Agroecological Analysis of a Polyculture Food Garden on the Adelaide Plains

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Abstract. Backyard polyculture garden systems have potential to improve the productivity, stability, sustainability and autonomy of the human food supply in and around cities. This report examines the theoretical basis for growing plants in a polyculture as well as the theory of designing agricultural systems that mimic natural ecosystems. An agroecological analysis is used to compare a backyard polyculture garden system with a model monoculture market garden system. This showed that while the monoculture market garden has high financial productivity, it falls short of the polyculture garden on the other measures of stability, biophysical sustainability and autonomy. Potential improvements to both the systems are discussed.

Introduction

In Australia it is well recognised that many of our current food production systems are not sustainable and can lead to negative on-site and off-site impacts (Pyper 2000, Hamblin 1996). Yet it is necessary to keep producing food for an ever-increasing population in a sustainable way. It is also essential for the conservation of many species of flora and fauna, that we limit the further spread of agriculture into natural ecosystems. So how is it possible to increase food production and make it more sustainable, economically, ecologically and socially, while limiting further destruction of natural ecosystems?

One possible answer to this question is the growing of food in backyard polyculture food gardens and forest gardens in and around towns and cities. Kass in 1978 (cited in Geno & Geno, 2001) states that polyculture distinguishes all of the multiple cropping situations from monoculture cropping and indicates that an area is being used for more than one crop at a time. For 98.5% of farming history, humans have produced food from integrated polycultures. It is only in the last one hundred years, and increasingly since 1945, that the large-scale production of food in monocultural systems has occurred and this has been mainly in developed countries. The majority of the world's farmers, particularly those in the tropical regions of the world, still depend for their food and income, on multi-species agriculture (Geno & Geno, 2001). Hart (1996) has suggested that small backyard polycultures and forest gardens, if well designed to mimic the structure and functions of a forest, are useful in providing a large variety of foods with the utmost economy of space and labour. Geno and Geno (2001) found evidence to suggest that polycultures can yield more from smaller areas than monocultures and their yield is more stable over time and space in terms of income level, stability and risk. While achieving sufficient production from a system is a necessary aim, Altieri *et al.* (1983) suggest that the central issue in sustainable agriculture is the long-term stabilisation of yields within the carrying capacity of the environment.

The complexity of polyculture systems, can make them difficult to assess. An agroecological analysis is one way of assessing complex agricultural systems. The science of agroecology, which is defined as the application of ecological concepts and principles to the design and management of sustainable agroecosystems, provides a framework to assess the complexity of polyculture systems. Agroecology goes beyond the use of alternative practices to develop agroecosystems with minimal dependence on high agrochemical and energy inputs. It emphasises complex agricultural systems in which ecological interactions and synergism between biological components provide the mechanisms for the systems for their own soil fertility, productivity and crop protection (Altieri, 2000). Nuberg *et al.* (1994) list five agroecosystem properties that have been suggested as being useful for analysing alterative agricultural ecosystems. These five agroecosystem properties are productivity, stability, sustainability, equitability and autonomy.

The aim of this project is to use four of the five agroecosystem properties outlined in Nuberg *et al.* (1994), to assess a working example of a backyard polyculture food garden in the Adelaide Region of South Australia. This will be compared to a model of a market garden monoculture, similar to those found on the Adelaide Plains, to determine what the benefits might be in producing food in a backyard polycultural system compared to a monocultural market garden system. The four agroecosystem properties used in this analysis are productivity, stability, sustainability and autonomy. It is believed that the agroecosystem property of equitability is not applicable to this analysis. Nuberg *et al.* (1994) give the following definitions and ways of assessing the four agroecosystem properties:

- *Productivity* refers to the outputs of the system that have direct market value. Productivity can be assessed as both financial productivity ($/ha/year) and labour productivity ($/labour day), provided that the price of domestically consumed food that is produced by the backyard system is included.

- *Stability* is more qualitatively assessed as fluctuations of productivity around a long-term average or trend. These fluctuations may be caused by climatic conditions or by pest and disease infestations but can also depend upon fluctuations in the prices of inputs and outputs.

- *Sustainability* is taken to mean biophysical sustainability. It refers to the depletive or regenerative effects of the agroecosystem on the biophysical resource base. This is measured first by the degree of soil degradation and second by the extent to which the biodiversity of the wild flora and fauna in the region is maintained.

- *Autonomy* refers to the degree to which materials, energy, and information flow between the agroecosystem and external ecosystems. An agroecosystem becomes less autonomous the more it relies on exogenous inputs. Significant inputs are water, agrochemicals, fuel, genetic material, finance, market information and technology.

There are several different ways of assessing the sustainability of alternative agricultural ecosystems. The four principals outlined in Nuberg *et al.* (1994) of productivity, stability, sustainability, and autonomy will be used for the purpose of this study but other methods of assessing systems and characteristics of sustainable polycultural systems are worth noting.

Discussion of agricultural production has evolved from a purely technical one to a more complex one characterised by social, cultural, political and economic dimensions. The concept of sustainability is controversial and diffuse due to existing conflicting definitions and interpretations of its meaning (Altieri, 2000). Holmgren (2001) believes that there is a natural currency we can use to measure our interdependence on our environment and assist us to make sensible decisions about current and future actions. That currency is energy. The energy laws governing all natural processes are well understood and have not been challenged by any of the revolutions in scientific thinking during the 20th century. These laws are called the first and second laws of thermodynamics. The first law of conservation of energy states that energy is neither created nor destroyed. The energy entering the system must be accounted for either as being stored there or as flowing out. The second law of degradation of energy states that in all processes some of the energy loses its ability to do work and is degraded in quality. The tendency of potential energy to be used up and degraded is described as entropy, which is a measure of disorder that always increases in real processes

(Holmgren, 2001). In all sustainable agricultures, and human cultures generally, the energy needs of a system are provided by the system (Mollison & Slay 1995). A continuous supply of free energy comes to planet earth from the sun. Holmgren (2001) poses the following questions, based around energy flows within and between ecosystems as a means of assessing the sustainability of food production systems:

- Does the system work to catch and store water and nutrients for as long as possible and as high as possible within its catchment landscape?

- How does it compare with the performance of pristine natural systems as well as wild and naturally regenerated ones, weeds included?

Holmgren (2001) believes that solar energy and its derivatives are our only sustainable source of life. This is supported by Ewel (1999) who states that natural ecosystems run on solar power and are thus self-sustaining. Forestry and agriculture are the primary, and potentially self-supporting, systems of solar energy harvesting available. It should be possible to design land use systems which approach the solar energy harvesting capacities of natural systems while providing humanity with its needs (Holmgren, 2001).

The Proposed Benefits of Polycultural Production

It is well recognised that large-scale monoculture food production systems are not sustainable and can lead to negative on-site and off-site impacts (Pyper 2000, Hamblin 1996). As well as concentrating on single species stands of a limited number of crops, many agricultural practices throughout the world depend on the annual tillage of soil. This disturbs the soil structure, making it more vulnerable to erosion and can cause a loss of fertility. Thus large inputs of fertilisers are needed to counteract these losses.

> Single-species, or monocultural plantings of annual plants lack weed, insect and disease resistance, encouraging the use of herbicides, insecticides and fungicides derived from petrochemicals. The ecological dangers and monetary costs of agriculture based on the extractive economy of petroleum-based fertilisation and protection has made research into new forms of agriculture necessary. Mixed-species, or polycultural, plantings of perennial plant species represent a viable alternative to annual monocultural forms of agriculture (Gomez, 1999, p.1)

A major proposed benefit of polyculture production is their yield advantage compared to monocultures. Geno and Geno (2001) found that polycultures were more efficient at gathering the essential requirements of light, water and nutrients than monocultures, particularly when tree based. In an extensive literature survey, they found evidence to suggest that not only do polycultures yield more total production than monocultures, they do so with greater stability and lower risk. They cite numerous examples where different polyculture methods have been found to yield 10% to100% more than monoculture methods. Yield advantages of polycultures are often correlated with the use of a greater proportion of available light, water and nutrients or by more efficient use of a given unit of resource (Geno & Geno, 2001). Will (1998) ran a trial that compared the productivity of cropping monoculture corn with the traditional Native American polyculture of corn, beans and squash. It was found that the polyculture treatments had significantly greater productivity, measured by plant mass per square metre, than the monoculture treatments. It has also been found that polyculture yield advantages are not restricted to low input conditions and that polyculture approaches are scale neutral and apply to any landuse system, from traditional intensive gardens to industrial mechanised systems (Geno & Geno, 2001).

Along with the yield advantage of polyculture systems, there are other proposed benefits. Jackson and Bender in 1984 (cited in Gomez, 1999) envision four significant benefits from an agriculture based on a polyculture of perennial species. These are zero net soil loss, less consumption of fossil energy, conservation and efficient use of water and pesticide redundancy. As well as protecting the resource base and making efficient use of energy, water and nutrients, polycultures are thought to suffer less from insect pest, disease and weed problems than monoculture systems. Perennial polycultures, utilise less soil disturbance, use canopy closure to shade weeds and use physical and chemical competition among root systems to reduce weed loads (Geno & Geno, 2001). Insect pest problems can also be significantly reduced. Geno and Geno (2001) cite two theories of plant/insect pest interactions that are thought to decrease the level of insect damage in polycultures.

The resource concentration hypothesis concerns the movement and reproductive behaviour of the pest insects themselves. Visual and chemical stimuli from host and non-host plants affect both the rates at which insects colonise habitats and their behaviour in those habitats. The total strength of the attractive stimuli for any particular pest insect determines what is called resource concentration and it is the result of the following interacting factors: the number of host plant species present and the relative preference of the insects for each, absolute density and spatial arrangement of each host species, and interference effects from non-host plants. The lower the relative resource concentration, the more difficulty a pest insect will have in locating a host plant. Relative resource concentration also influences a probability that a pest insect will leave a habitat once it has arrived. For instance, a pest may tend to fly sooner or farther after landing on a non-host plant than a host plant, which results in the higher emigration rate from polycultures than monocultures (Geno & Geno, 2001).

The enemies' hypothesis predicts greater numbers of insect predators and parasites in polycultures than in monocultures, which in turn better control pest populations. Polycultures supply better conditions for predators and parasites, reducing the likelihood that they will leave or become locally extinct. These conditions include: greater temporal and spatial distribution of nectar and pollen sources, both of which attract natural enemies and increase their reproductive potential; increased ground cover, which is especially important to some nocturnal insect predators; and more species of herbivorous insects that provide alternate prey when other prey are scarce or at inappropriate stages of their life cycles (Geno & Geno, 2001).

The resource concentration and enemies' hypothesis predict decreased pest populations in more diverse plant communities. Results from studies in this area have been mixed, but overall insect diversity is generally increased in polyculture systems compared to monoculture systems (Stamps & Linit, 1998). Based on numerous reports on pest population density in a variety of polycultures, Andow (1991) showed that 56 % of herbivorous insects had lower population densities, 16 % had higher densities and 28 % had similar densities in polycultures compared to monocultures. Andow (1991) also found that marginal benefits from arthropod pest control in polycultures could occur when polycultures have lower pest populations than monocultures, but that no benefit occurs when polycultures have similar or larger pest populations than monocultures. Thus in many cases, vegetational diversity provides some measure of crop protection from herbivorous insects. Polycultures may also contribute towards the management of insect borne diseases. Piper *et al.* (1996) studied the incidence and severity of viral diseases on a perennial seed plant, eastern gammagrass, when grown in monoculture and various polycultures with other perennial seed plants. They found that at one of the two study sites, in the early years of establishment, that the viral diseases where generally less severe when grown in polyculture with bundleflower. However, no treatment effects were observed at the second study site or after three years of establishment. The factors regulating pest, weed and disease incidence in polycultural systems are complex and are not easily extrapolated from one system to another.

In summarising the dynamic benefits of polyculture, Vandemeer (1990) lists the following benefits; they yield more, protect against risk, protect against pests, use available resources better, even out distribution of labour requirements and provide a more balanced human diet. The properties, principles, strategies and benefits of polyculture production as summarised by Geno and Geno (2001) and can be seen in table I. The emergent ecosystem properties in this table tie in with the five agroecosystem properties as outlined in Nuberg *et al*. (1994).

Table I. Properties, Principles, Strategies and Benefits of Polyculture Production

Emergent Ecosystem Property: Productivity	**Polyculture Principle: Intensify land use**
Strategy	**Benefit**
Produce more with less	Higher, more stable yield and income
Nutrient & maximise sunlight capture	Higher biological efficiency
Increase biological efficiency	Less waste, leakage
Higher land use diversity	Contributes to biodiversity conservation
More efficient utilisation of land	Higher energy efficiency
Apply to any land use	Integrate native and agricultural system management
Soil is always protected.	Enhanced soil and plant health with reduced erosion, decreased weed problems.
Emergent Ecosystem Property: Stability	**Polyculture Principle: Build diverse complexity**
Strategy	**Benefit**
Seek multiple benefit	Less market or yield risk & multiple values served
Integrate functions	Stability of yield, income resilience of agroecosystem
Increase complexity; Multiple function	Serves multiple values/produces multiple outcomes
Diverse crops for diverse markets	Income risk reduced
Diverse crops for variable climates.	Decreased climatic risk.
Emergent Ecosystem Property: Equitability	**Polyculture Principle: Polyculture is natural**
Strategy	**Benefit**
Both small and large, poor and rich can be polycultural	Higher social and individual diversity
Respect intuition and use traditional knowledge	Return of value in human instinct, expertise; Relearn lost skills, existing knowledge utilised
Apply to any climate/environment/enterprise scale	Socially just technique, widely applicable
Adaptable to varied sites & goals	Higher labour efficiency; optimum landholder options
Treat as opportunity, not vestige	Monoculture now seen as 100 year anomaly in a long history
Increase human presence	Increased employment; more knowledgeable land managers.
Emergent Ecosystem Property: Autonomy	**Polyculture Principle: Seek self-regulation**
Strategy	**Benefit**
Biotic process replaces external materials	Reduced input costs; reduced energy use
Internal nutrient and energy recycling	Reduced environmental impacts
Optimise resource capture	Improved resource use; inherent resource conservation
Seek farm self-reliance.	Reduced risk.
Emergent Ecosystem Property: Sustainability	**Polyculture Principle: Design analog land-use as ecosystem mimic**
Strategy	**Benefit**
Design from nature using ecological principles	Resilience of natural systems gained
Farm in nature's image	Existing ecosystems services used and maintained
Use pre-existing native vegetation as model	Agroecosystem persistence; natural strategies & processes retained
Use traditional knowledge of the place or from similar biophysical situations	Knowledge base utilised
Utilise natural and proven properties of ecosystem succession in production	Co-evolved complimentary production, reduced risk
Integrate native and managed ecosystem operation under common ecological theories	Integrated theme for management across all environmental wider landscape values met
Grow what is suited to the site.	Adapted production.

(Adapted from Geno & Geno, 2001, p. 85)

Polycultural Systems that Mimic Natural Ecosystems

Many current agricultural systems are not sustainable in the long term due to land degradation and the high levels of resource inputs involved in production. In Australia there is an increasing perception that achieving sustainable agriculture will require dramatic departures from current practices (Lefroy & Hobbs, 1998).

> We now have a chance to seriously work toward solving the problem of agriculture rather than constantly trying to solve problems in agriculture. It is feasible now for agriculture to be based on the way native ecosystems have worked over millions of years (Jackson, 1998).

A re-occurring theme in polyculture research is that the design of sustainable production systems should be based on the characteristics, such as the structure, function and diversity, of natural ecosystems (Geno & Geno, 2001). The natural ecosystems of any region are adapted to the key resource constraints and provide a site-specific model for sustainability if well mimicked by agriculture (Dawson & Fry, 1998). Natural systems are dynamic and sustainable as they have existed for millennia before Europeans settled in Australia. If we are to learn from natural systems we must apply the elements of any natural ecosystem; control of populations, recycling of nutrients and the efficient use of energy sources (Campbell, 1991). Table II shows the structural and functional differences between natural ecosystems and conventional agricultural systems. The goal in developing sustainable agroecosystems is to more closely mimic the structure and function of natural ecosystems.

Table II. Structural and Functional Differences Between Natural Ecosystems and Conventional Agricultural Systems

Characteristics	Agricultural System	Natural Ecosystem
Net Productivity	High	Medium
Trophic Chains	Simple, Linear	Complex
Species Diversity	Low	High
Genetic Diversity	Low	High
Mineral Cycles	Open	Closed
Stability	Low	High
Entropy	High	Low
Human Control	Definite	Not Needed
Temporal Permanence	Short	Long
Habitat Heterogeneity	Simple	Complex
Phenology	Synchronised	Seasonal
Maturity	Immature, Early Successional	Mature, Climax

(Adapted from Altieri *et al.* 1983, p. 46)

In southern Australia the development of agriculture has involved replacing predominantly summer active woodland, heath and forest communities with winter active annual crops and pastures. This asynchrony between the phenology of agricultural plant species and native vegetation has resulted in dramatic changes to the hydrologic cycle (Lefroy & Hobbs, 1998). This must be addressed urgently, if we are to develop sustainable agricultural systems in southern Australia.

The design of polyculture systems that mimic natural ecosystems is based on the application of the following ecological principles (Altieri, 2000):

- Enhancing the recycling of biomass, optimising nutrient availability and balancing nutrient flow.

- Securing favourable soil conditions for plant growth, particularly by managing organic matter and enhancing soil biotic activity.

- Microclimate management, water harvesting and soil management through increased soil cover.

- Species and genetic diversification of the agroecosystem in time and space.

- Enhancing beneficial biological interactions and synergism among agrobiodiversity components resulting in the promotion of key ecological processes and services.

These principles can be applied by way of various techniques and strategies. Each of these will have different effects on productivity, stability and resiliency within the farm system, depending on the local opportunities, resource constraints and, in most cases, on the market. The ultimate goal of agroecological design is to integrate components so that overall biological efficiency is improved, biodiversity is preserved, and the agroecosystem productivity is self-sustaining. The goal is to design a quilt of agroecosystems within a landscape unit, each mimicking the structure and function of natural ecosystems (Altieri, 2000). Many of the ecological principles listed above can potentially be met by incorporating trees into the system. Farrell (1987) lists the following benefits of tree based systems:

- Trees explore deeper soil profiles than most annual crops, and can access nutrients and cycle them back to the surface in leaf litter. Nutrient levels can also increase when trees are associated with nitrogen fixing bacteria or mycorrhiza.

- Trees create higher organic matter levels in the soil and can increase soil porosity and encourage stable soil aggregation.

- Trees reduce wind speed and in association with groundcovers can reduce raindrop impact and soil erosion.

- Trees moderate temperature extremes. Lower temperatures and reduced air movement leads to less evaporation and increased relative humidity verses open sites.

Added to this list is the function of trees and other deep rooted perennial vegetation in restoring the hydrological balance as being of great benefit especially in systems suffering from or susceptible to salinity problems (Lefroy *et al.*1992). It is accepted that trees can buffer some of the inter annual fluctuations in agroecosystems just as they do in natural ecosystems but the value to the farmer depends on the products which are obtained from the tree and the amount of competition with other components of the system. Competition between the components is less likely to be considered a problem if the components are given equal value, ie the products and services from the tree component is considered at least as valuable as the crop components (Van Noordwijk & Ong, 1999).

One of the key features of natural ecosystems is their high diversity at genetic, species and landscape levels. This diversity is seriously eroded under monoculture methods. Vietmeyer (1996) notes that although over 2000 species of plants have edible parts, only 12 crops now feed most of humanity. Discussions of diversity have tried to link increased diversity with increased stability in a system. There is significant disagreement on the relationship of stability and diversity in both natural and agricultural systems but the general view is that they are mutually complementary. Diversity enhances stability and stability facilitates diversification. Stability is viewed as a dynamic equilibrium rather than a static persistence (Geno & Geno, 2001). Diverse systems are able to compensate for the loss of individual species. The resources freed up by the loss of one species are taken up by another, thereby maintaining system wide performance and stability (Ewel, 1999). Altieri (2000) states that diversity is of value in agroecosystems for a variety of reasons:

- As diversity increases, so do opportunities for coexistence and beneficial interactions between species that can enhance agroecosystem sustainability.

- Greater diversity often allows better resource-use efficiency in an agroecosystem. There is better system-level adaptation to habitat heterogeneity, leading to complementarity in crop species needs, diversification of niches, overlap of species niches, and partitioning of resources.

- Ecosystems in which plant species are intermingled possess an associated resistance to herbivores as in diverse systems there is a greater abundance and diversity of natural enemies of pest insects keeping in check the populations of individual herbivore species.

- A diverse crop assemblage can create many microclimates within a cropping system that can be occupied by a range of non-crop organisms - including beneficial predators, parasites, pollinators, soil fauna and antagonists - that are of importance for the entire system.

- Diversity in the agricultural landscape can contribute to the conservation of biodiversity in surrounding natural ecosystems.

- Diversity in the soil performs a variety of ecological services such as nutrient recycling and detoxification of noxious chemicals and regulation of plant growth.

- Diversity reduces risk for farmers, especially in marginal areas with more unpredictable environmental conditions. If one crop does not do well, income from others can compensate.

Can we design diverse, persistent ecosystems? Computer modelling suggests that although persistent mixes are statistically rare, they are not hard to achieve, through successive addition and loss of species. Scientists from The Land Institute in Salina, Kansas, using a minimum of eight potential perennial grain crops, have been able to assemble a near weed free mix only three years after planting (Pimm, 1997).

There are many examples from around the world of both traditional and modern agricultural systems that mimic the natural ecosystems from their environments. Many of these systems have persisted for hundreds of years or more. Hanzi (2000) reports on a polyculture project in the drylands of Brazil, which is in part an adaptation of the traditional farming method of the region, which is itself, an imitation of the local ecosystem. The system incorporates a variety of legume trees to help fix nitrogen and provide woody ground cover from prunings to protect the soil during drought times. Many different plants are used in the system and include mulch and fodder plants, nitrogen fixers, short-term cash crops such as vegetables and a main cash crop of castor beans as well as crops for subsistence. All the trial plots in this project produced significantly better than conventional monoculture plots with one farmer doubling the regional average income per hectare.

Another form of polyculture production system that mimics the natural ecosystem is forest gardening or analog forestry, that is often practiced in the tropical regions of the world (Fernandes, *et al.*, 1984, Nuberg & Evans, 1993, Osentowski & Bane, 1997). Food production is the primary function and role of most tropical forest gardens. An aspect of food production in forest gardens is the almost continuous production that occurs throughout the year (Nair, 1993). Nuberg & Evans

(1993) give a good description of analog forestry as practiced in Sri Lanka. They state that analog forestry is the use of cropping systems that mimic the structure and successional processes of a tropical forest. Seasonal crops (pioneer species) are interplanted with a variety of perennials (climax crops) which come into production as they shade out the seasonal crops. Therefore, forest gardens are a densely planted, multi-story polyculture of useful and edible species that mimic the structure, function and diversity of a tropical forest. In his book on forest gardening, Hart (1996) lists seven cropping layers that occur in a typical forest garden. These are the canopy, mid-story, shrub, herb, ground cover, root, and climbing vines. Pacific Island forest gardens are based on a foundation of protecting and planting trees and are also structured with many layers. These systems made Pacific Islanders among the most self sufficient and well-nourished peoples in the world. The systems were managed and developed to meet not only the people's needs for food and other products, but also the needs of the system as a whole for fertiliser, mulch, animal fodder and shade. The trees in the system also provide protection from erosion, wind and salt spray (Thaman *et al.* 1999). Osentowski and Bane (1997) highlight the following principles as being important in the design of a temperate forest garden: the use of diverse polyculture plantings with an emphasis on perennials, the use of succession in both establishment and yield, dense multi-story plantings, little or no cultivation of the soil, the use of multi-functional plants, animals and structures, matching yields and needs of the elements in the system for mutual benefit, and close interaction between the resident/designer and the evolving system.

Forest gardens may be applicable in areas where forests once existed, but this is not the case in every area of the world. Wes Jackson and his colleagues at The Land Institute in the American Midwest have been working on a perennial polyculture food production system that mimics the native tallgrass prairie ecosystem. They are developing a system that is based on the energy input of contemporary sunlight rather than non-renewable fossil fuel. They have also found that some perennial plants are able to yield harvests comparable to the top annual domesticates. This research will go a long way towards reducing soil erosion and non-renewable energy use in grain production systems.

While the tallgrass prairie is a phenomenon of the American Midwest and tropical rainforests are a phenomenon of the tropics, natural systems agriculture acts as an uniting principal for all local ecosystems (Gomez, 1999). Altieri (2000) believes that diversified or polycultural forms of agroecosystems share the following features in common:

- They maintain vegetative cover as an effective soil and water conserving measure, met through the use of no-till practices, mulch farming, and use of cover crops and other appropriate methods.
- They provide a regular supply of organic matter through the addition of manure, compost and promotion of soil biotic activity.
- They enhance nutrient recycling mechanisms through the use of livestock systems based on legumes.
- They promote pest regulation through enhanced activity of biological control agents achieved by introducing and/or conserving natural enemies and antagonists.

Agricultural ecosystems that mimic the structure and functional complexity of natural ecosystems have the potential to play a crucial role for all societies. They already do in many tropical countries, and it may be those of us who have been spoiled by an excess of fossil energy riches that are going to need them the most (Ewel, 1999). Polycultural food gardens located in and around cities hold great promise for producing a fresh and varied range of food for people and do not rely on large amounts of non-renewable inputs for production or transport of the food to markets.

Description of the Polyculture Food Garden

The polyculture food garden used in this analysis is situated on Adelaide's coastal plain at Semaphore. The garden is about seven hundred metres from the waterfront on deep sandy soils. Semaphore has a Mediterranean climate with the moderating influences of the ocean. The average annual rainfall is around 500mm occurring mostly during the winter months. Two years ago the area now occupied by the garden was an unproductive couch grass tennis court. The garden covers an area of 350 square metres including paths and consists of mixed annual vegetable and herb beds as well as a mixed fruit orchard that is inter-planted with mulch plants, edible perennial shrubs, vegetables and herbs. Grape and passionfruit vines climb up the tennis court mesh that still borders the garden on the eastern and southern sides (see figure I for a layout of the garden). The intended purpose of the garden is two provide the two owners and their tenants with good quality fresh food, a pleasing environment and habitat for birds, lizards and other native organisms. The garden is run organically and no chemical pesticides or chemical fertilisers are used. The garden was developed by smothering the couch using a strip of black plastic that was moved across the garden when one area of couch was dead. When the couch had been killed, the area was sown to a green manure crop. This was incorporated into the soil to add organic matter to the system and then the area was heavily mulched with straw, compost, horse manure and newspaper. About two handfuls of rock phosphate were added to each planting hole for fruit and nut trees and several handfuls were spread per square metre of annual vegetable bed. Other soil amendments used during establishment include seaweed, wood ash and pigeon manure. Apart from compost and mulch generated on site it is envisioned that once the system builds up a level of fertility and appropriate nutrient cycling is in place that large additions of nutrients to the system will be unnecessary. The beds are never dug over and soil in the garden is rarely disturbed. This allows the soil structure to develop without any mechanical disturbance. The adverse effect of tillage on the stability of surface soil aggregates, over a wide range of soils, has been well documented in Australia (Tisdall & Oades, 1982). Many local acacias, such as *Acacia pycnantha,* have been included in the system. These are included to provide several functions, such as accessing and recycling subsoil nutrients, nitrogen fixation with the help of symbiotic bacteria, and the branches are lopped and used as mulch.

The Specht Vegetation Classification is one method of classifying vegetation in regards to its structure (Specht, 1972). The height and canopy density of the dominant vegetation at the site is used to classify the vegetation type. The Specht Vegetation Classification for the garden is based on the height and canopy density of the fruit and mulch trees. Currently the Specht Vegetation Classification for the garden is a Tall Shrubland, with shrubs two to eight metres tall and a sparse canopy with 10-30 percent cover. As the trees mature and their canopies grow closer together it is expected that the vegetation structure of the garden will develop towards a low woodland or low open forest with trees five to ten metres tall and canopies with 10-70 per cent cover. The structure of the garden can be compared to the structure of the local native vegetation to see how closely it mimics the local native ecosystem. A small area of remnant coastal vegetation exists near the garden. This highly disturbed patch gives a limited picture of the pre European vegetation of the region. The two main species at the site are *Myoporum insulare* and *Acacia sophorae,* both being shrubs around two metres tall with mid dense canopies of 30-70 per cent cover. The Specht Vegetation Classification for this vegetation type is Open Heath. The vegetation that existed on the Adelaide Plains before European settlement was Coastal Heath and Shrublands near the seashore with Woodland to Open Forest further inland. The Woodlands and Open Forests were dominated by *Eucalyptus camaldulensis, Eucalyptus leucoxylon, Eucalyptus viminalis* and *Eucalyptus odorata* with a herbaceous understorey. These trees were between 10-30 metres tall and had sparse to mid dense canopies of 10-70 percent cover (Specht, 1972). As the garden matures it will more closely resemble the structure of the pre-existing native ecosystem.

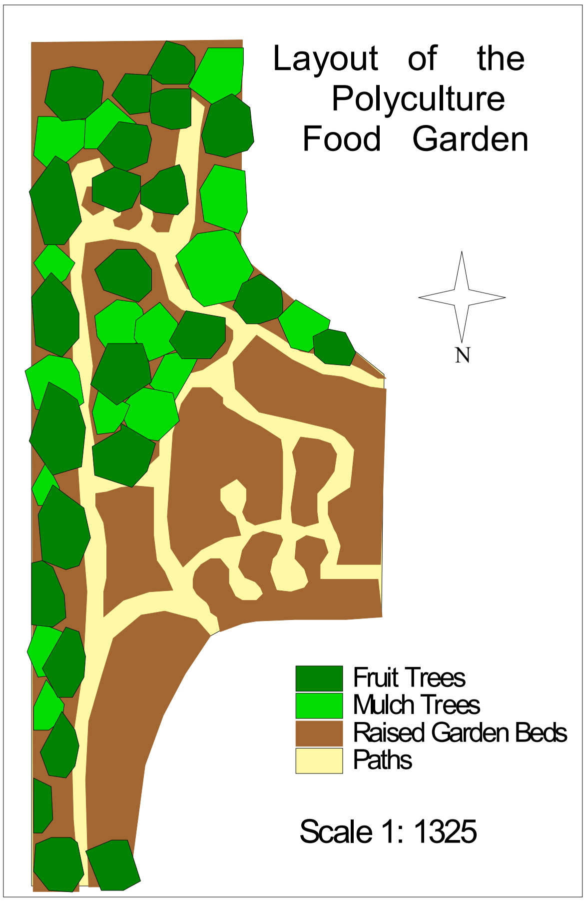

Figure I. Layout of the Polyculture Food Garden

Perennial and Annual Species found in the 350m^2 Polyculture Food Garden

Appendix A contains a list of the plant species counted in the polyculture food garden in mid March 2002. Not all species are utilised for food and many of them are included to provide mulch, habitat and a salubrious environment. The following plant densities are from the 350m^2 garden system. These plant densities have also been extrapolated out to an area of one hectare. There are 57 canopy trees in the garden. This equals 1628 trees per hectare comprised of 800 fruit trees and 828 mulch trees. There are 15 vines in the garden. This equals 428 vines per hectare. There are 40 perennial shrubs in the garden. This equals 1142 perennial shrubs per hectare. There are 24 perennial groundcovers in the garden. This equals 648 perennial groundcovers per hectare. There are 621 annual vegetables (603) and annual flowers (18) in the garden. This equals 17,742 annual vegetables and flowers per hectare.

Description of the Monoculture Market Garden

Vegetables are grown commercially throughout Australia. Most vegetables are grown on intensively cropped land. They may be rotated with grain crops and forage crops but are more often devoted exclusively to vegetable production. This may take the form of year round cash cropping, or rotation with cover crops or fallow periods (Henderson & Bishop, 2000). Most vegetables are grown after heavy cultivation of the soil, which leads to soil structural decline and enhances the chance of soil erosion. The five most commonly grown vegetable crops in Australia are potatoes, tomatoes, carrots, onions and lettuces (Salvestrin, 1991). Much of the vegetable production around

Adelaide occurs around Virginia on the northern Adelaide plains. The main field grown vegetable crops on the Adelaide Plains are potatoes, carrots, cabbages, cauliflowers and broccoli (PIRSA, 2002). Most growers on the northern Adelaide plains tend to specialise in growing one crop to supply the market continually. Potatoes and carrots are grown twice annually, while the brassicas are grown year round and harvested sequentially. Fallowing is used only by large growers with lots of land. Most growers will include a short rotation of rye sown as a green manure between vegetable crops. However this is usually too short to act as a disease break. (Howard Hollow, Senior Horticultural Consultant, PIRSA Rural Solutions, pers com. 13th May, 2002). Vegetable production is characterised by high outlays, particularly for harvesting and marketing of produce (Henderson & Bishop, 2000).

The vegetation structure that existed on the Adelaide Plains before European settlement was Woodlands and Open Forests with a herbaceous understorey (Specht, 1972). A market garden may mimic the herbaceous understorey for part of the year when crops are being grown, but they do not have the structure of woodlands or open forests. Market gardens often have bare soil for part of the year and do not closely mimic the structure of the pre-existing local native vegetation.

Agroecological Analysis of the Two Systems

A comparison of agroecosystem properties of the polyculture food garden and the monoculture market garden undertaken as part of this study are presented in table III. The reasoning behind the entries in this table is presented below.

Table III. Agroecosystem Properties of the Two Gardens

Agroecosystem Property	Polyculture Food Garden	Monoculture Market Garden
Financial Productivity	High	High
Labour Productivity	Low	High
Stability	Medium	Low
Biophysical Sustainability	High	Low
Soil Resource	High	Low
Biodiversity	Medium	Low
Autonomy	Low to Medium	Low

Productivity of the Two Systems

The financial productivity of the polyculture food garden is high. The financial productivity of the garden was determined by collecting weekly output from the garden, and extrapolating this out across the year. This was based on the number of plants yielding in the garden in any given month (See Appendix B) Also taken into account was the fact that the two owners obtained all of their fruit and vegetable needs from the garden from mid December until mid March, 2002 and did not need to buy any fruit and vegetables from the markets.

It must be noted that the plant counts used in this analysis were taken around two years after garden establishment and only trees that were currently yielding fruit were included. This excluded many of the citrus trees that make up a majority of the fruit trees in the garden. It is expected that as the trees mature there will be greater fruit yield and less annual vegetable yield due to shading and competition effects. It must also be noted that the prices used in determining the value of the produce were for retail organic produce as determined by a survey of various organic retailers from The Central Market. This value refers to the price that the owners would have to pay if they were to purchase produce equivalent to what they are growing. The financial productivity for the garden is $2630 per year. For the monthly yields see figure II. A conservative estimate of $500 a year for costs is taken off this amount to give a gross margin of $2130 per year. As the garden is only 350m^2, this figure needs to be converted to per hectare for comparison with the monoculture market garden. The gross margin for the polyculture garden is $60,857 per hectare. This seems like very high productivity but it comes at the expense of large amounts of labour.

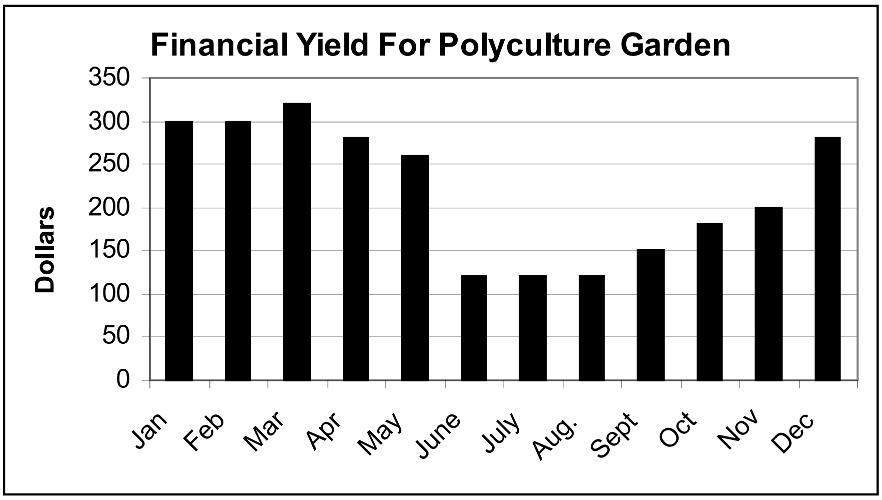

Figure II. Financial Yield for the Polyculture Garden

The labour productivity of the polyculture food garden is low. The average amount of labour spent in the polyculture garden is eight person hours per week or four hundred and sixteen person hours per year. The labour requirement is greatest in spring and autumn when planting of annual summer and winter vegetables occurs. Time spent observing the system was not been included in this analysis as it was considered by the owners to be relaxation time rather than labour. If the labour requirement is converted to per hectare, it comes to 11,885 person hours per year or 1485 labour days per year (eight-hour labour days). The labour productivity of the garden is determined by dividing the financial productivity of the garden by the labour days. This comes to $41 per labour day or $5.10 per hour.

The financial productivity of the monoculture market garden is high. This was determined by looking at the average gross margin per year for the four main field grown vegetable crops. In reality, the growers are likely to specialise in one or two crops. The gross margins used in this analysis were supplied by PIRSA and were from 1995. However, these were the most up to date gross margins available for the northern Adelaide plains. The gross margins for potatoes, carrots, cabbages and cauliflowers were used in the analysis. No gross margins were available for broccoli. It was assumed that two crops were grown each year and a simple rotation of potatoes, cabbages, carrots and cauliflowers was used (See Appendix C). This was then converted back to an average gross margin per hectare per year as well as the average amount of labour required. It must also be remembered that these gross margins refer to the prices paid to growers for conventional produce and are therefore considerably lower than the prices paid for retail organic produce. Table IV shows the gross margins and labour requirements for the various crops. The average financial productivity per year is $14,630 per hectare.

Table IV. Gross Margins and Labour Requirements for Vegetable Crops

Crop	Potatoes	Cabbages	Carrots	Cauliflowers
Gross Margin	$2,420	$13,000	$3,990	$9,850
Labour	85	200	100	382

The labour productivity of the monoculture market garden is high. The average amount of labour required is 384 hours per hectare per year or 48 labour days per year. The labour productivity of the garden is determined by dividing the financial productivity of the garden by the labour days. This comes to $305 per labour day or $38 per hour.

The productivity analysis gives some indication as to the productivity of the two systems. Another way to compare the productivity would be using the calorific value of the food produced from each system. However, this system would favour a system where large numbers of crops such as potatoes are grown and would not necessarily take into account the vitamin and mineral contents of the food. This process highlights the difficulty in assessing the productivity of complex systems.

Stability of the Two Systems

The stability of production in the polyculture food garden is medium. This garden relies on a large diversity of plant species to confer stability in the system. This can be seen in figure two, which shows the spread of yield throughout the year. There is production throughout the year with more production occurring in summer and autumn. As the system matures, there will be greater production, especially of fruit such as citrus, guava and tamarillo, in the autumn and winter. This will even up the production throughout the year. The garden uses locally available inputs such as pigeon manure, newspaper and composted prunings, as well other organic inputs and human labour. This means that the system does not rely on non-renewable resources to maintain production. Pests are dealt with by prevention, control and tolerance. Prevention involves having a diversity of plant species so pests of particular plant species never become to numerous and use of pest, disease and weed free planting material. If a pest species becomes a problem in the garden, it can be controlled by physical means such as hand weeding or removal of larvae, trapping of invertebrates such as snails and earwigs, mulching to reduce weeds, and some organically acceptable sprays such as garlic, chilli, and pyrethrum. A certain pest level is accepted or tolerated and a blemished fruit and vegetables are not discarded as they would be in a commercial system. Often the blemish is cosmetic or most of the fruit and vegetable can be utilised anyway.

The stability of production in the monoculture market garden is low. Current levels of production are only maintained by large inputs of non-renewable resources, such as fossil fuels, pesticides and artificial fertilisers. Reliance on synthetic fertilisers allows a population to grow beyond the natural carrying capacity of a region. This is an unstable strategy for feeding people over the long term (Crews and Gliessmann, 1991). Some enterprises in Australian vegetable production rely on practices with uncertain futures, such as soil fumigation and polyethylene plastic film for weed control. Others are dependent on a single herbicide option, which can lead to herbicide resistance in weed populations. These systems are also vulnerable to sudden withdrawal of chemicals from sale (Henderson & Bishop, 2000). These systems are also vulnerable to large fluctuations in commodity prices (Venton Cook, Economist, Primary Industries and Resources South Australia, Pers comm. 16th April 2002). This puts great pressure on the producers to increase yields in order to stay economically viable.

Biophysical Sustainability of the Two Systems

The biophysical sustainability of the polyculture food garden is High. The site is level with fences and trees surrounding the garden for wind protection and the soil is covered by a thick layer of mulch and vegetation and is rarely exposed. Wind or water erosion of the soil from the garden would be negligible. Mulched paths allow access to all areas of the garden without the need to step on the garden beds so compaction of the soil is unlikely. The soil resource has improved with the establishment of the garden. A drop penetrometer was used to measure the depth of penetration into the soil under a given pressure. This is a comparative measure of soil strength. The soil was well irrigated and then allowed to drain for two days to field capacity when the measurements were taken. This allows repeatable measurements to be taken over time to assess if the soil strength is increasing or decreasing. Twenty measurements were taken at random points in the small area of remaining lawn. This is a measure of how the soil was before the garden was put in. These were compared to twenty measurements taken at random points in the garden area. The weight on the penetrometer was raised and dropped ten times at each spot and the depth of penetration was recorded. The mean depth of penetration under the lawn was 9.9 cm and the mean depth of penetration under the garden was 17.9 cm. There was greater variation in penetration depth under the garden compared to the lawn. The data was analysed with a t-test for two samples assuming unequal differences. The hypothesised mean difference was zero. The t-statistic was statistically significant at a 0.05 level of significance, so it is concluded that there is a significant difference between the means. Thus, the soil under the garden was more open for root growth than the soil under the lawn.

The biodiversity conservation in the garden is medium. Many local native plant species such as *Acacia pycnantha, Carpobrotus* sp. and *Tetragonia tetragonoides*, as well as other native plants are integrated into the polyculture garden and some conservation of local flora occurs. Many of the hakeas and grevilleas used in the garden also provide a source of nectar for birds and insects. The total plant species diversity in the garden is very high. This provides a range of habitat for arthropods and other small fauna such as small lizards. An arthropod survey was conducted in the garden to compare the species diversity between the polyculture garden and the small remaining area of lawn in the backyard. Five micro pitfall traps were sunk in the lawn and five were sunk in the garden. These consisted of a 25mm diameter glass tube, half filled with 70% ethanol. These were left in the ground for 24 hours after which time, the contents of each tube were inspected and any arthropods in them identified. The total number of arthropods found in the traps in the lawn was 41 with a species richness of six. The total number of arthropods found in the garden was 59 with a species richness of 13. Simpson's Diversity Index was used to calculate the diversity of the two areas. This index calculates the probability of picking two organisms at random that are of different species. Simpson's Diversity Index for the lawn was 0.31 and for the garden was 0.7. This indicates that the garden has a greater number of species than the lawn and that the number of individuals within the species is more evenly spread. Clearly, converting the lawn to a garden has increased the species diversity of arthropods in the system.

The biophysical sustainability of the monoculture market garden is low. In Australia, soil used to produce vegetables is over tilled, over irrigated and over fertilised (Stirzaker, 1991). Irrigated market gardens have been found to impact on groundwater quality in many humid and arid regions. Overall, most of the impact is in increased salinity, followed by increased nutrients, such as nitrates, and the appearance of some pesticides (Pionke *et al.* 1990). Most market garden systems rely on tillage of the soil to prepare a seedbed. Tillage may also be used for weed control purposes or to prepare the land for a bare fallow. The adverse effect of tillage on the stability of surface soil aggregates, over a wide range of soils, has been well documented in Australia (Tisdall & Oades, 1982). Bare soil is also much more susceptible to erosion by wind or water. In potato growing areas, freshly worked soils are exposed at planting and post harvest time. It is at these times that the soil is at most risk of erosion (Soil Conservation and Management for Potato Growers, 1990). Chittleborough (1983) found that the sediment and nutrient loss from a catchment in the Adelaide Hills used for intensive vegetable production was more than ten times that for a native forest catchment and four times that for an urban catchment. Hollinger *et al.* (2001) recorded losses of 19 tons per hectare of sediment and large losses of nutrients from a market garden along the Hawkesbury-Nepean River in New South Wales.

Plant diversity in the monoculture market garden is low. While there may be diversity within the paddock, with several blocks of vegetables grown, there are little or no interactions between the species. Weeds are seen as a threat to production and are eliminated. There is very little biodiversity conservation within the production system, especially of indigenous flora and vertebrate fauna. Some areas of the paddock or farm may be set aside for biodiversity conservation but are not integrated with the production system. It was beyond the scope of this study to assess the arthropod diversity in a monoculture market garden. It is however expected to be considerably lower than a diverse system and certainly lower than the local native ecosystem.

Autonomy of the Two Systems

The autonomy of the polyculture food garden is low to medium. Significant inputs into the polyculture garden system include irrigation water from a bore and some captured rainwater, mulch materials such as newspaper, spoiled lucerne hay, pea straw, and chipped and semi composted tree branches. Several organic fertilisers and soil amendments have been used sparingly during establishment such as rock phosphate, liquid seaweed concentrate, kelp powder, some wood ash from the fireplace, horse manure, composted food scraps and pigeon manure collected from around buildings in Port Adelaide. Many of these inputs, such as newspaper, wood ash, spoiled hay and animal manures are currently considered waste material in our society. Once the level of fertility in the system is built up, along with internal cycling methods, the autonomy of the system will be improved. Initially large amounts of planting material and seed were added to the system. As the system has matured, there is a greater availability of planting material on-site for transplanting, striking cuttings and seed saving for re-sowing.

The autonomy of the monoculture market garden is low. Commercial market gardening relies on many inputs of fertiliser and pesticides in order to be productive, produce competitively priced and aesthetically pleasing produce for consumers, and to maintain stability in the system (Stirling & Wicks, 1975). Significant inputs into the system include water, chemical fertilisers, some animal manure and many applications of pesticides to combat weeds, insects and diseases. Fertiliser rates will vary depending on the soil type and past history but Salvestrin (1991) recommends rates of 140-240kg per hectare for nitrogen, a minimum of 20-30kg per hectare for phosphorous and 60-135kg per hectare for potassium. Most of the nutrients supplied to the system each year are exported from the site in produce or leached into subsoil and are effectively lost from the system. This is being reversed to some degree by the use of reclaimed wastewater for irrigation and the application of biosolids as a soil amendment (de Vries & Tiller, 1978, de Vries & Merry, 1980, PIRSA, 2000). These need careful management in order to prevent heavy metal contamination of vegetables (de Vries & Tiller, 1978).

Market gardening is one of the most intensive agricultural land uses in terms of water and nutrient use (Pionke *et al.* 1990). In market gardens on the sandy soils of the Swan Coastal Plain in Western Australia, where two to three vegetable crops are grown each year, irrigation rates are around 1500mm per year (Pionke *et al.* 1990). On the Northern Adelaide Plains, the main source of irrigation water has been from the Tertiary aquifers. This water source is now over utilised and degrading due to excess draw down and increasing salinity. This source of water is being replaced by reclaimed wastewater piped to the area from Bolivar (PIRSA, 2000).

Planting material, such as seeds and seedlings, are often brought into the market garden from outside suppliers each year (Salvestrin, 1991). The growing of vegetables in large-scale monocultures also relies on machinery and fuel, for tillage, chemical application and harvesting. If the food is destined for the domestic market in Adelaide it will travel up to forty kilometres from point of production to the market place. If the produce is destined for interstate of overseas export, this distance is considerably greater. Transport and refrigeration of vegetables is very energy intensive. On the other side consumers must go to the market place, often by fossil fuel powered transport and spend time purchasing their food. So the whole process of getting food to the table in a market garden system, while not quantified here, is far more energy intensive than in a backyard polyculture system.

Improvements in the Polyculture Garden System

The main improvements to the system involve becoming more autonomous with regards to inputs of water and nutrients. Irrigation with greywater can replace freshwater in many instances. Residential water use is almost evenly split between indoor and outdoor use. All wastewater except toilet water could be recycled outdoors achieving the same result with less water diverted from natural systems such as streams, rivers and aquifers. This has the added benefit that nutrients otherwise lost in the wastewater are retained in the soil and are available for growth (Ludwig, 2000). It is an ideal of the owners to try and balance the system so that nutrients cycle through the system rather than enter as mulch and leave as sewerage. A further possible improvement would be the addition of a composting toilet to allow the composting of all human wastes and their retention in the system. This would also serve to reduce water use. This technique combined with the growing of mulch on site and biological nitrogen fixation through the use of acacias and green manure crops could greatly reduce the need for imported mulch and fertilisers and make the system more autonomous. However, an assessment of the ability of various tree species in the system, such as *Acacia pycnantha,* to recycle subsoil nutrients would be a useful study. Schroth *et al.* (1999) studied the subsoil accumulation of mineral nitrogen under polyculture and monoculture tree plantations in Amazonian upland soil and found that not every tree species and management combination is suitable for the reduction of nutrient leaching and sub-soil losses. They note the importance of trees with deep root systems and management systems that encourage the formation of deep roots. There is also great variation between leguminous tree species in the amount of nitrogen fixation that occurs (Gutteridge & Shelton, 1993).

Improvements in the Market Garden System

Yields in monoculture market gardens are generally high and can produce good returns to the grower. However, as discussed above, this often comes at the expense of stability, biophysical sustainability and autonomy of the system. There is an urgent need to address this issue. Most of the issues relate to the degradation of the soil resource and the large amount of inputs required to maintain and stabilise production. Water use can be improved by changing from sprinklers to drip irrigation. Surface drip irrigation systems provide water savings of 20-40 % compared to sprinkler systems and can improve the yield and quality of the vegetables (Salvestrin, 1991). Pest management is another important issue. Pest problems in market gardens need to be managed without a sole reliance on chemicals. Integrated pest management is one approach that may provide a solution. This system of Integrated pest control seeks to identify the best mix of chemical and biological controls for a given pest species. Chemical controls are to be used in a manner that was least disruptive to biological control methods and only after regular monitoring indicated that a pest population has reached the economic threshold. The economic threshold is a level of pest abundance that requires treatment to prevent the population from reaching the economic injury level, at which economic losses exceed the cost of the artificial control measures (Ehler, & Bottrell, 2000).

The major concern in market garden systems is the degradation of the soil resource and fertility management. Much of the damage is caused by excessive tillage and leaving the soil surface bare. A number of techniques may be useful in improving the soil resource. These techniques are reduced or zero tillage, mulching, growing legumes in crop rotation and green manure crops. Reduced tillage is now widely used in broadacre crop production with many benefits to soil structure and conservation and increased yields in some cases (Wylie, 1993). Mulching and green manure crops are designed to increase the organic matter content in the soil with some additional benefits of protecting the soil surface, conserving moisture and suppressing weeds in the case of mulch. Growing legumes in a rotation can help to increase the nitrogen content in the soil and reduce the need for fertiliser inputs.

Converting market gardens from monoculture systems to polyculture systems can also have great benefits. In a commercial system, this is most likely to occur through interplanting a limited range of crops together, rather than a complex mix of species. This will help to keep the management relatively simple in a commercial system. In a series of mixed cropping experiments with vegetable crops, it was found that large yield advantages could be obtained by growing two crops together, rather than a single vegetable crop. This was believed to be due to a number of factors such as improved weed suppression, pest control and resource utilisation (Gliessman & Altieri, 1982). Future market garden systems that incorporate a range of these strategies should be able to maintain or improve yields while protecting the resource base at the same time.

Conclusions

This analysis has shown that backyard polyculture food gardens are very effective in providing ecologically sustainable food for people in and around cities and towns. These systems, if well designed are capable of supplying a large amount of the fruit and vegetable requirements of a household. This food is also supplied at a lower energy cost than food supplied by monoculture market gardens. It has also shown that conservation of biodiversity can exist with food production and that the soil resource can be improved. There is however, quite a large labour component in managing a complex garden system. This is expected to reduce as the system matures and the perennial crops come into production. The main improvements to the system would be becoming more autonomous with regards to nutrient inputs.

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Appendix A. List of Plant Species from the Polyculture Food Garden

Forest Layer	Scientific Name	Common Name	Number in Garden
Canopy	*Prunus persica*	Peach	1
	Prunus persica	Nectarine	1
	Prunus armeniaca	Apricot	1
	Citrus limon	Lemon	1
	Citrus sinensis	Orange Valencia, Navel, Blood	3
	Citrus sp.	Lemonade	1
	Citrus sp	Kaffir Lime	1
	Citrus aurantifolia	West Indian Lime	1
	Citrus x paradisi	Grapefruit	1
	Citrus x tangelo	Tangelo	1
	Citrus reticulata	Mandarin	4
	Ficus carica	Fig	3
	Musa sp.	Ladyfinger Banana	2
	Mangifera indica	Mango	1
	Carica sp.	Babaco	1
	Psidium guajava	Guava	1
	Diospyros sp.	Persimmon	1
	Casimiroa edulis	White Sapote	1
	Cyphomandra betacea	Tamarillo	1
	Annona cherimola	Cherimoya	1
	Acacia pycnantha	Golden Wattle	29
Vines	*Vitis vinifera*	Grapes	2
	Passiflora edulis	Passionfruit	8
	Hardenbergia violacea	Hardenbergia	5
Perennial Shrubs	*Solanum muricatum*	Pepino	8
	Salvia officinalis	Sage	1
	Rosemarinus officinalis	Rosemary	2
	Solanum aviculare	Kangaroo Apple	2
	Rubus idaeus	Raspberry	1
	Grevillea lanigera	Grevillea	2
	Grevillea sp.	Grevillea	7
	Geranium sp.	Geranium	3
	Hakea leucoptera	Hakea	1
	Callistemon sp.	Bottlebrush	3
	Boronia sp	Boronia	1
	Correa pulchella	Correa	1
	Lavandula dentata	Lavender	6
	Artemisia absinthium	Wormwood	1
	Chamelaucium uncinatum	Geraldton Wax	1
Perennial Groundcovers	*Canna edulis*	Arrowroot	1
	Origanum vulgare	Oregano	4
	Thymus vulgaris	Thyme	13
	Tetragonia tetragonoides	Native Spinach	1
	Cymbopogon flexuosus	Lemongrass	5

	Carpobrotus sp.	Pigface	1
	Rheum rhaponticum	Rhubarb	3
	Mentha piperta	Peppermint	1
	Mentha pulegium	Pennyroyal	4
	Allium tuberosum	Garlic Chives	13
	Fragaria sp.	Strawberries	40
	Kennidea prostrata	Running Postman	2
	Symphytum officinale	Comfrey	19
	Aloe vera	Aloe Vera	1
	Nepeta cataria	Catmint	1
	Achillea millefolium	Yarrow	3
	Chrysanthemum parthenium	Feverfew	1
	Melissa officinalis	Lemonbalm	2
Annual Vegetables and Flowers	*Capsicum annum*	Chilli	20
	Capsicum annum	Sweet Capsicum	7
	Solanum tuberosum	Potato	35
	Solanum melongena	Eggplant	30
	Eruca sativa	Rocket	50
	Lycopersicon esculentum	Tomato	22
	Helianthus annuus	Sunflower	4
	Cucurbita sp.	Pumpkin	13
	Cucurbita pepo	Zucchini	18
	Abelmoschus esculentus	Okra	4
	Phaseolus vulgaris	Climbing Bean	24
	Ocimum basilicum	Sweet Basil	36
	Lactuca sativa	Lettuce	15
	Zea mays	Sweet Corn	26
	Amaranthus hypochondriacus	Amaranth	6
	Cichorium intybus	Chickory	2
	Urtica dioica	Nettle	1
	Calendula officinalis	Calendula	13
	Tropaeplum majus	Nasturtium	1
	Brassica juncea	Mizuna	11
	Brassica oleracea	Broccoli	22
	Brassica oleracea	Brussels Sprouts	12
	Brassica oleracea	Cabbage	18
	Allium ampeloprasum	Leek	14
	Allium cepa	Onion	30
	Beta vulgaris	Beetroot	13
	Beta vulgaris	Silverbeet	17
	Vicia faba	Broad Bean	60
	Apium graveolens	Celery	12
	Daucas carota	Carrot	30
	Petroselinum sativum	Parsley	55

Appendix B. Spread of Yield throughout the Year in the Polyculture Food Garden

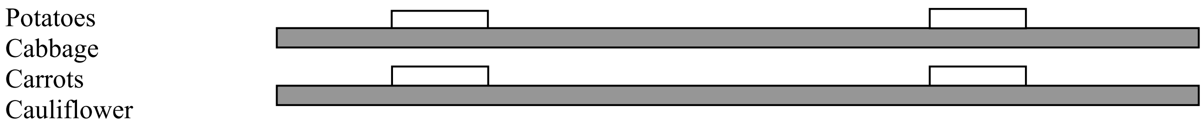
Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Median rainfall (mm)	21.0	10.7	20.5	37.2	53.1	58.6	69.6	62.0	50.8	44.6	28.0	28.7
Mean no. of rain days	5.0	3.4	6.0	9.1	13.0	14.2	16.1	16.7	13.5	10.7	7.4	6.6

(Climate data from Commonwealth of Australia 2000, Bureau of Meteorology)

Appendix C. Spread of Yield throughout the Year in the Monoculture Market Garden

Crop	Time in the Ground

Annual Vegetables



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(Climate data from Commonwealth of Australia 2000, Bureau of Meteorology)