such as brick, with passive ventilation and a cover that can be rolled down over the transparent side. The cover helps to retain heat at night or cool the greenhouse in excessive heat (De Decker, 2015), as can be seen in figure 2 below:

Their minimal energy requirements have even led to their promotion at the governmental level in China (De Decker, 2015); though they are currently not utilized to the same extent in most Western nations, they appear to have great potential as a technology globally.

Their lack of need for fossil fuels, low capital costs, and simplicity of construction have acted as incentives for this technology to be utilized on a large scale. The lack of fossil fuel requirements and low cost are particularly attractive in China where the 'Chinese Solar Greenhouse' design now covers over a million hectares (De Decker, 2015) and could, for example, be scaled up further to grow additional root vegetables as a replacement for declining grain yields. Passive solar greenhouse technologies have also been made use of on a small scale across the globe, being popular in the Permaculture movement and also utilized by the Aymara people of Bolivia who construct 'Walipinis', passive solar pit greenhouses (see Fig. 3 below), in which they can grow crops in highly arid conditions (Ceres Greenhouse Solutions, 2014).

Figure 2. Chinese Solar Greenhouse (De Decker, 2015)

Figure 3: Walipini (Ceres Greenhouse Solutions, 2014)

One of the main methods that such marginalized communities have also used to improve their food security is using permaculture, which is being promoted in many lower-income nations in the world, for example, in Malawi at the Kusamala Institute of Agriculture and Ecology (Kumbali, 2019). Such methods have been advocated for use in permaculture guild food forests to organize climate-resilient agriculture (McCleary & Moran 2019, pp.37-47). Such techniques could also be applied to use the permaculture design principles outlined in Table 1 to provide controlled environment growing conditions for staple root vegetable and tuber crops in structures such as Walipini.

Case Study Examples of Potential Root Vegetable Polycultures

Below is an example of a suite of crops that could be used for such a system using examples of traditional Andean food crops providing a generalizable template for further research. In this instance, being grown in a structure such as a Chinese Solar Greenhouse with the tallest crop species at the rear of the growing area and each successively shorter species being grown in rows in front to maximize efficiency:

- A row of mashua could be grown at the rear on a trellis; mashua is a climbing plant that provides both a leaf crop throughout the growing season and a root crop.

- In the next row forward, potatoes could be grown, as the next tallest crop species, with space between rows for weeding and maintenance.

- In front of this, oca could be grown, another productive tuber crop with a lower growing habit than that of potato.

- Ulluco, a root crop with a very low, spreading habit that is often used as a ground cover for weed suppression (Cultivariable a, 2022), could also be grown in complement with both the potatoes and oca.

Figure 3: Mashua, Potatoes & Oca in sequence (Cultivariable, 2013), (National Gardening Association, 2014), (Moran, 2021)

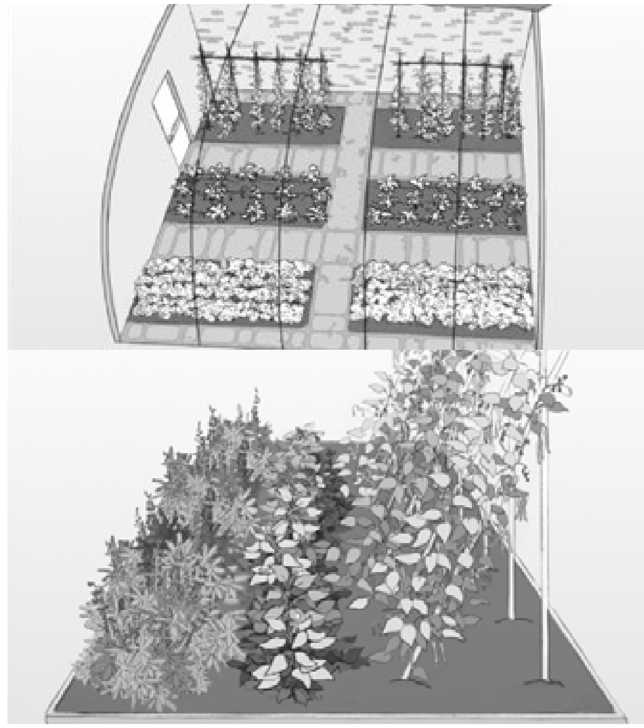
Figure 4: Ulluco ground cover (Cultivariable a, 2022)

This could be grown in rotation with a legume polyculture, alternating each growing season between the two to maintain soil fertility and minimize disease build up:

- Scarlet runner beans growing up the trellis at the rear of the greenhouse in rotation with the mashua, in addition to being a nitrogen fixing legume that produces a protein rich bean crop this species also produces an edible tuber
- A middle row of bush type French beans could be grown
- In the front, Tarwi, an edible lupin cultivated in the Andes could be grown in the front row as the shortest species. This plant produces a seed crop rich in protein and oils in addition to being a nitrogen fixer.

Figure 5: Runner Beans, French Beans & Tarwi in sequence (Gulisano et al. 2019), (West Coast Seeds, 2022), (Royal Horticultural Society 2007, p.2)

A full schematic is illustrated below as to what such a system could look like in profile, showing the two example polycultures in rotation in a Chinese solar greenhouse.



Tarwi, French Beans & Runner Beans in sequence

Oca, Potatoes & Mashua in sequence with Ulluco ground cover

Figure 6: Passive Solar Greenhouse Schematic (Howell, 2022)

The potential of root vegetable polycultures and passive solar greenhouses and scope for further research

This paper proposes an additional strategy to help provide food security and safeguard botanical heritage in the face of the biodiversity and climate change crises. Permaculture merits particular consideration as a set of design criteria as it aims to look at maximum energy efficiency as well as productivity (Bohler, 2017). In the context of staple crop production, this is especially pertinent as labor efficiency needs to be maximized as part of general efficiency. Whilst root vegetable and tuber crop production is space space-efficient, it also still needs to be done at scale, and agricultural labour is at a premium in many locations (Roser, 2019).

As outlined in the framework in Table 1, the permaculture design principles can be applied to crop production itself and the design, construction, and maintenance of structures to enable stable growing conditions in the face of abrupt climate change.

Food production in passive solar greenhouses has the potential to be simple, low cost, and energy-efficient, providing staples at scale in a hostile climate and, as such, merits further investigation. Whether utilized as a complete food nutrition system for a community, for local production of staples in a complementary fashion with other agricultural activities, or for supplementary income of cash crops, root vegetables, and tubers, polycultures in covered growing setups offer great potential. Its simplicity and replicability as a design system based on permaculture principles, with low costs, fast turnaround times and scalability, are also noteworthy for marginalized communities and agriculture.

It should also be noted that while biointensive methods have been investigated within a closed environment, there has so far been a lack of practical testing of such concepts within the context of permaculture (Jeavons 2001, pp.65-76). Such research could, for example, straightforwardly be conducted through multi-season comparative field trials between the indoor and outdoor growing of root vegetable and tuber crop polycultures and between polyculture and monoculture plots of each of the crops under investigation to compare respective yields.

Practical investigations of agroecological polyculture methods and solar-thermal greenhouse systems are required based on permaculture design principles. Both as a case study example of how those communities could safeguard such plants that indigenous peoples use for their benefit, and a more comprehensive application for the production of staple crops to safeguard food security more broadly. As part of a suite of adaptive measures, they may help us to mitigate the risk to food security posed by abrupt climate change and help us to sidestep the juggernaut.

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