applying polydome:

GREENHOUSE POLYCULTURES IN THE DUTCH CONTEXT
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metaboliclab

Stichting Innovatie Glastuinbouw Nederland

CONTEXT

This report is a continuation of the research on the polyculture greenhouse production system, Polydome, which was published in the spring of 2011 by Except Integrated Sustainability. The development of the Polydome concept and this continued research is supported by SIGN (Stichting Innovatie Glastuinbouw Nederland).

USING THIS REPORT

This report is intended to be a practical overview of strategies for polyculture cropping suitable to greenhouse production. The three polyculture designs are a starting point for broader thinking in this direction. They offer basic information on crop layout and planting cycles, but the grower will need to complete a detailed plan and cultivar selection.

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Introduction

symbiocultures: a pathway for greenhouse innovation

In 2011, a group of us at Except Integrated Sustainability, introduced Polydome, a greenhouse production model based on a new paradigm for agriculture called Symbioculture.

Symbioculture presents a radical departure from business as usual in agricultural production: rather than focusing on the idealized production of a single crop (as a monoculture), it instead proposes the production of many crops, fungi, livestock, and insects in a complex polyculture. It is designed to approximate some aspects of a natural ecosystem with self supporting plant and animal interactions, and the creation of ecological "niches" within the system that reduce need for mechanical and chemical interventions. Polydome was the first Symbioculture design for greenhouse conditions.

The original Polydome study was primarily commissioned to explore new pathways for greenhouse innovation in the Netherlands. The Polydome approach has many potential benefits both in terms of ecological performance (for example, the internal recycling of waste flows) and socio-economic benefit (the production of high, diverse yields for local retail sale). However, it also presents many new challenges in terms of production knowledge and marketing approaches.

APPLYING POLYDOME

After its publication, Polydome garnered worldwide attention in sustainability-focused media outlets and was a semi-finalist in the 2012 Buckminster Fuller Challenge. The pathway from concept to implementation remains complex. This study takes the ideas proposed in Polydome a step further and explores how and in which context they could realistically be applied to existing Dutch greenhouses.

Within this report we present three sets of crop combinations that illustrate the potential value of a polyculture approach to greenhouse producers. These crop combinations do not represent the full Polydome design, which includes layering of hydroponics with soil production as well as the inclusion of fish and livestock. The complimentary products from aquaculture and livestock production are essential sources of the original plan's profitability. The crop combinations in this document are instead an exploration of a potentially realistic step along the path from existing greenhouse culture to a different product and market approach. This approach focuses on diverse, local sales at high margins. It requires different kinds of labor inputs and more market coordination, but has the potential to bring higher profits directly to the producer if complimented with intelligent sales strategies.

OPPORTUNITIES FOR INNOVATION

As it has continued to mature, the Dutch greenhouse sector has rapidly consolidated, with the number of companies in the sector falling from over 16.000 in 1960 to around 6.000 at present. In recent years, the sector has also been under additional strain due to difficult economic conditions. Record numbers of greenhouse growers have registered losses in the past few years of economic downturn. Pressure from large food buyers like supermarkets has forced unprofitably small margins on food products, allowing only the largest operations to continue functioning comfortably.

Due to these combined trends, many greenhouses in the Netherlands now stand empty or have become unprofitable for their owners. These empty or unprofitable greenhouses represent an opportunity for innovation.

Most of the initial capital costs of establishing a greenhouse production facility are incurred in the design and construction of the greenhouse. Once these capital costs have been sunk, it is possible to re-purpose the greenhouse for new types of production that would previously have represented too much of a financial risk. With that in mind, the three polyculture designs presented in this report have been designed for year-round production in an existing greenhouse without supplemental heating or lighting.

THREE POLYCULTURE DESIGNS

These three polyculture designs give an indication of what is possible and what is needed to successfully shift to polyculture production. Two of the designs are for perennial cropping systems (one for greenhouse fruit tree production, and one for greenhouse berry production). The final design makes use of year-round annual plant production in both summer and winter conditions. It maximizes yield through high density plantings and a system of succession and relay cropping.

All of these designs focus on soil-based production for strategic reasons. Firstly, perennial crops cannot be cultivated hydroponically. Secondly, within the EU, in order to be classified as "biological," produce must be cultivated in soil. Because products cultivated in a polyculture can have a much better ecological profile than those cultivated otherwise, these products may also be ideally suited for eco-labeling, which presents an added reason to maintain soil-based production.

The three designs here are a starting point for testing and experimentation, both in terms of new products as well as new market approaches. Many variations on these designs are possible, and they can be further optimized for profitability and operational feasibility. From this starting point, more products can eventually be added, including livestock production, and hydroponic production can potentially be layered with soil-based cultivation.

MARKET FOCUS

Based on calculations of profitability, the strategy we recommend for transitioning to a polyculture production approach is a phased adoption process. Growers who currently produce a common commodity product such as tomatoes, peppers, eggplants, or zucchinis can scale down their existing production of these products and devote some of their greenhouse space to a more diverse set of products for local sale. Through this process, they can transition to building up a local market and retail sales channels, while also getting the additional benefit of selling some of their own standard produce at higher retail prices through these new channels. Such a local market development strategy can also be developed collectively by a group of growers to share the costs of marketing.

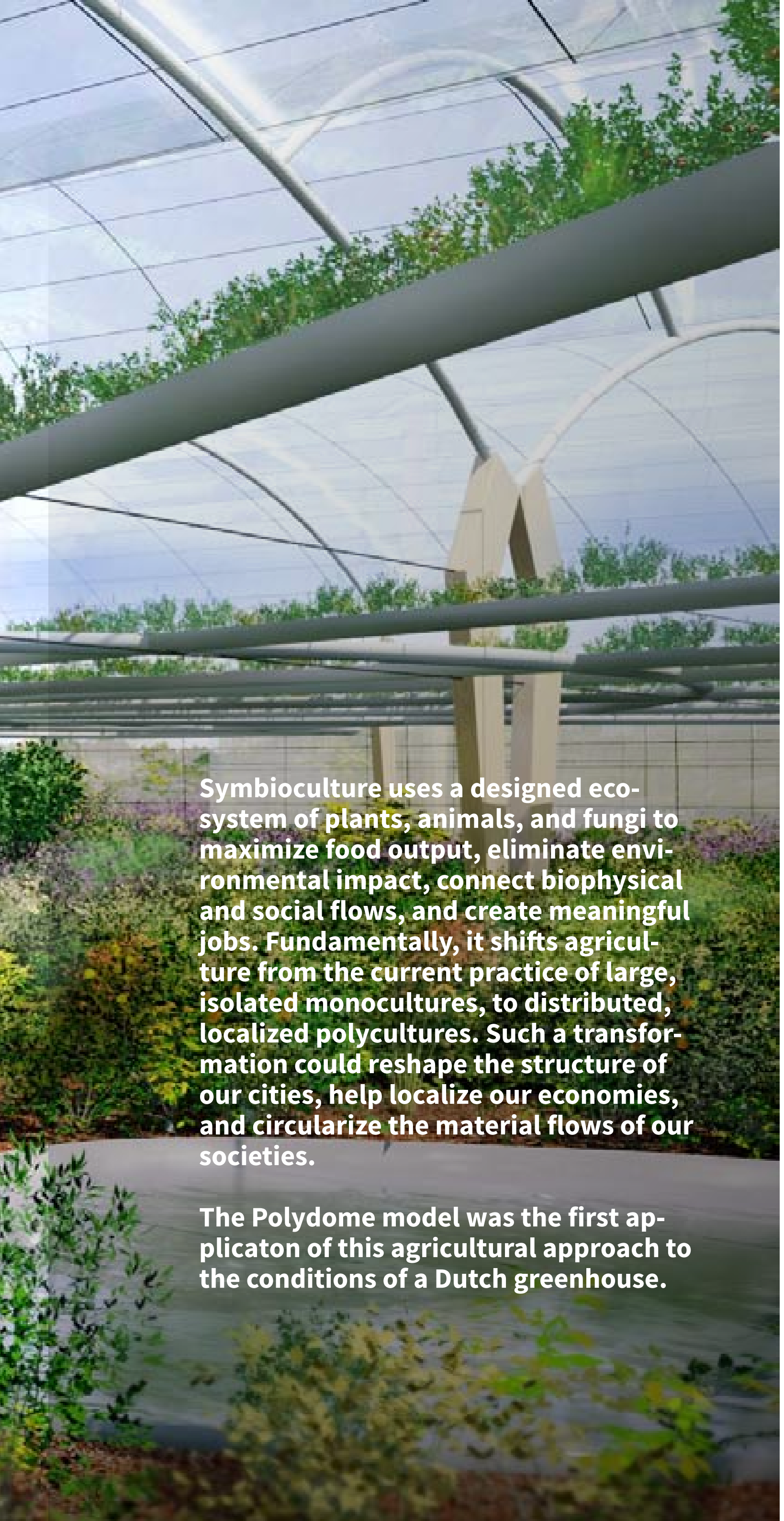
A prerequisite for the success of marketing products for local sale is to have a minimum diversity of products on offer. Without this, local sales approaches like a greenhouse shop or "vegetable packages" are not feasible. Successfully getting products to market remains the greatest challenge of this shift in paradigm.

MOVING FORWARD

The remaining challenge is for growers to begin adopting polyculture production. There is a world of opportunity in these new approaches to horticulture, which can bring connection with local clientele, greater economic stability, and a systemic change towards a more sustainable and regenerative agriculture.

applying polydome

symbiotic agriculture



Symbioculture uses a designed ecosystem of plants, animals, and fungi to maximize food output, eliminate environmental impact, connect biophysical and social flows, and create meaningful jobs. Fundamentally, it shifts agriculture from the current practice of large, isolated monocultures, to distributed, localized polycultures. Such a transformation could reshape the structure of our cities, help localize our economies, and circularize the material flows of our societies.

The Polydome model was the first applicaton of this agricultural approach to the conditions of a Dutch greenhouse.

In our calculations based on the original Polydome model, we estimated that such a polyculture system could produce four times the financial yields of a typical greenhouse monoculture. This would result both from higher yields due to beneficial crop interactions as well as new options for direct sales to clients.

The full Polydome model involves the implementation of many crops, fungi, aquaculture, insects, and livestock in one greenhouse. It is quite complex and involves some risk from the uncertainty of combining so many diverse elements at once. The potential benefits of this approach are, however, great enough that it merits further investigation and development.

One of the least certain components of the original Polydome model are the recommended “crop clusters,” which allow crops to be placed in close proximity to one another in order to increase symbiotic interactions.

There is a growing amount of research on the role of crop interactions on both yield and quality of produce. However, much of the existing information is also folkloric in nature. In designing the crop clusters recommended here we have gone through the existing scientific literature that uncovers the reason why these combinations work well, such as avoidance of root competition, pest repulsion, complementary crop maturity times, and other such factors.

The three crops sets worked out in this report are designed to make optimal use of polyculture design principles to maximize the ecological and economic functioning of the system.

BENEFITS OF POLYCULTURE

One of the core elements behind the Symbioculture approach is the use of specially designed crop polycultures in combination with additional components such as livestock and insects.

Polyculture cropping has been studied for decades and has certain known benefits. Some of these include:

- **Increased overall yields.** By stacking crops and combining them in space saving combinations, a single area can produces up to three times the amount of product for sale per year. Though yields of individual products may decrease, the overall production increases, which is why a focus on a retail sales channel is key to market success.

- **Reduced labor per crop.** Labor remains high in any agricultural system, particularly one focused on in-soil production and that requires manual work. However, relative labor per amount of crop output decreases in a polyculture design. Though pruning and harvesting labor remain the same, the labor required for site preparation, weeding, irrigation, and pest control are largely combined. One hectare of cultivation will have roughly the same site preparation and weeding demands whether it produces one or multiple crops.

- **Reduced pest damage.** When correctly executed, intercropping can reduce damage from pests by providing a mixed pattern of plants and slowing insects down when they are searching for their preferred food. Intercropping with beneficial "companion plants" can also repel pests. In the designs included here, marigolds are used to repel nematodes in the soil, which is a common problem in many soil-based greenhouses. Chickens are also often used as a natural pest control agent in polyculture systems since they do not damage vegetable crops, but bring added benefits: aerating soil through scratching and picking out pests.

- **Improved soil health and quality.** Different plants place different demands on the soil they are grown in. By cycling multiple plant types in annual crop rotations and interplanting crops, the depletion of soil can be reduced and beneficial communities of aerobic organisms can be supported. Growing mushrooms in soil along with plants has also been shown in certain trials to have great benefits for the soil quality and plants' ability to absorb nutrients.

- **Connecting material streams.** In a complete polyculture that has both crops and livestock, "wastes" created within the system can be reused internally in a nearly complete cycle. For example, plant waste can be reused as mulch or fish feed, while animal wastes are processed into nutrient supplements.

- **Reduced need for technological interventions.** A full polyculture system also reduces the need for certain costly technological interventions. Rather than shading plants using mechanical screens, shade-loving plants are intercropped below plants with a high demand for direct sunlight. In a similar fashion, supplemental CO_2 is provided by mushroom cultivation, chickens, and composting rather than by CO_2 generators or the combustion of fossil fuels.

GREENHOUSE POLYCULTURE

Applying these principles within a commercial greenhouse presents additional unique advantages and challenges.

Some of the primary advantages include season extension through the controlled climate and the avoidance of many pests (particularly birds). The greenhouse structure can also be used to add additional hanging elements and effectively create more "layering" within a polyculture.

Some challenges include dealing with the relatively closed conditions inside a greenhouse, which can concentrate pests and prevent the natural flow of beneficial insects into the space. Along these lines, natural pollinators, such as bees and butterflies, do not generally do well inside greenhouses. As a result, some of the benefits of the polyculture approach are lost.

Another limitation of the use of polycultures in greenhouse conditions is the fact that greenhouses are typically costly to operate and maintain, and as a result, it does not always make economic sense to grow many low-value crops within a greenhouse even if it is of benefit to the polyculture. For this reason, a complete Symbioculture would ideally include both indoor and outdoor horticulture in combination.

Pictured above is a vineyard row cropped with fava beans. In the same amount of space devoted to a single crop in traditional monoculture, the grower can harvest and sell two successive crop yields.

A common practice in outdoor polyculture systems is to use chickens for weeding and pest control. This approach has also been used successfully in several greenhouses (for example, at Kainga Farm in Venlo).

POLYCULTURE DESIGN PRINCIPLES

Above is an example of an intensive companion planting arrangement, showing how much diverse productivity can be achieved in a single area. Root, light, and nutrient competition is a factor, but can be minimized through appropriate pairings. When practiced outdoors, polyculture also attracts beneficial pollinators.

The basic principles of polyculture design have been thoroughly developed through the years. Some of these are summarized here to give a quick overview of how a polyculture can generate benefits for greenhouse production.

MAXIMIZE COOPERATION, MINIMIZE COMPETITION

Plants are co-located based on their physical and biochemical properties. Plants with deep root structures are generally paired with shallow-rooted crops to avoid root competition. Timing is also an important factor: early maturing plants can be co-cropped with later maturing ones. An example of this practice is planting radishes and lettuces in the same bed. The radishes mature early and can be harvested from in between the lettuces, allowing them to fill in the space left behind the radishes as they mature.

DIVERSE FUNCTIONS

Every polyculture design should make use of several different element types that complement one another and together make the complete system function. These elements include:

- **Producers.** These are the productive crops which produce harvestable yields.
- **Nitrogen fixers.** Legumes are the primary nitrogen fixers in polyculture, bringing valuable nitrogen back into the soil in usable form to other plants.
- **Dynamic accumulators.** Plants such as comfrey pull valuable nutrients (and micro-nutrients) from deeper layers of soil. These plants can be used as mulch or turned into compost to provide a boost in nutrient availability for neighboring plants.
- **Ground covers.** Using plants to cover otherwise bare ground is a useful way of maintaining moisture, preventing weed growth, and, in the case of nitrogen-fixing ground

covers such as clover, increasing the nutrient content of the soil.

- **Pest suppressors.** Certain plants generate pest suppressing compounds and can be strategically intercropped to provide protection to their neighbors. For example, plants in the allium family (onions, garlic, leek) are generally pest repellent due to their strong odor.
- **Structural support.** Some plants can be used as natural trellises. A well known example is growing corn together with beans, allowing the bean stalks to climb the corn. Competition for nutrients is minimized because beans fix nitrogen in the soil. Trees can also be used as a structural support.
- **Shading, windbreaks, shelter.** Shade loving plants can be grown underneath bushes, trees, or taller plants. This creates a natural micro-climate without the need for mechanical shading.

ECOSYSTEM STABILITY

Some polyculture principles that particularly apply to outdoor cultivation include:

- Reducing tillage and soil disruption to reduce the growth of weeds and maintain a living soil structure.
- Maintaining 'permanent' ground covers in untilled areas to improve soil structure, retain moisture, and reduce unwanted runoff of nutrients.
- Using cover crops under perennials to increase moisture retention. Ideally these are also nitrogen fixing cover crops.
- Increasing crop diversity to disrupt pest growth.

INTEGRATED PEST MANAGEMENT

Integrated pest management is a goal of polyculture design. Stress is applied to pests by interrupting their life cycle, removing alternative food sources, and enhancing populations of beneficial insects.

To maintain biological crop production, agrochemicals are avoided. As suggested in the designs here, leaving greenhouses unheated in winter can also help disrupt some pest populations by reducing favorable conditions for their survival. Regular crop rotation also breaks the reproductive cycle of pests.

ASSEMBLAGE CONSIDERATIONS

Key factors in designing a successful polyculture are how crops and other elements are arranged within the system. All elements should be easily accessible when needed.

Time also plays a factor in ideal spatial arrangements. Companion plants can be planted near trees, blocking easy access to the tree, as long as they are harvested before the fruit from the tree itself needs to be harvested.

Nitrogen fixers:

- clovers
- eleagnus
- acacia
- beans
- peanuts
- vetch
- alfalfa

Dynamic accumulators:

- comfrey
- nettles
- yarrow
- borage
- chicory
- dandelion

Ground covers:

- alyssum
- clover
- yarrow
- mint
- strawberries

Pest suppression:

- alliums
- dill
- coriander
- parsnip
- anise
- cumin
- carrot
- most herbs
- marigolds
- calendula

Insectary:

- borage
- lemon balm
- alyssum
- clover
- comfrey
- fennel
- linden

Windbreaks / shelter

- sunchoke
- fig
- loquat
- mulberry
- acacia
- elagnus

pathway to innovation

making greenhouse polyculture profitable

The Polydome model represents a potential pathway for innovation and greater profitability for greenhouse growers by creating opportunities for local sales at prices closer to retail standards. However, several challenges remain in achieving this greater level of profitability.

Beyond the additional practical knowledge required for polyculture production, growers will need to develop new skills in branding, marketing, and creating their own sales channels. This cultural shift will require a new mental framework.

The Dutch greenhouse sector has one of the world's best track records for process innovation. Over the past decades, improvements in production methods have led to constant improvements in production outputs and efficiency, increasing production volumes and driving prices down. This condition has resulted in sales of larger quantities of product at lower profit margins, and progressively reduced grower earnings.

Adopting a polyculture approach requires innovation across multiple categories: process, product, and market. Innovating across these categories can effectively rejuvenate the Dutch greenhouse industry, bringing it to an earlier state of market maturity when profits were higher and the sector was more dynamic. Polyculture offers opportunities to develop closer relationships with local customers, sell products under new unique brands tied to the point of sale, create "product bundles," and make direct use of new technologies and social media to boost sales.

If these marketing and product innovation efforts are executed correctly, the could bring great benefits to growers in terms of profitability. However, the polyculture approach also comes with a steep learning curve and substantial risk.

POLYCULTURE: BEYOND PROCESS INNOVATION

For the last several decades, the Dutch greenhouse sector has led the world in technological innovation, efficiency, and high yields. Innovations in the sector have mostly focused on process-oriented improvement, leading to cheaper and more efficient production, but for only marginal increases in profit. As these process improvements have diffused throughout the sector and around the world, product prices have continued to fall, turning the business into an efficiency game.

As reported in a recent study by Hekkert and Farla (InnovatieNetwerk, 2010), this focus on process innovation is a natural trend in a maturing sector. Once a production approach is working and successful, the tendency is to continue down that path and perfect it. As evidenced by recent trends in the sector, this approach ultimately leads to market uniformity and a downward price spiral.

Another indication of the aging of the Dutch greenhouse sector has been the consolidation of the market (shown in the graph at right). Since the 1960s, the number of companies in the Dutch greenhouse horticulture sector has fallen from over 20.000 companies in 1960 to around 6.000 currently. This trend is projected to continue, with the number of companies falling to as low a number as 1.000 in the coming decade.

Combined with the recent economic climate, these converging factors have placed the Dutch greenhouse sector under stress, with profits generally decreasing and companies going out of business.

REVITALIZING THE SECTOR

A different approach to innovation is clearly needed for Dutch horticulture to maintain its global competitiveness and health. The Hekkert and Farla innovation study made two primary recommendations for how trends in the sector could be reversed: shifting focus from process innovation to product and market innovation, and getting closer to their consumers by developing identifiable personal brands.

In some regards, these suggestions require the Dutch greenhouse sector to re-enter an earlier stage of development where experimentation and new products are once again part of the core approach. Innovation isn't easy. It requires risk, investment, and usually failure. With these cautions mind, it can be approached in an intelligent way.

POLYCULTURE AS A PATH TO INNOVATION

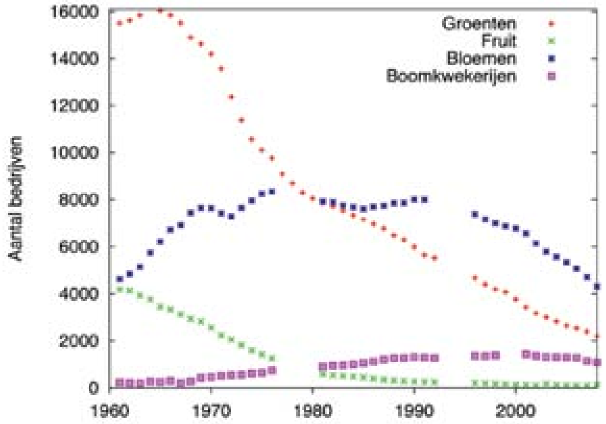
Robert de Jong, from tomato producer Looije Tomaten, recently told of his company's product and market innovation strategy with their product "Honing Tomaten." They have focused on creating the highest quality, best tasting, pesticide free tomato that a consumer can buy. They sell it only through to smaller greengrocers at a premium price (around 10 euros per kilogram).

They have been very successful in marketing their product, which is recognized for its quality and has developed a following among a group of consumers. They have even been cleverly using social media: offering customers shots of vodka and a tomato chaser at festivals and events, and allowing them to view their photo on the Looije facebook page. By including a prize for the portrait with the greatest number of "likes" they were able to greatly increase their online traffic.

The branding effort that Looije Tomaten has devoted to to a single product can also be applied to a whole production facility. A local polyculture greenhouse with a range of very fresh products catering to a local population can be marketed as a product in itself. By building a brand around a whole production facility, the benefits of the branding extend to multiple products. This opens the window for new products to be introduced under this brand over time with only a marginal extra effort needed for the marketing of each new product.

Transitioning to a polyculture focused production system requires innovative thinking both in terms of products and marketing strategies. The goal is, in many ways, for farms to replace supermarkets, and develop true relationships with local customers. By communicating with these customers, growers can also begin to create more responsive production facilities that supply specialized products that their customers want and are willing to pay for.

Greenhouse harvests can also become an opportunity for inviting the local community into the production facility to see where their food is made. In the case of the perennial polycultures described later in this document, customers can even have the opportunity to harvest their own berries once or twice a season. This could become both a cost saving strategy (reduced harvest expenses) as well as a marketing approach: bringing customers closer to home. Hundreds of new, creative opportunities for using social media and local, direct marketing have opened up in the last decade, all of which coincide with the potential shift to polyculture.



Trend of consolidation in the Dutch greenhouse sector. (Innovation Network report: “Het innovatiesysteem voor de glastuinbouw in 2020, authors: Marko Hekkert and Jacco Farla. Data source: Productschap Tuinbouw and LEI, 2010)

OPPORTUNITIES & APPROACHES FROM POLYCULTURE

Moving to a polyculture focused approach to greenhouse production requires an entirely new market strategy from existing wholesale production. This switch can in many ways be considered more of a marketing challenge than a production challenge. The list below outlines some opportunities and approaches for product differentiation and market innovation that naturally occur in the shift to polyculture.

- Increase product portfolio to sell products to local consumers: sell lower quantities of product at higher prices.
- Collective product marketing for local sale (sharing risks and marketing costs between growers).
- Make use of new technology to match customers with their desired products. For example, create an online community of customers where they can vote for their favorite products, assemble customized “vegetable packages,” and pre-order products at a guaranteed price. Use this data to automatically adjust production plans each year.
- Build local markets by offering the same products consistently year-round through winter greenhouse production, but also emphasize the value of a seasonal sales pattern in marketing efforts.
- Cater to local tastes: develop new products as test cases and add them into the production mix.
- Develop relationships with local customers ensuring their loyalty even in times of crisis.
- Use sustainability credentials and local production for product differentiation.
- Create targeted product collections (salad mixes, stir fry mixes, fruit pie mixes, etc.) for bundled sales.
- Sell “mix and match” vegetable packages, allowing customers to exchange unwanted items at the shop and giving them a chance to buy added goods.
- Allow customers to pick selected crops (berries, tree fruit) on their own from certain sections of the greenhouse, thus saving money on harvest labor.
- Integrate product drying and processing for products that cannot be sold fresh.

Claytonia, pictured above, is a very cold-hardy salad green that can continue to be produced throughout winter months without supplemental heating, as with many other types of salad greens and root vegetables. When it blooms in spring, claytonia also becomes a very attractive addition to any salad mix.

Vegetable packages are a popular means of supporting local farmers and can offer a convenient means for bundling together products for sale. New approaches to these vegetable package sales can allow customers to exchange unwanted items for ones they prefer, bringing them to the shop where they may purchase additional goods.

The salad mix above that includes mesclun greens and chive flowers is just one example of an innovative mixed salad package that can be sold from polyculture production.

These heirloom tomatoes are one example of products that can be sold at higher premiums when catering to a local market.

MAKING POLYCULTURE PROFITABLE

The scenario below imagines how a Dutch greenhouse grower, with a typical monoculture of a common vegetable crop, could transition to polyculture production in a gradual and profitable way. This process illustrates the steps a grower could take in making this transition, as well as some of the costs and earnings he might incur.

THEORETICAL CASE STUDY

Consider a fictional grower, Jaap, who currently has ten hectares of greenhouse tomato production. If we assume that Jaap has an overall yield of 60 kilograms of tomatoes per m^2 and is able to sell these an average price of 0,60 euro cents per kilogram, he has an annual revenue of 3,600,000 euros for his ten hectares, or around 360.000 euros per hectare. His operating costs must stay below 36 euros per square meter and he must sell all of his product in order for his operation to break even. With rising energy prices, high labor costs, and changing market conditions, Jaap's business needs to be a tightly managed operation to ensure that it continues to run successfully.

SHIFTING TOWARDS POLYCULTURE

The two perennial polyculture designs presented in this report generate a projected 350.000 - 600.000 euros per hectare in retail crop value, and the annual polyculture design has a retail crop value of up to 2,5 million euros per hectare. At first glance, it would seem unwise for Jaap to move to any production method that results in a cut in revenue, such as with the perennial systems. This move begins to make a great deal of financial sense when we reframe Jaap's production approach and marketing strategy to one that is focused on diverse local production. To understand this, we consider the following situation:

› Jaap decides to shift part of his production to a diverse polyculture system. He reduces the total area of his greenhouse devoted to tomato production from 10 to 8 hectares.

› Jaap switches over the other two hectares of greenhouse production to a combination of other crops grown in polyculture (tree fruits, berries, and a year-round annual polyculture, as described later in this document).

› In cooperation with some neighboring growers - a cucumber producer and a pepper producer, they form a consortium that shares the responsibility for developing a local marketing strategy.

› He grows a mix of cold-tolerant crops in the winter months that provide a continued product supply without the need for supplemental heating. Some of these crops can be stored in the ground to maintain optimal freshness and harvested directly in step with demand (onions, root vegetables, leeks).

› His labor costs remain consistent, while his energy costs drop significantly because two of Jaap's hectares no longer require winter heating or supplemental light.

› The diversity of products that Jaap is now producing allows him to develop and sell through local retail channels: directly to customers through a farm subscription, to local markets and restaurants, and through a shop that is jointly operated by him and his neighboring growers.

› The extra marketing costs, which can be significant, are shared between the three growers in the consortium. If a single grower is paying for all of his own marketing, we estimate that this could cost up to 30% of the value of the produce. When shared between growers, the cost to each company should go down significantly, though this is highly dependent on the particular arrangement.

NEW SALES APPROACH

The result is that Jaap is now producing 4,8 million kilograms of tomatoes per year instead of the 6 million kilograms he was producing previously. The average European per capita consumption of tomatoes is around 20 kilograms per capita per year. Thus, by producing 4,8 million kilograms of tomatoes, Jaap produces enough for 240.000 people's annual consumption.

Jaap continues to sell the majority of his tomatoes through normal wholesale channels. However, with his newly diversified product portfolio and his partnership with two other growers, he now also sells products into retail sale through a local shop near one of his partner's greenhouses.

If he reaches around 5.000 local customers and is able to sell 80.000 kilograms of these tomatoes locally for a retail price of 3.00 euros, he receives 240.000 euros. This local sale is facilitated by the production of complimentary products (berries, tree fruits, other vegetables), which Jaap now also produces on his two remaining hectares and is able to offer in the cooperative shop. He sells these products at a total price of 2.000.000 euros to the same 5.000 local customers (each spending an average of 400 euros at his farm over the course of the year). He sells an additional 100.000 kilograms of mixed products to local restaurants and markets at an average price of 3 euros per kilograms, earning an additional 300.000 euros.

The remainder of his tomatoes (an estimated 4,6 million kilograms) is sold at regular wholesale prices for an average of 60 euro cents, earning Jaap a further 2,76 million euros. Thus, Jaap sells his products for a total of 5,3 million euros, a potential 47% increase on his original revenue.

COSTS OF PRODUCTION AND SALE

Though Jaap's potential increase in sales value is clearly significant, it is important to thoroughly investigate whether the costs of production and sale will stay relatively low enough for Jaap to truly capture this additional value.

Jaap's costs will be significantly higher in the initial years of switching to polyculture due to the capital investments in new crops and equipment. These costs vary per polyculture scenario. The tree and berry polycultures are the most expensive in terms of initial investment because of the cost of the plants. Growers can reduce these costs by opting for younger plants that will take longer to fruit and focus on growing annual plants in that period.

Labor costs will also increase by an estimated 20% throughout the production period, depending on the specific polyculture scenario, though much of the standard labor associated with weeding, soil care, irrigation, and greenhouse maintenance will remain similar to what needs to be done in a standard monoculture. With the polyculture approaches suggested here, energy costs should decrease significantly due to the removal of supplemental heating and lighting, which can counterbalance the increase in labor costs.

The highest increase in costs is most likely the cost of marketing and sales. If we take a high estimation of cost of sale, where marketing and product management personally cost Jaap around 30% of the value of his crop, then this will decrease his potential revenues by 1,6 million euros. This would still result in an overall increase in revenue, but only by a small fraction. Thus, a key takeaway of this test scenario is that it is essential to develop smart and effective shared marketing models for product sale. If the cost of marketing is too high, the grower will not capture much, if any, of the value increase represented by direct to retail sales.

However, Jaap has the potential to gain many economic benefits beyond annual profits, including the potential to develop a visible brand with a local clientele. This local customer base is more likely to continue to buy from him, even in economically difficult times.

Over time, Jaap can shift his production to increasingly cater to his local customers, adding in more unique products, and expanding the amount of hectares dedicated to polyculture as it becomes more profitable.

A SYSTEMIC CHANGE

A broad trend toward switching to high-efficiency polycultures could greatly reshape the overall greenhouse horticulture sector in the Netherlands. The industry would begin to shift towards smaller-scale, more diverse farms focused on serving their local client base. These smaller scale farms could potentially work in cooperatives, each supplying targeted portions of the population's local diet. These farms could also exchange waste materials in order to close local nutrient cycles, and co-invest in decentralized renewable energy technologies.

In this smaller-scale, polyculture-focused scenario, growers could earn more money from cultivating smaller areas of land than under a monoculture regime. Export would no longer be the primary focus of production. Cropping cycles would be more closely aligned with local market demand and less food would be wasted or spoiled during transport. The overall carbon footprint of most products would fall dramatically and there would be less demand for packaging or long-term cooling. Finally, the connection between growers and consumers would be strengthened, creating a stronger and more transparent local economy.

Such a system could bring great benefits in the long-run, but there are many challenges - technical, economic, and cultural - that need to be addressed before a shift in this direction is possible.

The three polyculture designs presented in the following section are a stepping stone along the path to testing the feasibility of this approach.

CASE STUDY: RON VAN ZWET

Ron van Zwet, a grower in Almere, currently has two greenhouses, which, until recently, were both used to cultivate vine roses.

Ron is among a few pioneers in the greenhouse sector who are experimenting with new business models and integrated retail sales. Earlier this year, he opened one of his older greenhouses to an entirely new model: renting plots inside his greenhouse for use as community gardens by local customers. Pictured to the right are some images of his customer's plots, all of which are naturally polyculture systems. In the second half of this greenhouse, Ron and his team have been growing a mix of additional vegetables for local sale to the same customers who have personal garden plots on site.

PILOT POLYCULTURE CROPPING

Ron's greenhouse is in some ways ideally suited to applying a test polyculture because he already has begun establishing a retail sales channel. Ron still has six additional hectares of greenhouse available for cultivation. A 740 m^2 area in one of these greenhouses will potentially be dedicated to testing out an experimental polyculture. The plot will be used without supplemental heating or lighting.


ONZE
Streekwinkel


Appels 3 kg €2,50
Paprika
Rood 2 st €1,50
groen 3 st €1,50
VANDAAG
ONZE

greenhouse polyculture designs

three options for greenhouse use

The following section has descriptions of three greenhouse polyculture designs, each yielding a diverse set of agricultural products.

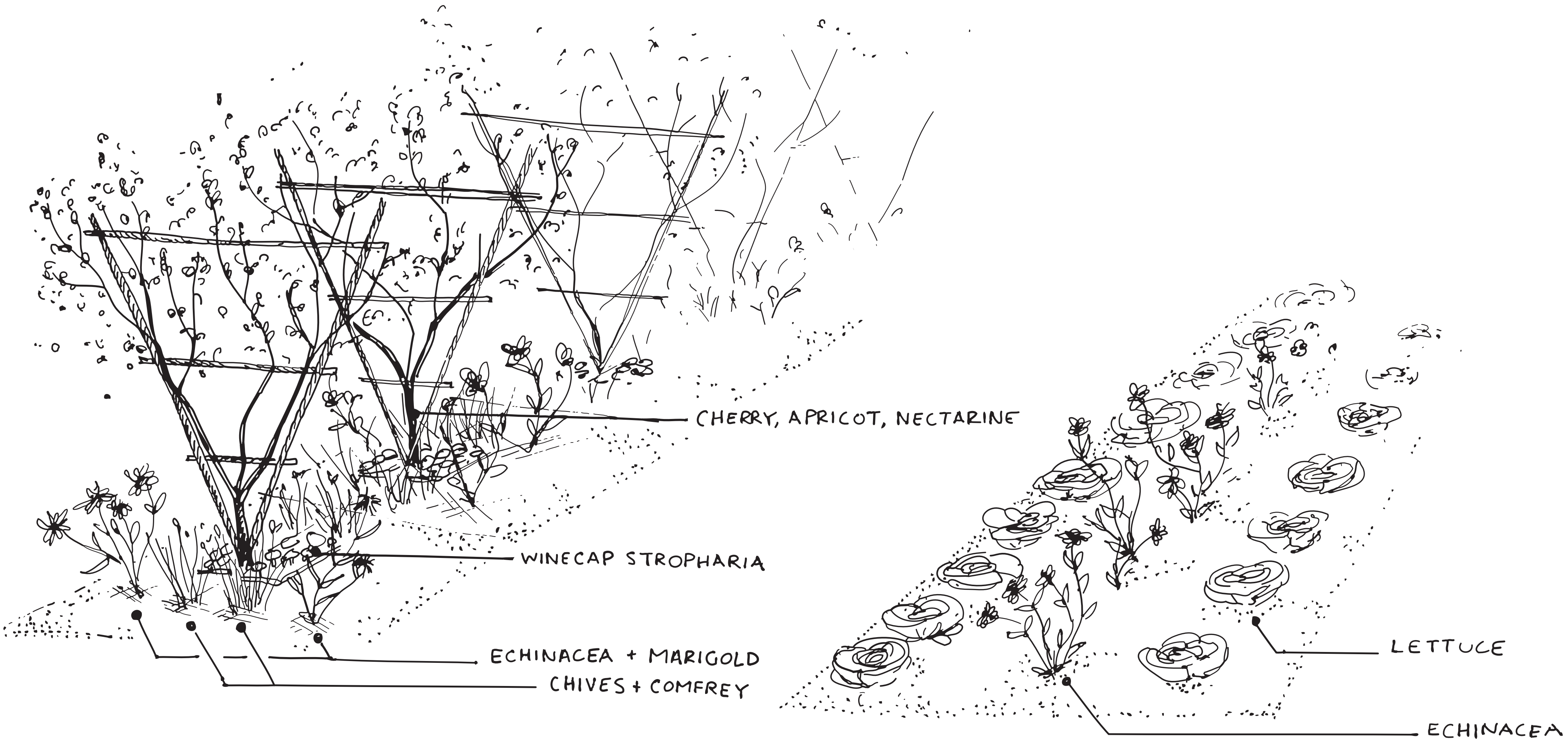
Two are perennial cropping systems with a lifespan of ten to twenty years, and one is an intensive annual polyculture.

The first design, focused on tree fruit, describes an orchard under glass with apricot, nectarine, and cherry production. It draws on knowledge of best practices in agroforestry and forest farming to make optimal use of space. Shallow-rooted companion plants are intercropped with the trees to ward off nematodes and other pests, and spatial use is maximized by intercropping with annual vegetables during the orchard's immature stages.

The second design is focused on the cultivation of perennial berries (raspberry, currant, gooseberry, and blueberry). It is another soil-based polyculture that will remain productive for around 20 years.

The final design is for the cultivation of annual plants and vegetables, with a strong focus on succession planting and late season growing.

All of these greenhouse designs are meant to be applied in greenhouse that has no supplemental heating in the winter and without the need for supplemental lighting.


CHERRY, APRICOT, NECTARINE
WINECAP STROPHARIA
ECHINACEA + MARIGOLD
CHIVES + COMFREY
LETTUCE
ECHINACEA

DESIGN 1 : TREE FRUIT POLYCULTURE

TREE FRUIT POLYCULTURE

As shown in the artist's impression to the left, the tree fruit polyculture consists of alternating rows of Y-trelissed trees, intercropped with herbs, mushrooms, and companion plants. Each row is planted with either cherry, apricot, or nectarine trees. In between the rows of trees are lettuce and echinacea varieties, making use of space that would otherwise be left empty.

A more detailed layout sketch can be found on the following page.

DESIGN SUMMARY

This soil-based greenhouse polyculture design is centered around the production of apricots, nectarines, and cherries complemented with a number of strategically intercropped plants and fungi.

One hectare of such a cultivation system is projected to have a per hectare yield (at maturity) of approximately: 11.700 kilograms of apricots, 5.600 kilograms of cherries, 17.800 kilograms of nectarines, 912 kilograms of chives, 1.800 kilograms of green beans, 3.000 kilograms of lettuce, and 2.200 kilograms of shiitake and 1.800 kilograms of winecap stropharia mushrooms. In addition, the system produces annual harvests of cut flowers (echinacea), edible flowers (calendula), and medicinal herbs (echinacea, comfrey, and calendula). In total, the system produces around 42.000 kilograms of productive yield per hectare, which is much higher than the typical 25.000 kilograms of yield from a high-density orchard.

CULTIVATION APPROACH

All tree crops in this design are planted in high density rows using intensive orchard practices. Apricots and nectarines are suited for high intensity trellissing using an Open Tatura system. This Y-shaped trellising system is optimal for stone fruit and allows for continuous fruiting from the second year of production. Cherries can be cultivated using either the Open Tatura system or the Upright Fruiting Offshoots (UFO) method, where a number of productive shoots are guided vertically from horizontal leader.

In the first three years, while the trees are still young, the orchard is suitable for intercropping with a variety of annual crops – particularly shallow-rooted vegetables such as lettuces and nitrogen fixing crops such as beans. The added nitrogen production from the beans adds valuable nutrients to the tree crops and also provides a secondary source of revenue as the trees mature. Perennial support crops (such as comfrey, chives, marigold, and echinacea) are also interplanted closer to the trees for additional marketable yields of culinary and medicinal herbs. These plants also provide significant side benefits in the form of pest repulsion and nutrient mining.

Comfrey does not compete with tree roots and is also a dynamic accumulator, pulling essential minerals from deep soil into its leaves. The cut comfrey leaves can be used as a direct mulch on the soil below the trees without any additional processing, providing nutrients and preventing weed growth. This practice can easily address mineral deficiencies in the tree crops, which are a key factor in limited productivity in orchard settings. Comfrey, which is a highly productive crop, can also be sold directly as a medicinal herb (leaves and roots) or processed into liquid manure (for own use or sale).

Chives are a common culinary herb that can be regularly harvested through the season and sold directly. Planting them as a border crop gives additional pest resistance advantages: most alliums secrete compounds that repel a broad range of predatory insects. Echinacea provides an additional source of revenue and space utilization. It can be sold both as an ornamental flower and a medicinal crop: echinacea root demand continues to increase throughout Europe, with dried root sold at between 20 and 60 euros per kilograms.

Mushroom production is also a key component of this intercropping strategy. Bags of shiitake medium can be placed on racks in the shade of the trees. Soil-based mushroom production using mycelium inoculated wood chips can additionally be used to fill shaded gaps in the understory of the system. Winecap Stropharia is suitable for this kind of production. The mushrooms add another stream of revenue, and the soil-based mushrooms can also greatly enrich the soil. Trees in particular flourish in fungal soils.

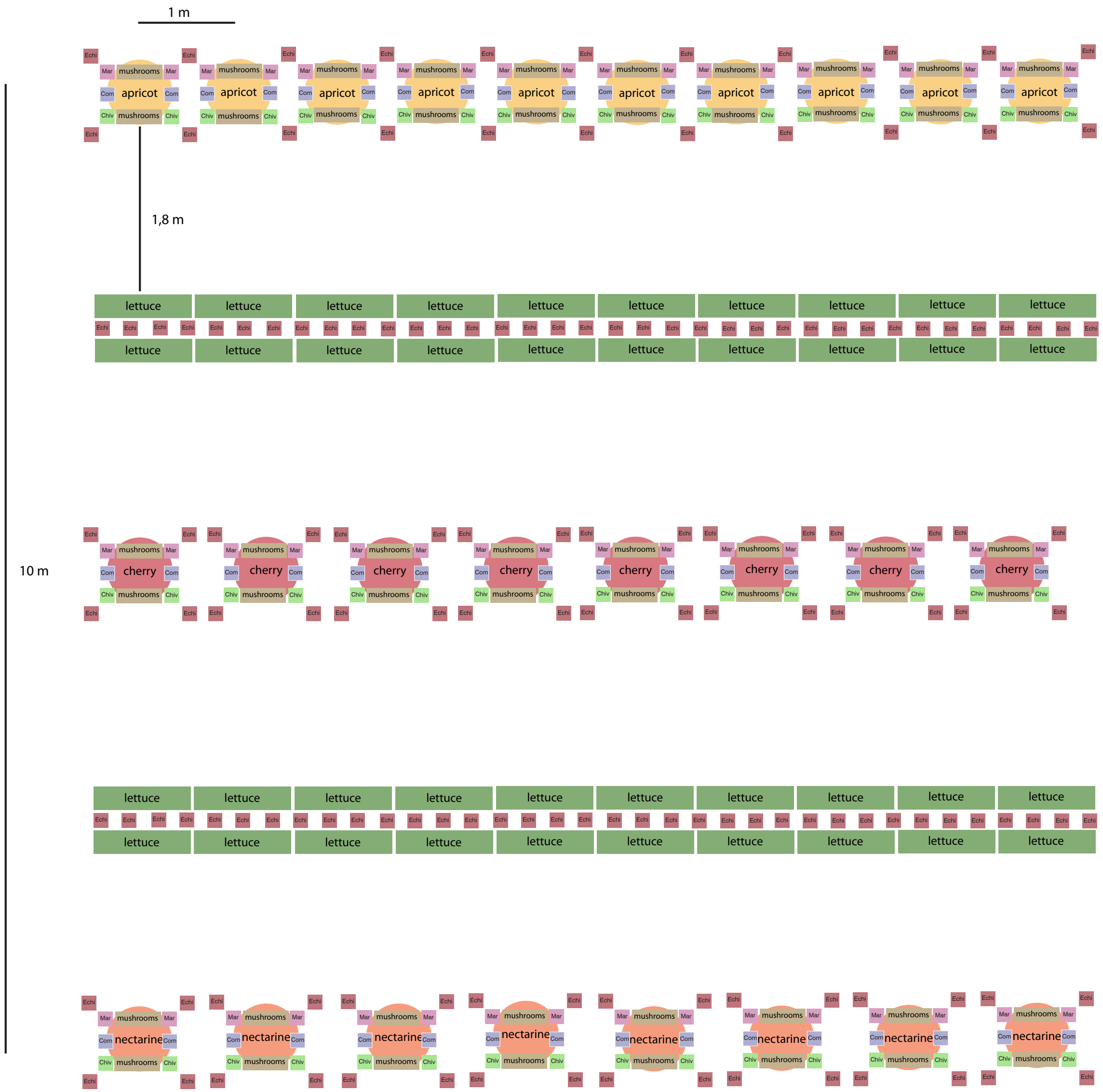
An additional support element in this system includes French marigold. French marigold releases nematode-repelling chemicals from its roots and also acts as a weed suppressant. Nematodes are a common pest problem for the three fruit trees selected in this polyculture, and in soil greenhouse cultivation in general. The marigolds can also be sold as edible flowers, medicinal plants, pigment plants, or ornamental crops for additional revenue.

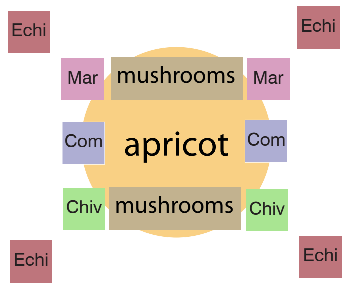
KEY BENEFITS

Producing this set of crops in a greenhouse has some key financial advantages:

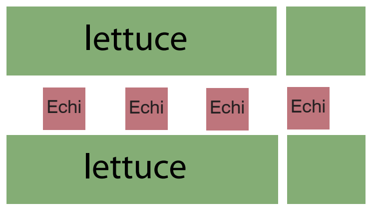
- **The grower can avoid common problems facing outdoor orchards:** bird predation (all tree crops), fruit loss due to early frost (particularly for apricots), winter frost damage (particularly for cherries), and sunburn.
- **The production season can be strategically extended:** by planting a mix of early and late cultivars, the harvest period can be greatly extended, especially by taking advantage of the early fruiting possible in a greenhouse.
- **Additional co-products, such as mushrooms, are easier to produce in climate controlled conditions than in an outdoor agro-forestry system.**
- **Crops that are currently not grown in the Netherlands (e.g, apricots) can be grown in this system for potential added local price advantage.**

DESIGN 1 : TREE FRUIT POLYCULTURE





The three tree varieties are planted in alternating rows and intercropped with comfrey, marigolds, chives, and echinacea. Mushrooms are cultivated in two ways: in substrate bags on covered racks under the trees (shiitake), and directly on soil-innoculated wood chips under the trees (winecap stropharia).



In between the rows of trees are low-growing, short-cycle crops: mixed varieties of lettuce. In between the rows of lettuce is an additional row of echinacea which will provide localized shading and add to the overall volume of the echinacea crop that can be sold as a cut flower and medicinal roots.

CROP SELECTION

Production crops:

- Apricot
- Nectarine
- Cherry
- Lettuces
- Bush Beans
- Chives
- Potted Herbs

Mushroom Production:

- Shiitake
- Winecap Stropharia

Nutrient Recovery:

- Shiitake
- Winecap Stropharia
- Comfrey

Nitrogen fixers:

- Bush beans
- Clover

Dynamic accumulators:

- Comfrey

Ground covers:

- Clover

Pest suppression:

- French Marigold
- Chives

Insectary:

- Clover
- Comfrey
- Echinacea

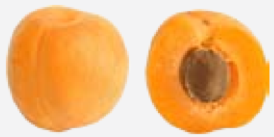
Shading

- Apricot
- Nectarine
- Cherry
- Echinacea
- Comfrey

Ornamentals:

- Echinacea
- Comfrey
- French Marigold

APRICOT



Function	Food Crop
Spatial Role, Height	Canopy, 3 meters
Rooting	Deep
Sunlight	Full Sun
pH	6,5 - 8
Water (annual)	900 mm
Minimum Temperatures	-30° C to -13° C
Nutrient Requirements	high
Soil	fine sandy loam, good drainage
Pests & Diseases	nematodes
Pollination	self-pollinating

The apricot is a small tree of 2 - 3 meters tall with a dense spreading canopy. The fruit is a drupe with yellow to orange flesh. Globally most apricot cultivation is in Turkey, with fruits sold fresh, dried, or canned. Apricots bloom early in spring. The blossoms are often killed by early frosts in all but the most favorable locations. Apricot cultivars require between 300 and 1000 chill hours per year. The shelf life of fresh harvested fruit is 14 -28 days.

NECTARINE

Function	Food Crop
Spatial Role	Canopy, 3 meters
Rooting	Deep
Sunlight	Full Sun
pH	6,5
Water (annual)	900 mm
Minimum Temperatures	-20° C to -13° C
Nutrient requirements	high
Soil	fine sandy loam, good drainage
Pests & Diseases	root lesion, dagger nematodes, oriental fruit moth, tarnished plant bug, European red mite, two spotted mite, aphids, peach borer.
Pollination	self-pollinating

Nectarines do best in a climate where rain rarely falls in the three weeks before ripening, since they are susceptible to brown rot disease. This preference can be somewhat controlled for in the closed conditions of a greenhouse. Using the Tatura Trellis system, the nectarine orchard life is 8 - 12 years. In this system, the plants are planted at a 5 meter x 1 meter distance and yield around 23 tons per hectare. Nectarines require 100 - 1.200 chill hours, depending on the cultivar.

DESIGN 1 : TREE FRUIT POLYCULTURE

SWEET CHERRY

Function	Food Crop
Spatial Role, Height	Canopy, 2,5 meters
Rooting	Deep
Sunlight	Full Sun
pH	6.5
Water (annual)	900 mm
Minimum Temperatures	-2,7° C to 0° C
Nutrient requirements	high
Soil	fine sandy loam, good drainage
Pests & Diseases	root lesion, dagger nematodes
Pollination	cross-pollinating

Sweet cherries are sold for fresh consumption, juicing, canning, or drying. In polytunnel trials at Michigan State University in the United States, high density trellised croppings of cherry trees (at 0,5 meter x 2,5 meter spacing + leg space or 7.518 trees per hectare) yielded 6,9 short tons per hectare in the third year of production. This translates to an average of 0,67 kilograms per tree.

LETTUCES

Function	Food Crop, Space Utilization
Spatial Role	Understory, Alley Cropping
Rooting	Shallow
Sunlight	Full Sun / Partial Shade
pH	6,0 - 7,0
Water (annual)	3.600 - 5.500 mm (drip irrigated)
Minimum Temperatures	1,7° C
Nutrient requirements	high
Soil	fine sandy loam, good drainage
Pests & Diseases	aphids, cabbage looper, fungus gnats, whiteflies, botrytis grey mould, downy mildew, powdering mildew, pythium damping off and root rot. russet spot from too low temp.

Lettuces are heavy feeding, shallow-rooted crops, which are ideal for intercropping in the alleys between immature fruit trees. Head lettuces (Lactuca sativa var. captain) include iceberg, crisphead, and butterhead. Leaf lettuce (L. sativa var. longifolia) include romaine, greanleaf, and redleaf. 6 - 12 weeks from seedling to harvest. In continuous greenhouse production, 8 - 10 harvests are possible per year. Ideal production temperature is between 15 - 18 C at night and 19 - 22 C during day. Colder cultivation temperatures are ideal. Post harvest, lettuce should be stored at 2 - 4 C under high humidity (75 - 85%). Lettuce is sensitive to damage from freezing.

WINECAP STROPHARIA

Function	Food Crop
Spatial Role	Ground Cover
Sunlight	Shade
Humidity	70%
Growing temperature	15° C - 25° C

The elm oyster and winecap stropharia have both been identified as types of mushrooms that are suited for growing in soil in and around plants. These can be produced on inoculated wet wood chips that are scattered in and around the shade of trees or bushes. The degrading wood chips can also add nutrients into the soil, though the mushrooms themselves also consume nutrients as they grow.

Wet wood chips can be purchased for a low price (an estimate of 40 euros per ton). These should be inoculated with 30 liters of spawn per ton (with spawn costing 2 euros per liter). A spring spawn run will take 2 - 3 months in time for a summer harvest. Yields are 5 - 10 % of total substrate weight. These particular mushrooms should be harvested young. The caps have a nutty flavor and the stems a more earth-like taste. Winecap stropharia is not a common product, which is a potential challenge in securing sales.

CROP SELECTION

SHIITAKE

Function	Food Crop, Nutrient Recovery
Spatial Role	Understory
Sunlight	Shade
Humidity	Substrate 55% moisture, Relative humidity less than 75% for mycelial growth, 85 - 95% for fruiting.
Growing Temperatures	18° C. to 23° C, with 18° C during early stage growth, 20 - 23 during middle stage, and below 20 during the late stage.
Pests & Diseases	mice, snails, competing fungi

In the Netherlands, Shiitake mushrooms are typically cultivated indoors on prepared substrate in industrial mushroom production facilities. However, Shiitake can also grow outdoors on the understory of trees in a managed shade environment. Possible substrate for shiitake production under trees includes: hardwood logs, synthetic logs, and sawdust substrate in bags. In this polyculture design, bags of shiitake substrate can be placed on racks below the trees and harvested as they fruit.

BUSH BEAN

Function	Food Crop, Nitrogen Fixation
Spatial Role	Vine, Interstory
Rooting	Shallow
Sunlight	Full Sun
pH	5,5 - 6,0
Water (annual)	800 -1000 mm
Minimum Temperatures	- 2° C
Nutrient requirements	high (cover crops or fertilizer)
Soil	broad range: sandy loam optimal
Pests & Diseases	nematodes, aphids, bollworm, pusia looper, spider mite, bean fly, thrips, seed maggots, beetles, stinkbugs, rust, bacterial blights, sclerotina rot, damping off.
Pollination	self-pollinating

Bush beans are a variety of bean that stand erect without support and have all of their pods develop simultaneously. Optimum mean temperatures for bush bean production are between 15 and 27 C. Ideal germination temperatures are 20 - 30 C. Bush beans should be planted 40 - 70 mm apart with rows 450 - 600 mm apart, with the seed planted to a depth of 30 mm. They reach picking maturity within 50 - 60 days. Yields at this density are 5 - 8 tons per hectare.

COMFREY

Function	Pest Repellent, Medicinal Herb
Spatial Role	Understory
Rooting	Medium, Tap Root
Sunlight	Part Shade
pH	6,5
Water (annual)	800 - 1200 mm
Minimum Temperatures	-26° C
Nutrient requirements	high N demand
Soil	loam, moist
Pests & Diseases	rust, mildew
Possible Cultivars	Bocking 14

Comfrey is a high-yielding perennial that should be harvested 3 - 8 times per year for its leaves. It is an abundantly producing plant, with harvests of around 2 kilograms of leaves per plant. When densely planted can produce over 100 tons per hectare in a monoculture.

Comfrey is an extremely robust plant that spreads through rhizomous growth, and is difficult to eradicate once planted. The Bocking 14 strain doesn't self seed, which can somewhat contain the spread. Comfrey root can be harvested once the plant is mature at 3 years. For fertilizer production, it should be cut before flowering (around April) and is ready to recut every five weeks until September.

DESIGN 1 : TREE FRUIT POLYCULTURE

FRENCH MARIGOLD

Function	Pest Repellent, Ornamental
Spatial Role	Understory
Rooting	Shallow
Sunlight	Full Sun
pH	5,8 - 6,5
Water	500 - 800 mm
Nutrient requirements	high
Soil	fine sandy loam, good drainage
Pests & Diseases	Alternaria leaf spot, damping off, grey mold, tomato spotted wilt virus, bacterial leaf spot, Southern bacterial wilt, thrips, caterpillar
Possible Cultivars	*Tagetes patula* varieties

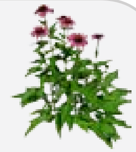
The French Marigold is an annual crop ranging in size from 15 centimeters to over a meter tall. Dwarf cultivars are appropriate as bedding and borders. There are 250 - 450 seeds per gram. Seeds germinate in 3 - 5 days at 24 to 27 C. Fertilization is recommended twice a week. Optimal growing temperature for the marigold is 15 - 18 C at night and 18 - 22 C during the day.

CHIVES

Function	Food Crop, Pest Repellent
Spatial Role	Understory
Rooting	Shallow
Sunlight	Full Sun - Part Shade
pH	6 - 7
Water	500 - 600 mm
Nutrient requirements	needs high nitrogen
Soil	fine sandy loam, good drainage
Pests & Diseases	nematodes
Pollination	self-pollinating

Chives can be propagated from seed or divided roots and can be grown as an annual or a perennial. Seeds germinate in 10 - 14 days. Chives should be planted 10 centimeters apart with rows 30 centimeters apart. Adequate nitrogen is important. Leaves are cut as needed for harvest, and the plant can also be used as a cut flower in spring.

ECHINACEA



Function	Medicinal Herb, Ornamental
Spatial Role	Interstory
Rooting	Deep Tap root
Sunlight	Full Sun to Part Shade
pH	5,5 - 7,5
Water	300 - 800 mm
Nutrient requirements	low, does well without fertilizer
Soil	fine sandy loam, good drainage
Pests & Diseases	fungal leafspot, fungal root rot, phytoplasma, aster yellows, Sclerotinia crown, powdery mildew, aphids, leafhoppers.
Possible Cultivars	*E. purpurea, E. augustifolia*

Echinacea plants should be spaced 30 centimeters with 60 centimeters between rows. Prior to germination, the seeds need a one- to - four week cold, moist stratification in peat moss or sand at 0 C to 5 C. Germinate at 18 - 26 C, and transplant within 20 - 30 days. One gram of *E. purpurea* contains 280 - 320 seeds. A gram of seeds costs approximately 50 euro cents. Yield ranges from 1.000 to 5.000 kilograms per hectare in 2 - 4 years after planting.

PRODUCTION DEMANDS & TIME LINE

SYSTEM LONGEVITY

Most of the crops suggested here are perennials with a long production cycle of at least 10 years. The lettuces, beans and marigolds are the only annual crops within the system. Echinacea and comfrey are long-lived perennials, but as they are harvested for their roots every 3 - 4 years, they need replanting at regular intervals.

PRODUCTION PLAN SKETCH

Site establishment
In outdoor orchards, site preparation can often take as long as three years to allow for cycles of plowing, soil amendment, and cover cropping with nitrogen fixers.

For this greenhouse orchard site, a minimum soil depth of 0,5 meters is needed. The soil must first be tested, corrected for nutrient deficiencies, and brought to an appropriate pH (6,5 for this scenario). If possible, soil organic matter can be built up using a cover crop, such as clover, which can then be plowed under prior to the planting year. Typical horticultural practice also recommends a fumigation regime to sanitize the soil. For organic / biological production, this fumigation is not possible. Instead, attention should be paid to selecting disease resistant cultivars. The marigold interplanting suggested here can also assist in suppressing nematode populations, which are a common problem in fruit orchards. If possible, marigolds can also be grown in the soil during the preparatory phase to ward off these pests.

Cultivar selection
Cultivars should be selected with two primary goals in mind: disease resistance and fruiting period. Fruiting can be extended by picking several cultivars: early and late blooming varieties. All of these trees have a chill hour requirement, which means that they need to experience an appropriately long dormancy period to set fruit.

Many apricots need around 700 hours of winter chilling to produce a full bloom in spring. The Gold Kist variety has a very low chilling requirement of 300 hours. “Katy” a California variety, has a 400 hour chilling requirement. There are also high and low chill hour varieties of nectarines and cherries.

In the early years of the orchard’s production, the trees can be intercropped with bush beans to fix additional nitrogen in the soil and for an early additional crop. Lettuces can be grown in between the rows of trees throughout the life cycle of the orchard.

Mushrooms in this system are produced in two ways. The shiitake can be produced on freestanding racks below the fruit trees equipped with humidity covers. Some varieties of mushrooms produce high quantities of spores that can cause allergic reactions through inhalation. The closed covers can somewhat contain the spores, though care must be taken to harvest the mushrooms in a timely manner. The small overall quantity of proposed mushroom production means that the spores will be relatively diffused. The winecap stropharia mushroom can be produced directly on the surface of the soil using inoculated fresh wood chips.

Year 1 (planting year):
After the soil has been prepared, the plot should be marked for the construction of a Tatura Trellis and an irrigation system.

Tatura is a high density training system that uses a v-shaped trellis to maximize the bearing area of crops. Complete training of trees on this system usually takes three years. Tree density of up to 2.000 trees per hectare can be achieved using this method (spacing trees 1 - 1,5 meters within rows, and 3 meters between rows), allowing for the high-intensity production required to make tree fruit profitable in a greenhouse context. Tatura trellising produces yields almost three times higher than comparable orchards with free standing trees.

This high production intensity also reduces the productive life of the orchard to around 10 - 15 years for the three tree types selected here. Free standing trees, growing at much lower densities (around 300 per hectare) can continue to produce for up to 50 years in the case of apricots. Planted trees should be 1 - 2 years old. Detailed guides for Tatura training can be found on the websites of agricultural extension services.

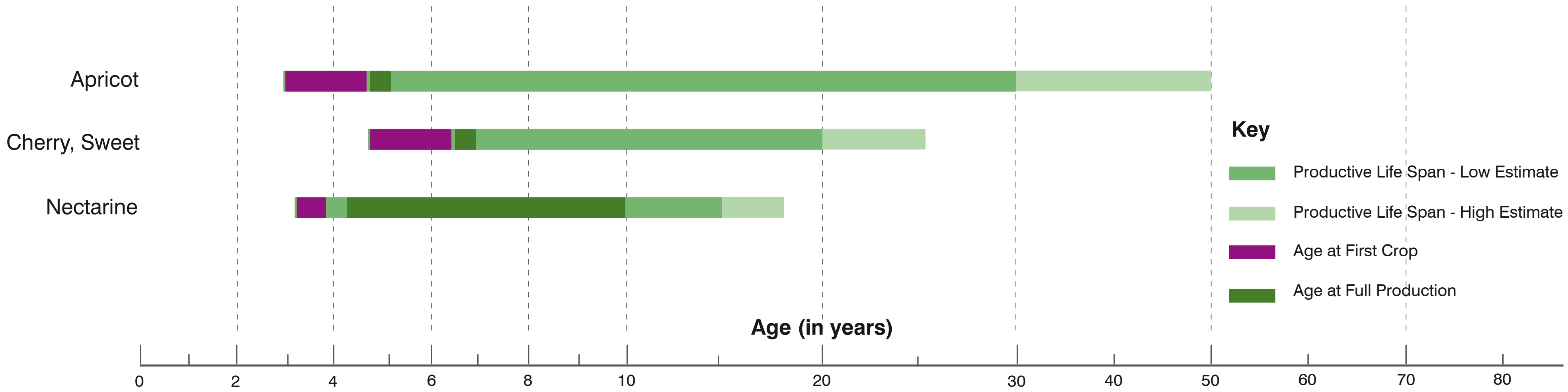
After the first pruning and irrigation, trees should be cleaned of any dead branches and the companion plants can be added into the system. The bush bean, lettuce, chive, and mushroom intercropping can all commence in year one. In the fall, the trees should be painted as protection from mice.

Year 2:
In the second year, Tatura training should proceed as recommended with the selection of the strongest leader and a reduction of tree height if growth was greater than one meter. The trees should be fertilized and pruned, and fruit should be thinned by hand to improve tree growth. Bush bean intercropping should be reduced, but lettuce and companion plant intercropping can continue.

Year 3:
In the third year the trees should be completely trained on the trellis system and the general production cycle of companion plants and fungi should be established. Echinacea root can also be harvested for the first time in this year, and the echinacea plants re-established if the harvest was successfully sold.

DESIGN 1 : TREE FRUIT POLYCULTURE

Productive Life Span of Selected Fruiting Trees



WATER & NUTRIENT INPUTS

This system has relatively high water demands and should be irrigated with at least 1200 mm of water per year. However, the water demand will need to be constantly evaluated since little data exists on the amount of water competition in a densely planted system such as this one. Direct at-root water and fertilizer delivery is possible with a pressurized in-soil fertilization system such as the Earthmister. Such a system could increase the efficiency of fertigation and reduce overall water and nutrient demand. The use of nutrient-holding gels at the root, such as Agrodiamonds, could also reduce total nutrient application demand. Without such measures, there is a risk that total nutrient demand for the site could exceed legal limits for nutrient application.

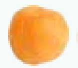
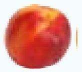
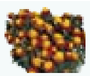
POLLINATION

Apricots and nectarines are self-pollinating, however cherries are not. A bumblebee population needs to be brought in during the spring to pollinate the cherries and other annual crops.

HARVEST & PROCESSING

The fruit trees need to be hand harvested in two or three picks in most years, with a spacing of 3 - 5 days. If there are both early and late cultivars in the greenhouse orchard, then the number of picking sessions will also be greater and more spread out throughout the season. Standard harvesting and storage guidelines should be followed for each of the crops identified here. Harvesting cycles for multiple crops can easily be combined or alternated, allowing pickers to have a more continuous, but diverse flow of work throughout the harvesting season.

MARKET & PROFITABILITY

	PRODUCT	YEAR 1 (KG/HA)	YEAR 2 (KG/HA)	YEAR 3 (KG/HA)	YEAR 4 (KG/HA)
	apricot	0	9.000	10.800	11.700
	nectarine	0	12.200	14.600	17.800
	cherry	0	3.200	4.000	5.600
	lettuces	2.700	2.700	2.700	2.700
	shiitake	2.250	2.250	2.250	2.250
	comfrey (leaf)	9.000	9.000	9.000	9.000
	winecap stropharia	1.800	1.800	1.800	1.800
	beans	3.600	1.800	1.800	1.800
	echinacea (root)	0	0	910	0
	marigold	3.600	3.600	3.600	3.600
	chives	450	450	450	450

ESTIMATED YIELDS

The graph to the left shows estimated system yields for a 1-hectare plot of the tree fruit polyculture system. These numbers are estimates derived by calculating per-plant productivity in monocrop systems with similar cultivation methods to the ones recommended here. These were then applied to this polyculture scenario.

In addition to the products listed at left, the system additionally produces cut echinacea flowers at an estimated rate of 45.000 stems per hectare per year. Echinacea leaves also have medicinal value and can also be harvested annually, but this may lead to reduced quality of the root crop that should be harvested every third year.

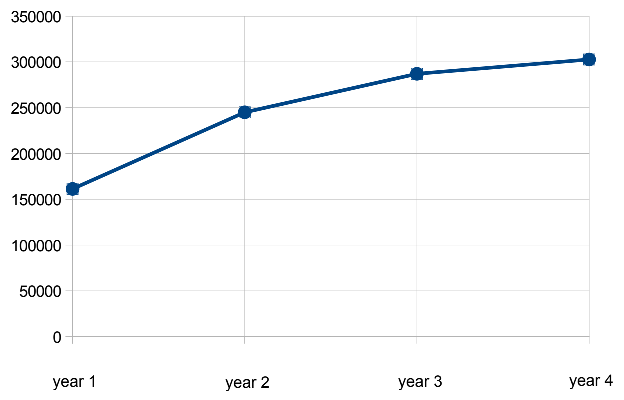
Comfrey root can also be harvested for sale as a medicinal product, though the market for comfrey root is much weaker than that for echinacea due to recently identified safety concerns.

Increasing yields

This system can also easily produce higher yields of certain products than projected here. For example, the number of production cycles of lettuces can be increased per year to raise lettuce output. Likewise, the number of mushroom production cycles can also be significantly increased. This model assumes only two flushes (from a single substrate purchase) per year. The space allocated for mushrooms can easily be used for additional production.

Once the tree system is established, it is also possible to experiment with other types of crops for alley or understory cropping. Rows of floating bed hydroponic systems in between the trees could also be an option for intercrop production for greater productivity and easier harvesting. However, these would also come with a higher investment cost.

ESTIMATED RETAIL CROP VALUE (EUROS)



MARKET & SALES POTENTIAL

Common products

The products generated in this system have a range of market potential. The fruits from the tree harvests have a generally ready market. One potential advantage in marketing and sales for apricots is that they are currently not produced in the Netherlands. The world's crop primarily comes from warmer climates such as Turkey and Iran.

The lettuces, chives, and beans are also commonly consumed vegetables in the Netherlands. Shiitake mushrooms can fetch attractive prices in retail sales (up to 20 euros per kilogram at farmer's markets).

Echinacea, or purple coneflower, is also an increasingly common cut flower. When produced in a biological polyculture, some value could be added to the flower sales by having the plants certified according to an ecological standard, such as the EU Ecolabel, Rainforest Alliance standard, or Fair Flowers Fair Plants (FFP).

Specialty products

Some of the more unusual elements in this system will require special marketing approaches and preparation. These include the winecap stropharia mushroom, the comfrey leaf and root, the echinacea leaf and root, and marigolds for non-ornamental purposes.

Marigold flowers, particularly those produced within an organic or biological cultivation system, are suitable for sale as edible flowers. They have a natural orange color and a mild peppery flavor, which can be used to enhance salads or add coloring to blandly colored dishes (in a similar manner to saffron). Direct sale of marigold flowers to restaurants, or inclusion of marigolds petals in pre-made salad mixes are two potential sales channels.

The flowers can also be dried and kept sealed away from exposure to moisture and sunlight: in this form they retain their valuable properties for up to one year. Dried marigolds can potentially be sold to restaurants or the health and nutritional supplements industry.

The winecap stropharia is an additional specialty crop, since it is not a typical commercial mushroom. If well-marketed, however, it could potentially sell at high prices for its scarcity. Otherwise, it can be sold as part of a produce package along with a collection of other crops.

ESTIMATED COSTS

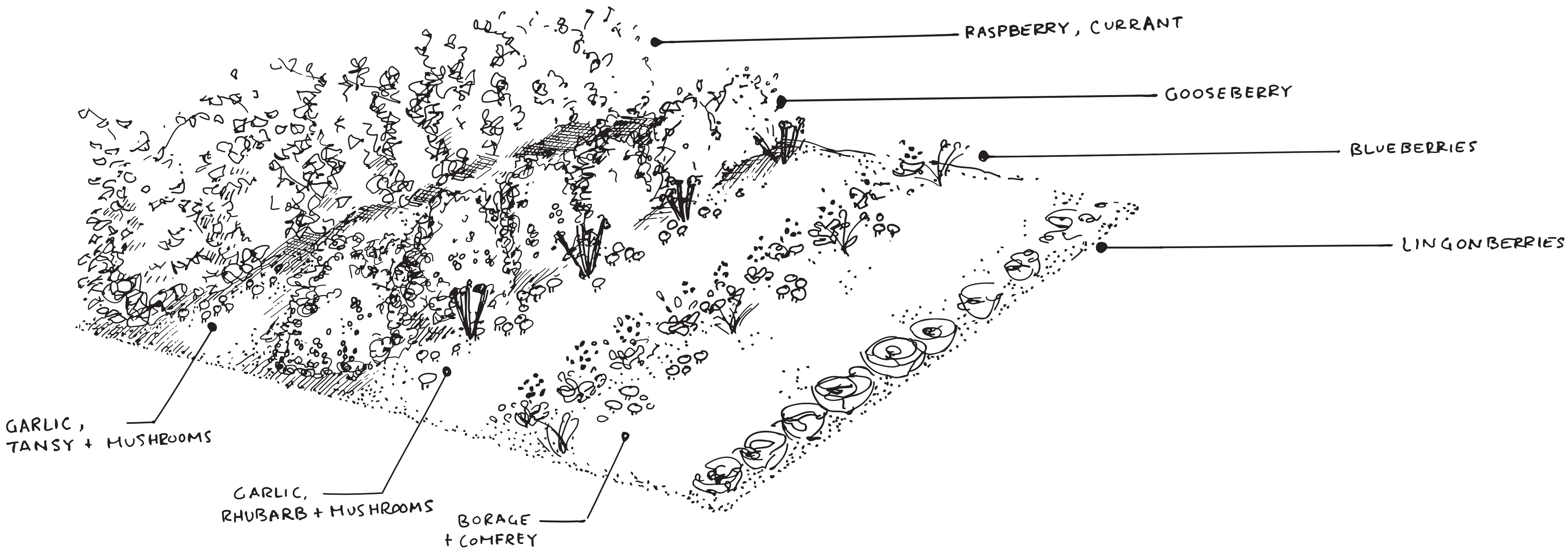
Because most of the plants in this system are perennials, most of the capital costs for production are incurred during site establishment and the planting year: the construction and installation of the trellising system, installation of the irrigation system, installation of mushroom racking under the trees, and the purchase of tree stock.

We estimate that the cost of 2-year old tree stock for one hectare of this intensive orchard would cost an estimated 20.000 euros (assuming a cost of roughly 7 euros per tree). The annual and companion plants will vary in cost depending on whether they are purchased as young plants or grown from seed. Land preparation, trellis construction, and planting will take an estimated 450 hours per hectare, with an additional 100 hours of labor for the planting of annual and companion crops. Fruit thinning, tree girdling, and pruning will require an estimated 150 hours per hectare per year. Weeding and pest control will take an estimated 20 hours per hectare, assuming the site is properly mulched, and harvesting requires an additional estimated 1.500 hours per hectare in the initial years, rising to around 3.000 hours once the trees are mature.

All together, establishment costs per hectare can be estimated at a ballpark figure of 30.000 euros for plants and materials and 10.000 euros of labor (calculated at 15 euros per hour). Annual replanting of the annual crops, such as the lettuces, beans, and marigolds, is an additional recurring cost. The labor costs for annual operations are estimated at 1.770 hours per hectare per year, which translates to 26.500 euros. These costs do not include energy, property taxes or insurance, office expenses, or overhead. Nor do they include marketing expenses, which, as was discussed earlier, can be as high as 30% of the total value of the crop yield, depending on what kind of strategy is used.

ESTIMATED PROFITABILITY

Unlike traditional orchards, this indoor version begins to produce at least some valuable crops in the first year, reducing the overall time needed to make a return on investment. By year four, one hectare of the tree polyculture produces a crop with an estimated value of 350.000 euros. Assuming that an old greenhouse is being repurposed for this production system and that the primary costs are the ones described above, we estimate per hectare costs at: 40.000 euros for establishing the system, 30.000 euros for annual operations, and 45.000 euros for marketing. Even with an added 30.000 euros for the un-itemized costs, the system could be profitable from the first year of production.


RASPBERRY, CURRANT
GOOSEBERRY
BLUEBERRIES
LINGONBERRIES
GARLIC, TANSY + MUSHROOMS
GARLIC, RHUBARB + MUSHROOMS
BORAGE + COMFREY

DESIGN 2 : BERRY POLYCULTURE

BERRY POLYCULTURE

The berry polyculture consists of a progression of various berry bushes arranged from tallest to shortest in the north-south orientation of the greenhouse.

In the rows furthest to the north are raspberries and currants, intercropped with several varieties of mushroms depending on the season. Garlic and tansy are used as pest-repelling companion plants.

Progressing further to the south, we have gooseberries, blueberries, and lignonberries in successive rows. An additional perennial crop that can be grown together with these berries is rhubarb, since it is both cold tolerant and drought resistant, and can handle the acidic soils preferred by the berries. In peak summer, winter squashes, turnips, and beans can also be planted in between the berries for additional harvests from the same site later in the year.

A more detailed design plan can be seen on the following pages.

DESIGN OVERVIEW

DESIGN SUMMARY

The berry greenhouse polyculture design is focused around the production of perennial crops of raspberries, currants, gooseberries, blueberries, and lignonberries intercropped with rhubarb and a variety of herbs and fungi.

One hectare of such a cultivation system is projected to have a per hectare yield (at maturity) of approximately: 1.400 kilograms of currants, 5.000 kilograms of gooseberries, 9.300 kilograms of low-bush blueberries, 8.500 kilograms of high bush blueberries, 5.000 kilograms of raspberries, 2.800 kilograms of lignonberries, 10.800 kilograms of rhubarb, 500 kilograms of garlic, 4.000 kilograms of various mushrooms, 1.500 kilograms of thyme and sage, and 2.700 kilograms of winter squash.

In addition, the design also incorporates some support crops such as tansy, borage, and comfrey. These have soil enhancing and pest repelling properties identified as beneficial and non-competitive with berries.

CULTIVATION APPROACH

This polyculture involves the cropping of alternate rows of different perennial berries, each of which has its own set of selected companion plants or fungi.

All of these berry crops prefer acidic soil and most have shallow delicate roots. This makes them generally unsuited for close intercropping, though some successful companion plants have been identified to provide pest repelling benefits.

Mushrooms are cultivated both directly in soil (elm oyster and winecap stropharia), or on racks with humidity covers in the shade of the berry bushes. Different mushroom varieties are produced depending on the season.

In fall, spring and winter, Oyster mushrooms are one of the options for mushroom cultivation. Fall and spring are suitable for Shiitake, King Oyster, and Nameko. Summer is suitable for soil-produced Winecap Stropharia and substrate grown Pink or Yellow Oyster mushrooms (though these may produce excessive spores). In winter, Enokitake mushrooms are a possibility, though like the Winecap Stropharia, these are a niche product without an established market.

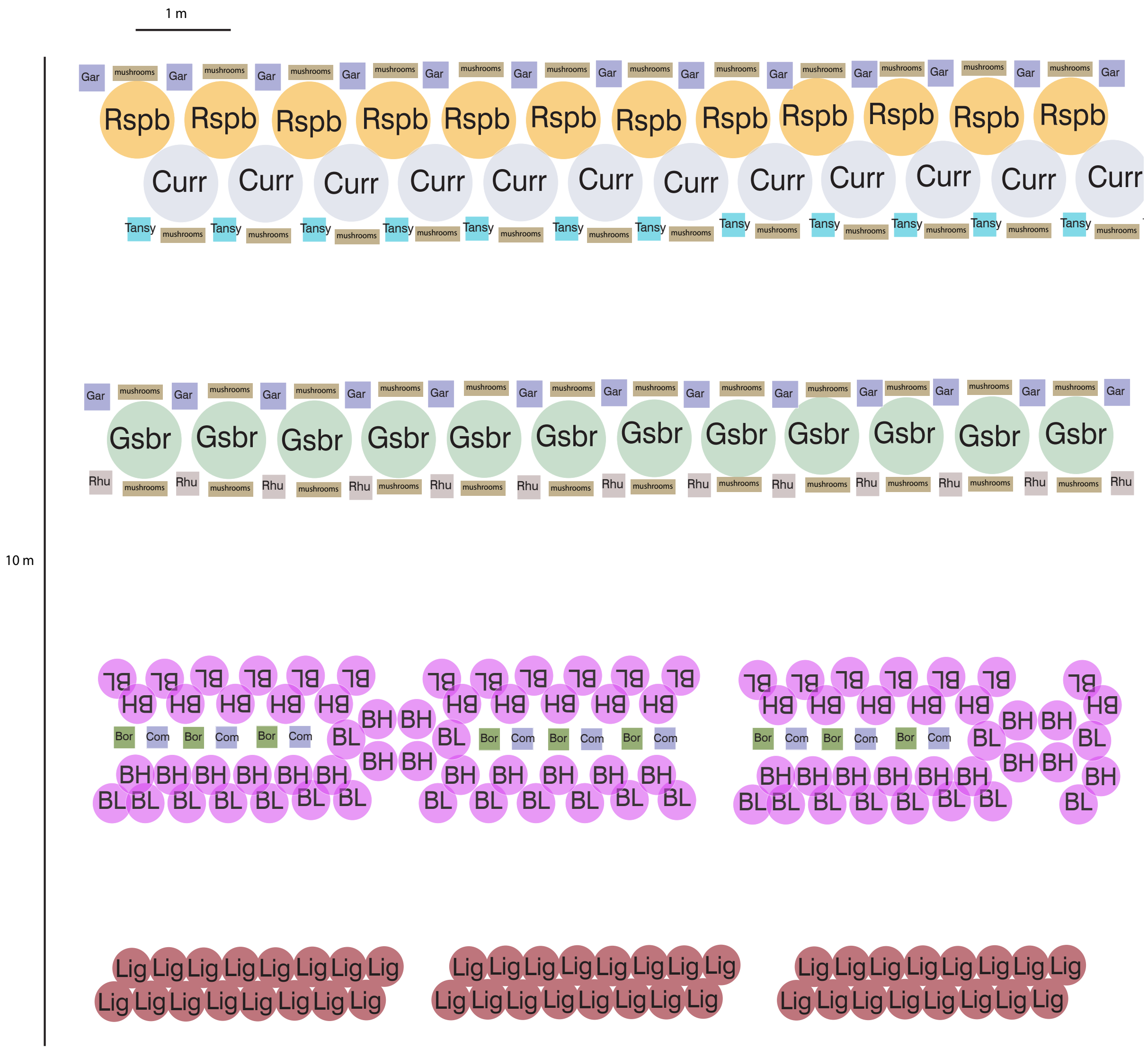
As in the previous design, the comfrey can be used as a green manure. Borage is also an edible plant: its flowers are one of the only non-toxic natural products with blue pigment, and both leaves and flowers can be consumed as a fresh vegetable in salads or soups. It is also classified as a traditional medicinal herb. Currently, borage is primarily commercially cultivated for its seed oil, which is a source of gamma-linolenic acid (GLA), which is used in dietary supplements. The quantities of borage in this design are too low for this purpose, but it can be sold as an edible plant in creative salad mixes.

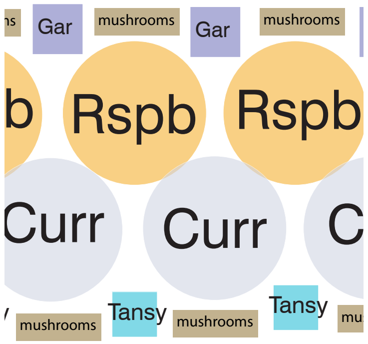
KEY BENEFITS

Producing this set of crops in a greenhouse has some key financial advantages, similar to those gained through the tree polyculture.

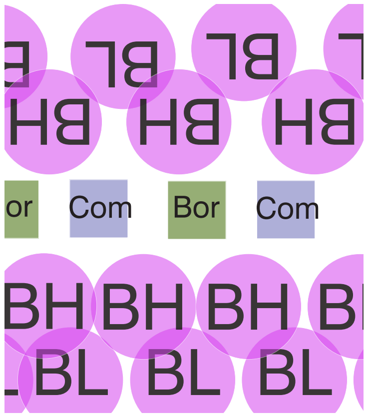
- **The grower can avoid common problems facing outdoor berry production:** bird predation (all berry crops).
- **The production season can be strategically extended:** by planting a mix of early and late cultivars, the harvest period can be greatly extended, especially by taking advantage of the early fruiting possible in a greenhouse.
- **Additional co-products, such as mushrooms, are easier to produce in climate controlled conditions than in an outdoor agro-forestry system.**
- **This system produces a large variety of high value berry products for local sale at retail prices, and can potentially be very profitable.**

DESIGN 2 : BERRY POLYCULTURE





Berry varieties are planted in alternating rows with garlic, tansy, and rhubarb as companions. Mushrooms are cultivated on racks in the shade of the bushes as well as on soil. In early years of production, beans are intercropped among the berry bushes.



Highbush blueberries are stacked with low bush blueberries, taking advantage of similar soil demands. A row of borage and comfrey is planted between. Thyme and sage are planted in the understory. In early production years, winter squash grows in between the berry rows.

CROP SELECTION

Production crops:

- Raspberry
- Red Currant
- Gooseberry
- Blueberry
- Lignonberry
- Rhubarb
- Garlic
- Turnips
- Beans
- Winter Squash

Mushroom Production:

- Elm Oyster
- Shiitake

Nutrient Recovery:

- Elm Oyster
- Winecap Stropharia

Nitrogen fixers:

- Bush beans
- Clover

Dynamic accumulators:

- Comfrey

Ground covers:

- Thyme
- Sage

Pest suppression:

- Borage
- Tansy (raspberries)
- Garlic

Insectary:

- Clover
- Comfrey
- Borage

Shading

- Raspberry
- Red Currant
- Gooseberry

Ornamentals:

- Borage
- Tansy
- Comfrey

RASPBERRY

Function	Food Crop
Spatial Role	Mid-Story
Rooting	Shallow
Sunlight	Full Sun - Part Shade
pH	5,6 - 6,2
Water	1000 mm
Minimum Temperatures	-30° C
Nutrient requirements	high (cover crops or fertilizer)
Soil	sandy loam
Pests & Diseases	raspberry beetle, downy mildew, powdery mildew, redberry mite, leafrollers
Pollination	self-pollinating

Raspberries need rich organic matter and heavy mulching (15 – 20 centimeter layer). They need to be planted fairly shallowly because they send up new canes every year. They fruit on 2-year old canes. After the 2-year old canes fruit they die and should be pruned out. The yield per plant roughly 2,5 kilograms. They reach full production in 2 - 3 years, and their productive lifespan is 10 - 20 years. 600 - 1000 chill hours per year. Recommended planting distance 0,45 x 1,7 meters. Ultimate size is 1 X 2 meters (height x spread).

RED CURRANT

Function	Food Crop
Spatial Role	Mid-Story, 1 - 3 meters high
Rooting	Medium
Sunlight	Full Sun - Part Shade
pH	5,5 - 6,5
Water	1300 - 1500 mm
Minimum Temperatures	-5° C
Nutrient requirements	medium - high
Soil	fine sandy loam, good drainage
Pests & Diseases	root lesion, dagger nematodes
Possible Cultivars	Red Lake, Krasnaya viksne
Pollination	self-pollinating

Red and black currants reach a mature height of 1 - 2 meters. They will live 40 to 50 years or more. The plants should be spaced 1,6 meters with 2 meters between rows. They require 800 - 1500 chill hours per year, depending on cultivar. They are typically harvested in June - July. Fruit storage life is 4 - 7 days. Age at first crop 3 - 5 years, Age to full production 5 - 10 years. Yields 3 - 4,5 kilograms per plant. Perhaps the most promising currant cultivars are Krasnaya viksne, Red Lake, Jonckheer van Teets, and Rovada, because of their high yield and high berry stability. The fruit may be eaten fresh or used for pies, jams, jellies, or juice.

DESIGN 2 : BERRY POLYCULTURE

GOOSEBERRY

Function	Food Crop
Spatial Role	Mid-Story, 1 - 3 meters high
Rooting	Medium
Sunlight	Full Sun - Part Shade
pH	5,5 - 6,5
Water	1300 - 1500 mm
Minimum Temperatures	0° C
Nutrient requirements	high
Soil	rich clay loam, good drainage
Pests & Diseases	root lesion, dagger nematodes
Pollination	cross-pollinating

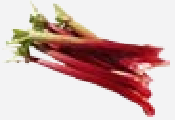
The gooseberry is a bush growing 1 - 3 meters tall, covered in sharp spines. Most European gooseberry cultivars are quite susceptible to disease. The best options are US hybrids such as Glendale (low chill requirement) and Poorman (few thorns, high yield, good taste, and disease/ mildew resistance). Multiple cultivars can increase yield through cross pollination opportunities. Gooseberries are eaten fresh, used in desserts or jams, or made into fruit wines or teas.

BLUEBERRY

Function	Food Crop
Spatial Role	Mid-Story
Rooting	Shallow
Sunlight	Full Sun - Part Shade
pH	4,5 - 5,5
Water	1000 mm
Minimum Temperatures	-40° C
Nutrient requirements	high (cover crops or fertilizer)
Soil	fine sandy loam, good drainage
Pests & Diseases	birds, blueberry maggot fly, strawberry rootworm, blueberry spanworm, blueberry flea beetle, blueberry leaf beetle, blueberry thrips, blueberry sawfly, gall midge, grasshopers.
Pollination	self-pollinating

There are two common blueberry variants: high bush and low bush (wild). Blueberries prefer sandy, well-drained, acid (pH 4.5 – 5.5) soils high in organic material. They have shallow roots that form a mat, seldom reaching deeper than 35 centimeters and mostly found within 15 – 25 centimeters of the soil surface. Blueberries need good drainage, which can be improved by cultivating them in a raised bed.

RHUBARB



Function	Food Crop
Spatial Role	ground crop
Rooting	Deep
Sunlight	Full Sun
pH	6,5
Water	500 mm
Minimum Temperatures	° C to ° C

Rhubarb is a perennial plant that thrives in cool conditions, is very winter hardy, and resistant to drought. It remains productive for 8 - 15 years. It's stems are harvested for the production of jams and pie fillings. The plant becomes dormant in winter. Temperatures below 5 C are required to stimulate spring reemergence. High summer temperatures suppress plant growth, leaving only early leaves. Foliage growth resumes in later summer when temperatures fall.

PRODUCTION DEMANDS & TIME LINE

SYSTEM LONGEVITY

Most of the crops suggested here are perennials with a long production cycle. Blueberries can continue to produce for 40 - 60 years, raspberries for 10 - 20 years, lignonberries for 30 years, and rhubarb for 10 - 15 years. This system is therefore quite a bit longer-lived than the tree polyculture described in the first design.

Beyond the primary perennial crops, there are a variety of annual crops, companion plants, and fungi that are recommended here to complement the plant system.

PRODUCTION PLAN SKETCH

Site establishment
To prepare the site for berry production, the soil at the site will need to be well-drained and acidic. An average pH of 5,5 is suitable for all of the plants selected here. Blueberries prefer slightly more acidic soil (4,5 - 5,5) and rhubarb slightly less (6,5), but both can tolerate a mean acidity in the 5,5 range.

Most berries also have a fairly shallow rooting structure and require heavy mulching with wood chips or leaf litter for optimal growth.

Cultivar selection
As with the tree polyculture, berry cultivars should be selected for disease resistance and optimal fruiting period. Different berry cultivars with a range of chill hour requirements can be selected to extend production season. Berry cultivars also range in terms of yield, quality, and size of the berries. Lignonberries require specific pollinator cultivars to be included as part of the cropping cycle (at least 10% pollinator cultivars).

General guidelines
Detailed cultivation guidelines need to be looked at for each of the crop types recommended here. The general pattern of production involves planting the bushes in late fall or early spring. All of these berries do well a well-drained, acidic loam of about 5,5 pH. They need rich organic matter, heavy mulching, and relatively shallow planting.

Raspberries are not pruned in the first year, but are trained on a trellis from then on. The other berry varieties need annual pruning to keep an open center for better light access.

Berries produce fruit on wood of various ages. Raspberries produce on 2-year old canes, which should be pruned out after fruiting. Blueberries produce on one year old wood, which continues to fruit through its fifth year. Currants and gooseberries produce on tow and three year old wood. Pruning of all varieties is usually done in winter.

As with the tree polyculture, the spaces underneath the berry bushes are suitable for mushroom cultivation. Depending on the season and the ambient greenhouse temperature and humidity, a range of seasonal mushrooms can be cultivated.

In high summer, additional annual crops such as winter squashes and turnips can be planted among the berries for an added yield. These will grow in and mature as the berries head for dormancy. As in the other designs, the greenhouse is left unheated in winter months.

WATER & NUTRIENT INPUTS

The berry polyculture requires greater water inputs than the tree polyculture, since the majority of the crops in this selection have high water requirements. An average of 1500 mm of water should be applied per year. Drip irrigation, or sub-soil pressurized irrigation should be applied twice per week immediately after planting. The plants should also be irrigated in the fall just prior to dormancy (around October).

POLLINATION

To achieve adequate pollination, at least two hives per hectare are needed in the first year and four hives per hectare in May of the second year onwards. At the densities recommended in this plan, it is possible that the number of hives should even be further increased. Several of the berry varieties suggested here are self-fruitful, but in large plantings, even these crops can benefit from additional pollinators.

HARVESTING & PROCESSING

Blueberries ripen from mid-July to late August. They will hold on the bush for several days after ripening. Their full flavor peaks a few days after they turn blue. They should be picked after ripening at several points during the harvest season.

Floricane raspberries, which bear on 2-year old shoots, produce over a 6 – 8 week period. Several varieties are usually planted to extended the harvest season to a four month period (June – September). They are harvested by hand every few days (twice per week) throughout the growing season. An average worker can collect 5 kilograms of fruit per hour.

Lignonberries flower on 1-year old growth, and bloom in two periods: March-April and July – August. The fruit from these blooms ripens in mid-August and mid-October respectively.

Currants and gooseberries ripen over a two week period. Red currants are usually picked as whole clusters. Gooseberries are harvested as individually berries and can be shaken from bushes onto canvas spread below.

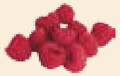
DESIGN 2 : BERRY POLYCULTURE

Most berries are harvested by hand to prevent damage to the fruit. Punctured or crushed fruit has a highly reduced shelf life and needs to be used immediately.

The hand picking of berries is a labor intensive process and is often done using small rakes. Mechanical harvesters are now also available, but often damage the berries too severely for sale as whole fruit.

Berries require immediate chilling after they are picked in order to retain their shelf life.

MARKET & PROFITABILITY

	PRODUCT	YEAR 1 (KG/HA)	YEAR 2 (KG/HA)	YEAR 3 (KG/HA)	YEAR 4 (KG/HA)
	raspberry	0	4.000	5.100	5.100
	red currant	0	0	700	1.400
	gooseberry	0	0	2.500	5.100
	blueberry	0	2.700	2.700	18.300
	lignonberry	0	400	1.500	2.800
	rhubarb	10.800	10.800	10.800	10.800
	garlic	450	450	450	450
	winter squash	2.700	2.700	2.700	2.700
	mushrooms (various)	4.000	4.000	4.000	4.000
	bean	1.800	1.800	0	0
	thyme & sage	1.500	1.500	1.500	1.500

ESTIMATED YIELDS

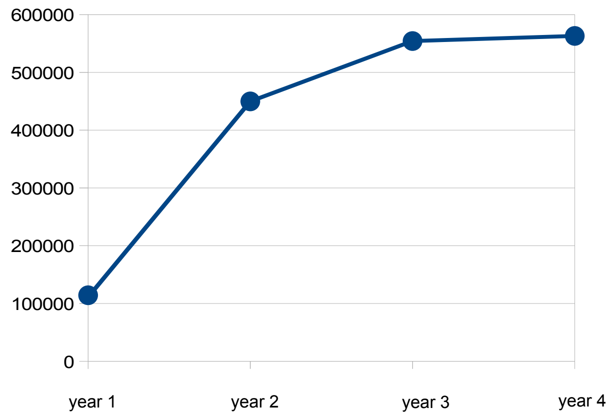
The chart to the left shows estimated system yields for a 1-hectare plot of the berry fruit polyculture. These numbers are estimates derived by calculating per-plant productivity in monocultures with similar cultivation methods to the ones recommended here. These were then applied to this polyculture scenario. The total crop yield per hectare in year four is around 52.000 kilograms. This yield is projected to rise in subsequent years as most berry crops come into peak production in years 5 - 7.

Increasing yields

If the sales of certain co-products in this design are particularly successful, then those products can be increased as years go on. The initial mix of berry crops can also be adjusted from this exact design to increase the balance of certain products in favor of others.

As some of the berries reach the end of their productive life span, they can also be replaced with alternative berry crops that have not been included in this system (for example, blackberries or cape gooseberries).

ESTIMATED RETAIL CROP VALUE (EUROS)



MARKET & SALES POTENTIAL

Common products
One of the values of this particular polyculture design is that most soft fruit berries have very high retail prices, ranging from 12 - 18 euros per kilogram. Though yields in the first year are low, they quickly rise and are maintained for a period of over a decade.

Specialty products
As with the tree polyculture, some of the products produced here will also require special approaches to marketing. Gooseberries, and particularly lignonberries, are more unusual fruit crops that may require thought through sales strategies. Likewise, the more unusual mushroom varieties in this system will also require special marketing approaches.

ESTIMATED COSTS

As with the tree polyculture, most of the capital costs for this horticultural system are in the site establishment: the cost of young plants, the installation of an irrigation system, initial soil preparation, the installation of trellises where needed (for raspberries), and other initial investments.

Based on a per plant cost of 2 - 3 euros and the recommended planting densities here, the initial cost for the berry plants will amount to between 37.000 and 56.000 euros. Land preparation, trellis construction, and planting will take an estimated 450 hours per hectare, with an additional 100 hours of labor for the planting of annual and companion crops. Annual operational labor includes an estimated 20 hours per hectare of weeding and pest control, and an estimated 2.000 hours per hectare for harvesting in the initial two years, rising to approximately 8.000 hours of harvest labor at peak production in years five and onwards. Post-harvest cleanup and pruning will require an additional estimated 250 hours per hectare.

Once again, these costs are estimates derived from data based on monoculture systems and these assumptions need to be tested in practice. Energy costs, insurance, office costs, and additional material inputs such as nutrients are also not included here. Based on the labor and plant costs alone (assuming labor is charged at 15 euros per hour), the cost of establishing this system come out to an estimated 50 - 60 thousand euros. Annual operational labor thereafter is estimated at 9.000 hours per hectare, or 135.000 euros.

The cost of marketing and sales, when taken to be 30% of the overall retail value of the crop, could potentially reach 165.000 euros per year. Because the system requires chilling and dormancy in the winter, no additional heating or lighting is required, saving on these costs over a standard operation.

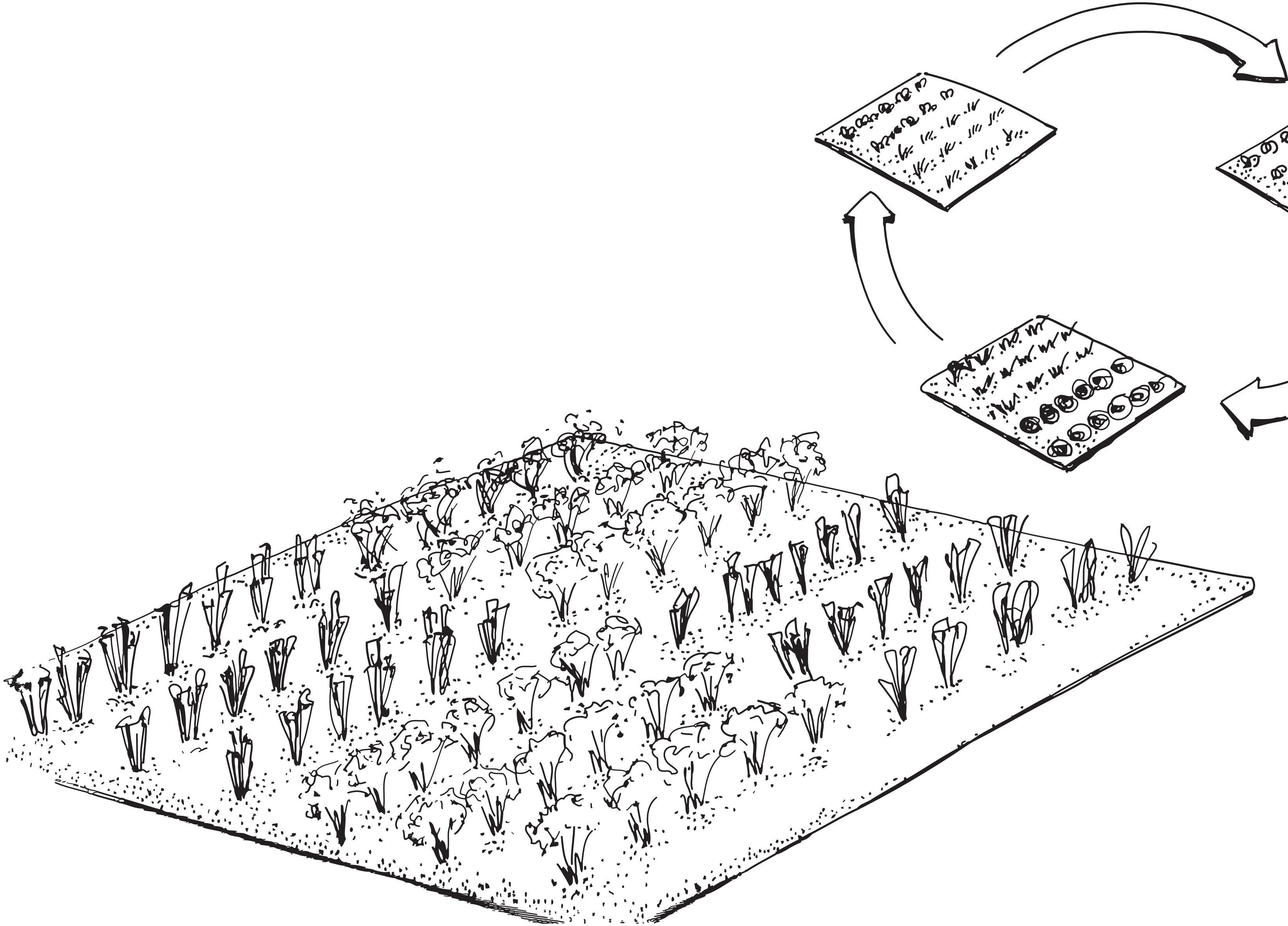
ESTIMATED PROFITABILITY

In the first year of the berry polyculture, some of the costs of establishing the system can be offset by sales of beans, herbs, winter squash, and mushrooms, which have yields from year one. However, as shown in the graph on the left, annual revenues quickly rise as berries begin producing in the second year.

One risk factor for achieving this upper range of profitability is the perishability of some of these soft fruits, in particular raspberries and currants. Sales channels need to be secured well in advance of harvest. Processing options (such as juices or jams) are one means of avoiding total crop losses.

By year four, the estimated retail values of the crops produced reach approximately 560.000 euros.

As with the tree polyculture, if this system is established in an existing greenhouse not in need of particular maintenance, and assuming a high rate of successful sales at near-retail prices, the berry polyculture as described here should produce a return on investment within the first two years. However, many standard costs are not accounted for here because they vary so greatly between operations, so these figures would need adjusting based on individual farm conditions.



DESIGN 3 : ANNUAL POLYCULTURE

ANNUAL POLYCULTURE

The annual polyculture has a very different format from the other two designs presented in this report. it consists of a crop rotation and relay cropping strategy for a series of four plots under continuous cultivation.

The combination of crops selected here is focused on achieving a year-wide production schedule with harvests in each month, including throughout the winter. This is possible by using cold-tolerant varieties of greens and root vegetables.

Some of these crops are typically not considered high-value enough to be grown in a greenhouse. The benefits of doing so in this case are to make use of unheated greenhouse space and to gain slightly higher margins for early and late varieties of these typical crops.

DESIGN OVERVIEW

DESIGN SUMMARY

This greenhouse polyculture design focuses on an in-soil annual crop combination that is suitable for year-round production in an unheated greenhouse. The plan takes advantage of succession planting (using the same area for the production of multiple crops that mature in sequence throughout the year) and relay cropping with the same crop to create an extended production season.

This design is very different from the previous two in that uses a very intensive and high density cropping approach to produce year-round, with harvests made in every month of cultivation. One hectare of such a system is projected to have a per hectare yield of approximately 500.000 kilograms of produce per year, using conservative yield estimates. At estimated retail prices for all of these products, the total potential revenues amount to around 2,5 million euros per hectare.

There is a great deal of flexibility in the selection of crops and cultivars in this system. The current selection used in this design includes:

› mizuna
› claytonia
› mache
› red oak lettuce
› tomatoes
› green onions
› onions
› leeks
› carrots
› beets
› spinach
› beans
› zucchini
› radish
› head lettuce
› peas
› arugula
› parsley
› bok choy

CULTIVATION APPROACH

This production of these crops is focused on the annual rotation of four types of plots, pictured in the graphic to the right. Each block represents an area of 10 by 10 meters, with beds of 75 centimeters in width.

Over the course of four years, the production cycle will return to same plot where it initially was (plot 1 takes on the cropping cycle of plot 2 in the second year, plot 2 takes on plot 3, and so forth). The cultivation requires very dense crop spacing (much denser than typically recommended)[1], and multiple cycles of harvest per year.

Several of the crops are planted over the winter in an unheated greenhouse (onions, greens, root vegetables). During these winter months, growth is much slower than usual, but the cold-hardy crops selected can easily withstand very low temperatures (even freezing temperatures in some cases).

These “overwintered” crops can be left in the ground and harvested as needed. This also means that crops can remain perfectly fresh without the need for storage or refrigeration, and the overall crop losses can be reduced. With this naturally-extended storage time, growers can have more time to spend on getting their crops sold in local markets.

1 *The recommended planting distances are derived from the “Winter Harvest Handbook,” which also presents the results of similar succession cropping cycles at a farm in Maine, USA.*

The crops sold in winter are also somewhat limited in this particular design, but these can easily be expanded to include turnips, turnip greens, Swiss chard, watercress, fennel, kale, and broccoli.

KEY BENEFITS

With each plot in constant production, the potential yields of the system are very high. This polyculture approach offers the additional potential benefits:

- **Crops are produced year-round without supplemental heat or lighting, which also results in some cost savings to the grower.**
- **Winter-grown crops can be left in the ground for harvesting as needed, saving on storage costs.**
- **The design is flexible and crops can be switched out on a yearly basis if they are not selling at the desired rate.**

DESIGN 3 : ANNUAL POLYCULTURE

	January	February	March	April	May	June	July	August	September	October	November	December
PLOT 1	winter salad mix			fallow	tomatoes					fallow	onions	
PLOT 2	onions			leeks, carrots, & beets				fallow	spinach			
PLOT 3	spinach			fallow	early beans & zucchini			zucchini & carrots		winter carrots & leeks		
PLOT 4	winter carrots & leeks	radish & head lettuce			peas + arugula & herbs			arugula & herbs + asian vegetable mix			fallow	winter salad mix

PRODUCTION DEMANDS & TIME LINE

SYSTEM LONGEVITY

This is an annual polyculture system, which requires the same continuous inputs every year in terms of equipment, seeds, nutrients, and labor. For this reason, it is also a flexible system where crops that are selling unsuccessfully can be replaced, provided they also fit into the crop rotation scheme without causing any known conflicts.

PRODUCTION PLAN SKETCH

Site establishment
The site should be prepared to a standard pH of 6,5, with high nutrient quality (ideally a nutrient -rich loam). The crop designs here are planned out using beds of 75 centimeters in width with 75 centimeters of spacing. Each bed is 10 meters in length.

Cultivar selection
The selection of cultivars for this polyculture is one of the most important factors in ensuring that both production and sales are successful. Though many of the plants described here are common vegetables, selecting particularly tasty varieties that can outperform competing vegetables on the market is an essential step to achieving successful sales.

General guidelines
Once again, detailed cultivation guidelines should be followed for each crop and cultivar. The general principles of production in this model are based on the very dense planting of complementary crop varieties. Crops that are recommended for interplanting in this plan, such as radishes and head lettuce, have complementary maturing times. The radishes mature very quickly and can be picked out in time for the lettuces to grow in between them and mature.

Winter planted crops are protected with rolls of fabric for added insulation and protection against freezing.

HARVEST & PROCESSING

The vegetative crops here are harvested continuously for their leaves, and can go through 4 - 5 harvests prior to plant removal. All harvests are done by hand. Vegetables that are planted for the winter season will grow at half of their usual rate without supplemental heat or lighting, however, they will continue to grow. These can be harvested as needed throughout the winter season. In some cases, winter cold can improve the flavor of the crop and further boost its value.

All other crops are harvested according to specific crop guidelines.

OVERALL LABOR ESTIMATES

Seeding, transplanting, and harvesting of each plot will require an estimated 12.000 hours of labor per year. This figure assumes that root vegetables and bulbs are harvested mechanically, while all other crops are harvested by hand. Crop thinning requires around 30 hours per hectare, hand weeding requires an additional 30 hours per hectare.

DESIGN 3 : ANNUAL POLYCULTURE

PRODUCT	(KILOGRAMS/ HA)
mizuna	7.400
claytonia	7.400
mache	7.400
red oak lettuce	14.900
tomatoes	29.800
green onions	1.800
onions	13.400
leeks	14.000
carrots	153.000
beans	1.200
zucchini	2.400

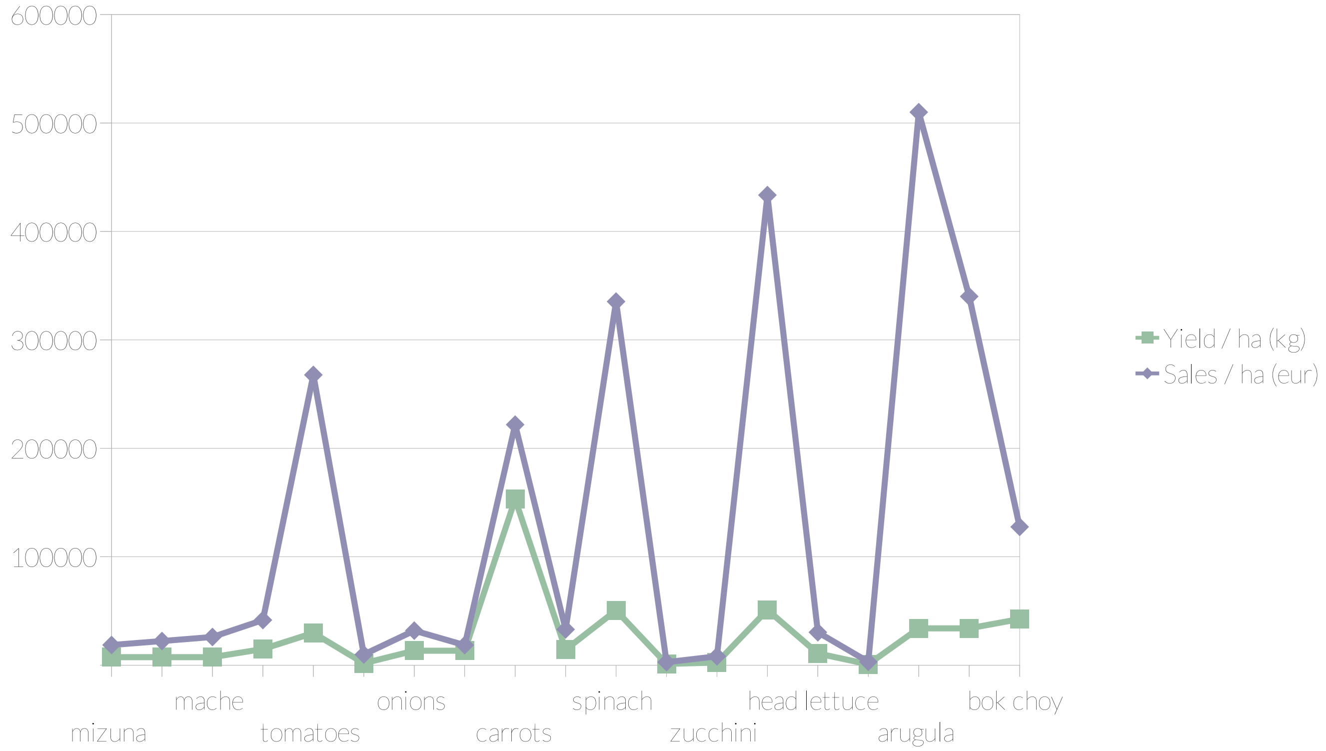
PRODUCT	(KILOGRAMS/ HA)
radish	51.000
romaine lettuce	11.000
peas	900
arugula	34.000
parsley	34.000
bok choi	12.800
beets	14.400
spinach	50.600

ESTIMATED YIELDS

The chart to the left shows estimated system yields for a 1-hectare plot of the annual polyculture system. These numbers are estimates derived by calculating per-plant productivity in monocrop systems with similar cultivation methods to the ones recommended here.

The yields are based on low-end estimates of per plant productivity with a very high density of spacing. They appear very high compared to conventional yields, but this results from the multiple cropping cycles per crop, the year-round cropping plan, and the very high densities. Farmers with small holdings in the United States have reported success at these densities, which is where these recommendations have been taken from.

ESTIMATED YIELDS VERSUS RETAIL CROP VALUE (KG & EUROS)



MARKET & SALES POTENTIAL

Common products
Most of the products here are common vegetables and greens with well established markets. One advantage of this system is that it produces these crops much earlier and later in the season than can normally be achieved. In those parts of the season, the prices for these crops will likely be higher than what is anticipated in these projections.

Specialty products
One of the key ways to gain additional benefit from this production approach is to choose crop cultivars that are not typically available in supermarkets. In this design, we have included some less common greens (mizuna, claytonia), which are very cold tolerant, but also reputably very tasty in salads.

Selecting heirloom varieties of tomatoes or root vegetables is also a possible approach for developing a unique product portfolio that caters to local tastes.

ESTIMATED COSTS

The costs of the hand labor required to manage and cultivate a hectare of this very-intensely cropped polyculture rotation are quite high. The labor is continuous as there is always seeding, planting, or harvesting occuring on one of the four plots. A ballpark estimate of 40.000 hours of labor per hectare is required for all of the functions described here. Once again, this number does not include the cost of inputs, insurance, energy, or other contextual costs. This amount of labor, if paid at 15 euros an hour, would amount to 600.000 euros per year in costs.

ESTIMATED PROFITABILITY

If all of the crops produced in this system are successfully sold, then the profits can be quite high, even despite the high labor costs. Based on retail prices, the overall value of the crops produced in this system is around 2,4 million euros. Even considering high labor costs, a high marketing expense, and a significant amount of additional costs, the potential for a profitable outcome if sales at retail prices are successfully achieved remains very high.

GENERAL CONSIDERATIONS

APPLYING THE POLYCULTURE DESIGNS

The three polyculture designs described in this section can be applied separately. However, as described earlier, an ideal scenario is one where all three designs are used in combination in different sections of a single greenhouse. The main goal of the polyculture production approach is to limit production to what can feasibly be sold locally at retail prices (matching production to the consumption of local consumers). If a grower is transitioning to polyculture production, then some products can initially be sold wholesale.

A best case scenario is if the grower has his own point of sale, either through a shop or through a produce package that is filled weekly with the crops that were harvested in that time period. Alternatively crops can be sold to local shops or restaurants at slightly lower prices, but still above standard farm-gate values.

The estimated revenues from each of the three designs described here vary considerably. At maturity, the berry polyculture, for example, has an estimated potential revenue of 560.000 euros per hectare per year at retail prices. This is in contrast to the lower revenue of the tree polyculture, which is estimated to produce 350.000 euros per hectare at maturity. The highest potential revenues are predicted by the annual crop polyculture, which can make up to However, they are both worth growing together for the purpose of maintaining product diversity. Assuming that a single family will purchase an average of 5 kilograms each of a variety of fruit crops, a grower can estimate how many families he can service in his local area and scale the system to match. Using this measure, each hectare of the tree and berry polyculture designs is suitable for providing fruits and some vegetables for 1.000 - 2.000 families. Assuming that each family will purchase an average of 40 kilograms of vegetables, the annual polyculture described here can provide for around 10.000 families. These estimates can be adjusted based on local consumption patterns, and the mix of products produced in the greenhouse should also be optimized for these local demands.

The costs of establishing a polyculture system are higher than those for a monoculture. However, these costs generally get incrementally smaller for each crop that is added. The basic costs of soil preparation, weeding, and installation of irrigation equipment remain similar on a per hectare basis. Additional labor is required per crop for pruning and harvesting. However, the shared labor for basic crop establishment can ultimately translate to reduced labor per crop output.

MARKETING FOCUS

Because a good marketing strategy is so essential to achieving a financially successful polyculture greenhouse, a sales strategy needs to be a core factor prior to embarking on production. Prior to starting soil preparation and creating a detailed planting schematic, the grower must answer the following key questions related to his or her target market:

› How long should the harvest season be?
› When should fruit production start and end for each fruiting crop?
› What is the required quality of fruits?
› What is the maximum quantity of each fruit type that I can locally sell, and through which potential channels?

SEASONAL PRODUCTION SHIFTS

Both the annual polyculture and the mushroom production in the tree and berry polycultures go through a significant seasonal cycling pattern. To take maximum advantage of temperatures within the greenhouse, a variety of mushrooms can be intercropped in the polyculture depending on the season.

A target for any polyculture system designed for local sales should be to maintain production year-round. The marketing strategy also should reflect this seasonal shift, with specialty products highlighted at the change of each season.

PRODUCT LONGEVITY AND PROCESSING

A unique concern with polyculture production is the risk of not selling all the products that the system outputs. One way of managing this risk is to set up a small facility for processing unsold products. Many products can be canned or dried, retaining their value for over a year in processed form. The added costs of setting up and running a small scale processing facility have to be measured against the potential added benefit. This is also a cost that could be shared between several growers if a cooperative sales model is developed.

CONCLUSION

We believe that moving to polyculture greenhouse cultivation can have system-wide benefits for the human food production cycle. It can bring more profits directly to growers, supply a more consistent year-round labor cycle, and provide opportunities for connecting people with their food supply.

If each greenhouse producer in the Netherlands catered to supplying the needs of 10.000 local customers rather than selling to a broad, distributed global chain of wholesalers, there would be a need for around 1.600 fruit and vegetable producing greenhouses in the Netherlands, each with the opportunity to earn at least 5 million euros in turnover from these local customers. Adding in livestock and fish production to create full "food-producing" ecosystems would make this production approach even more cost effective and profitable for growers.

Though this end scenario is unlikely to ever be fully achieved, moving towards it from the current extreme focus on monoculture has many potential benefits. There also remain some significant challenges.

CHALLENGES

Current greenhouse locations

Many greenhouse growers are located in relatively remote areas, far from population centers that they could readily sell to. Transporting their produce long distances to where it can be sold adds additional logistical complications and costs. Adopting a polyculture approach is therefore best suited to growers located close to more densely populated areas, or those with relatively easy access to those areas.

Knowledge demands

The knowledge required to transition to a multi-cropping solution is a high barrier. Most growers are extremely specialized in their understanding of a single crop, and shifting to a polyculture approach represents, in many ways, a cultural shift.

Marketing expertise

Many growers do not have sufficient marketing expertise or enough time to develop it. Forming collectives of growers working towards local sales can be one way of overcoming this barrier.

ADOPTING POLYCULTURE

Moving to a polyculture approach to production is most likely to be achieved in two ways:

- Old greenhouses can be repurposed directly for polyculture production at low capital investment.
- Existing monoculture greenhouses can scale down some of their primary crop production and replace it with polyculture, using their newly diversified output to develop local markets.

Simply adding in one or two crops to an existing system is unlikely to be sufficient for building out significant local sales channels and marketing. A local shop or vegetable package needs to have some amount of diversity before it becomes appealing to customers.

TOWARDS THE FULL SYMBIOCULTURE VISION

The greatest benefits of polyculture are to be found in a system that approaches more of the complete Symbioculture approach, as outlined in the original Polydome design. This includes livestock and aquaculture alongside crops. The waste flows between plants and animals can be connected, saving money on nutrient inputs and pest control. A move in this direction becomes more feasible once the first barriers of establishing multiple product streams for local sale are crossed.

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IMAGE CREDITS

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