Foundation of Synecoculture: Toward an agriculture of synthetic and profitable ecosystems

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Abstract

We introduce a novel system, called synecoculture, for small-scale agriculture mainly for the culture of vegetables and fruits based on the synthesis of ecosystems. The synecoculture consists of associating a strategic variety of edible plants with high density in accordance with their symbiotic interactions with soil, environment, and other vegetation in order to realize high productivity in total output and augment the biodiversity of the culture beyond the natural state. In this system, a thinning harvest from mixed and dense vegetation is effective for both year-round harvest and weed control without machinery. In this article, we report basic experiments of synecoculture in Japan without soil cultivation, external fertilizer, or pesticide/herbicide. The results strongly imply that, if sufficient information on ecosystem dynamics is provided, synecoculture's multifaceted possibilities can make it more ecological and profitable than conventional monoculture systems.

Keywords: High-density polyculture, thinning harvest, non-cultivation, non-fertilizer, chemical-free, relationalism

1. Introduction

1-1. Problems of conventional agriculture (CA)

Today's conventional agriculture (CA) is causing many environmental problems due to intensive agriculture caused by excessive use of chemical fertilizers and pesticides/herbicides: degradation of soil, pollution of underground water, and loss of biodiversity (Bates and Hemenway, 2010).

1-2. Problems of biological agriculture (BA)

To resolve these problems of CA and to propose alternatives for sustainable development, the advantages of biological agriculture (equivalent to organic agriculture in France) (BA) have recently been studied from ecological and economic viewpoints (Fleury, 2011). Although BA generally implements quantitative changes such as replacement of chemical substances by natural ones and biodiversity conservation around the exploitation, it is still based on three basic principles of CA: tillage, fertilization, and elimination of weeds and pests. These three principles are actually interrelated and form a vicious cycle: tillage is necessary to suppress weeds, which consequently destroys the soil ecosystem, which to compensate for lost soil fertility requires the use of more fertilizer, which augments pests and the propagation of pathogens.

1-3. Element-based optimization and physiological optimization of CA/BA

The common typology of methods between CA and BA is a direct consequence of an agronomical paradigm based on elementalism. Since the emergence of agriculture, humans have been exploiting nature by cutting complex interactions in wild ecosystems to facilitate the control of vegetation and augment the productivity of a small variety of edible species. The extreme realization of such element-based optimization on individual plants is represented by a vegetable factory, which extends the artificial control of plant growth to all possible environmental parameters.

If the productivity of an agricultural system is not compatible with the preservation/construction of the environment, so-called sustainable agriculture systems are actually situated somewhere between the natural ecosystem and CA, always on the course of elementalism.

CA and BA are based on the physiological optimization of products, by providing edible plants with sufficient space, light, nutritive elements, and water, to maximize the growth of a single species without ecological competition.

1-4. "Monoculture on desert"

Consequently, today's agricultural exploitations with sufficient productivity offer similar scenery in terms of vegetation, which can be described as "monoculture on an artificial desert".

In the paradigm of elementalism, physiological optimization of individual plants inevitably requires the reinitialization of field vegetation by tillage. This treatment eliminates weeds and essentially destroys soil's ecosystem functions, which makes the soil similar to a desert in terms of existing vegetation and soil structure. In contrast, nature contains the self-organization of ecosystem functions that spontaneously establishes dense and rich vegetation under the constraint of given climate conditions. Today's agriculture benefits from this capacity only in the period of fallow, which does no more than simply recover the soil quality. However, non-tillage practice in CA/BA cannot provide a practical solution to control weeds and prevent productivity decline.

2. Foundation of synecoculture

2-1. Definition of synecoculture

We introduce a novel system of small scale agriculture to produce vegetables and fruits by synthesizing edible ecosystems, namely synecoculture, to resolve the dilemma of elementalism in a completely ecological manner and to develop agriculture that is more profitable than CA.

Synecoculture consists of the strategic association of plants according to their functional properties, such as interactions with soil ecosystem and other environmental factors, in order to assure their diversity and productivity by augmenting their biodiversity and associated ecosystem functions beyond the natural state. Synecoculture is based on the following three principles, which present the solution to the dilemma of CA: high-density and high-diversity polyculture, thinning harvest from competitive plant population, and no usage of tillage/fertiliser/pesticide/herbicide. We introduce nothing more than the seeds and seedlings of vegetables and fruits in the field.

2-2. Many-to-many correspondence between elements and functions

These principles methodologically contrast with the elementalist framework of CA/BA, the latter being based on the one-to-one correspondence between the elements and desired functions. In CA, we invest seeds for the harvest, fertilizer to augment soil fertility, and pesticide/herbicide to control animal pest/weed.

In contrast, synecoculture is always based on the many-to-many correspondence between plural elements and functions present in ecosystem dynamics, and each is superposed on others. For example, seeds and seedlings are introduced not only to gain harvest but also to control pests and weeds with their allelopathic properties. In fact, the presence of insects that are considered harmful in CA is not completely negative in synecoculture. If excess nitrogen fertilizer remains in the soil, or if the field has been tilled before and soil structure is destroyed, it is natural as an ecosystem process for certain insects to emerge during the process of recovery. In this phase, vegetables damaged by insects help to restore soil quality.

As an example, asteraceae and fabaceae plants grow relatively well on poor soil. We could actually count on the harvest of these plant families from the first year of a synecoculture experiment. Furthermore, asteraceae plants repel harmful insects, and fabaceae plants augment the biological fixation of nitrogen in soil, which helps to stabilize the ecosystem and ameliorate soil quality. In contrast, brassicaceae plants are generally too weak to survive in the initial phase and are damaged easily by insects, in which case they serve as natural fertilizer and an indicator of soil quality. After a few years of ecological succession, with the construction of rich biodiversity and associated soil amelioration, the situation changes: the field harbors better growth of brassicaceae, while asteraceae propagates much less than in the initial phase.

The role of fruit trees in synecoculture is another example of functional superposition. The desired functions of fruit trees are to 1) create sufficient shadow to give environmental advantage to vegetables against photophilic weed, 2) attract bird species for insects control, and 3) provide the field with withered leaves that serve as natural compost on soil surface. The harvest of fruits is considered only as the 4th function in this case.

2-3. Utilization of ecological succession

Even weeds that are rejected in CA have important value in synecoculture. If we look at a populational level, weed invasion is a part of long-term ecological succession. Each weed species thus contributes a certain property to ameliorate soil quality toward the realization of climax phase vegetation. If a weed species invades despite a high-density polyculture, we will consider utilizing its positive effect and involving it in the wider context of ecological succession. Annual weeds have especially important effects on the formation of soil ecosystem functions. In summer, they grow apace and protect soil surface from aridity. In winter, they wither and leave small gaps and capillaries along the roots filled with organic substances, which harbor the propagation of useful microbes.

All the relationships and functions of each species in the actual development of an ecosystem are still beyond our knowledge, which makes it principally difficult to have full control over it. It is therefore essential to diversify possible functions of the field ecosystem in order to minimize the risk and to fortify the capacity for self-organization with natural regulation ability.

2-4. Relationship-based optimization

This approach of optimization at the level of ecological population composed of the superposition between plural functions and elements, or synecological optimization, belongs to the framework of "relationalism" not elementalism, which is limited in terms of individual and physiological optimization. Relationship-based optimization studies the correspondence between plural elements and functions and tackles complex systems where organization of interactions plays an important role in the emergence of global dynamics (Funabashi, 2010).

Synecoculture is therefore based on relationalistic optimization, which aims to augment the productivity by enhancing interactions in ecosystems beyond the natural state.

2-5. Physiological optimization and ecological optimization

The principle of high-density polyculture is what typically distinguishes synecoculture from CA/BA. In wild prairies or fallow fields where tillage is not necessary for maintenance, we can easily find more than 10 plant species in competition and symbiosis. In other words, to realize ecosystem functions that can achieve self-sufficient sustainable material circulation, agricultural exploitation requires at least this level of biodiversity.

In this respect, even the prevalent concept of companion plants is not sufficient if it treats only the association of fewer than 10 species on a cultivated field without other vegetation.

In a synecoculture experiment, we initially introduced a mixture of about 500 kinds of vegetables and fruit trees on a surface of $1000m^2$. In addition, each plant attracts particular insects (For example, cabbages attract butterflies), which further attract other animals in the region. This has led to constructing a highly concentrated food chain in the culture and therefore augmented biodiversity that is largely beyond the natural state.

In synecoculture, plants are simultaneously in competition and in symbiosis as on a natural prairie. They organize complementary relationships with each other and with the state of soil. Therefore, no plant can fully attain its physiological optimum, but can find viable conditions in accordance with the surrounding vegetation. This state of complementariness in polyculture away from the physiological optimum is called ecological optimum, which corresponds to most growth environments of plants in natural environments (Putman et Wratten, 1984). In contrast to CA/BA, which pursue principally physiological optima, optimization of productivity in synecoculture is based on ecological optima.

2-6. Modality of harvest in synecoculture: Thinning harvest from competitive population of vegetables

Application of ecological optima naturally changes physiological characteristics of plants from those of CA/BA. We found that young shoots and flowers of most vegetables also become edible with high quality in the environment of synecoculture. Additionally, the growth rate also varies among individual plants in the state of ecological competition. As a consequence, we need to reconsider the modality of harvests in diverse and asynchronous culture. Since the culture density is high with numerous species in competition, a thinning harvest from a competitive population is appropriate to maintain the system. Weed control is made possible by slight manual labor simultaneously with the harvest and sowing. This modality drastically changes the harvest frequency and rate. Unlike CA/BA that require the maintenance of culture for several months until the harvest season, synecoculture is composed of a year-round daily harvest without an off season and, according to necessity, light duty maintenance of weeds without heavy machinery. High-density polyculture can drastically reduce the need for weed control. Although the daily harvest cannot generally exceed that of CA/BA during harvest season, the total annual sum of synecoculture can be far superior.

3. Experiment of synecoculture

3-1. Preliminary experience and estimated productivity

We first measured species-wise productivity in polyculture on a $10m^2$ surface.

Preliminary experience on the $10m^2$ surface is summarized in Table 1. The monthly mean of a harvest is 9,000 yen, a total of 108,000 yen/$10m^2$ per year. If we proportionally calculate the productivity for a larger surface, the result would largely exceed that of CA, which is generally limited between 200,000 and 300,000 yen per year on a $1000m^2$ surface without counting input cost.

Table 1. Productivity of synecoculture on $10m^2$ surface. Unit: Yen (1 Euro = 105-135 Yen in 2010). Productivity is calculated with the price equivalent to CA produce in Japan.

October-May (8 months)

Vegetables	Productivity (Price/month/$10m^2$)
Mixture of leaf vegetables, radishes, carrots, broccoli, haricot, soybeans, peas	￥9,000
Haricot, soybeans, peas on fences around the	￥600

field	

July-September (4 months)

Vegetables	Productivity (Price/month/10 m^2)
Mixture of fruit vegetables, tomatoes, cucumbers, melons, eggplants, peppers	￥3,600
Chinese chives for insect control	￥3,000
Tomatoes, cucumbers, melons, haricot on fences around the field	￥1,200

3-2. Experiment on $1000m^2$ with 500 edible species, 20% of practice

Second, we tested a polyculture of 500 edible plant species for three years on a surface of $1000m^2$ (Fig.1). This degree of mixture is much richer than CA or BA, even those with biodiversity concerns. On the most concentrated surface, more than 10 vegetable species coexist (Fig.2). Behind big leaf vegetables hide small seedlings waiting for their turn to grow after the harvest of bigger ones. With this level of biodiversity, ecological regulations for weed and insect control functioned sufficiently and we did not need tillage or pesticides/herbicides. A wide variety of yield was obtained. The region of Japan where the experiment was conducted usually has two months of agricultural off-season (January - February) because of low temperatures. However, the field of synecoculture remained covered with vegetables, and harvest was possible.

This experiment prioritized the observation of biodiversity effects beyond the natural state as well as examined ecological properties of each vegetable and weed. Therefore, the surface is not yet optimized in terms of productivity: high-density polyculture of vegetables was limited to about 20% of total surface, with one hour of daily maintenance work and harvest by one person. The productivity of this experiment is shown in Table 2. Although the productivity optimization is realized only on 20% of the surface, the total amount of harvest in 2010 reached 473,450 yen, which exceeds the standard of CA/BA.

Table 2. Productivity of synecoculture experiment on $1000m^2$, 20% of practice. Unit: Yen (1 Euro = 105 – 135 Yen during 2010). The produce was sold onsite or by home-delivery, with prices equivalent to the produce of BA in Japan, which correspond to more or less 1.5 times higher than the CA prices.

Month	On-site selling	Home-delivery	Sum

12/2009	￥21,000	￥162,200	￥183,200
1/2010	￥2,000	￥27,400	￥29,400
2/2010	￥20,000	￥19,500	￥39,500
3/2010	￥14,000	￥12,600	￥26,600
4/2010	￥21,000	￥4,200	￥25,200
5/2010	￥33,000	￥44,800	￥77,800
6/2010	￥30,000	￥3,750	￥33,750
7/2010	￥14,000	￥0	￥14,000
8/2010	￥0	￥12,000	￥12,000
9/2010	￥0	￥0	￥0
10/2010	￥18,000	￥2,000	￥20,000
11/2010	￥2,000	￥40,000	￥42,000
Sum	￥175,000	￥298,450	￥473,450

4. Conclusion

We proposed a novel method of small-scale agriculture for vegetables and fruits, namely synecoculture, which is based on the high-density polyculture and modality of harvest adapted to ecological optimization.

This system can potentially replace the use of heavy machinery and chemicals with the ecological properties of plants and animals without consistent irrigation, fertilizer, pesticide/herbicide, or tillage. The method may be possible to practice in depopulating and aging communities, or in developing countries that do not have sufficient infrastructure for CA.

Instead of investing energy and materials with element-based optimization, synecoculture aims to control interactions of ecosystems with the use of information. In this sense, synecoculture also present a challenge to transform agriculture into an information-based industry, with even greater concern placed on productivity and preservation/construction of environment.

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Figure 1. Experimental field of synecoculture on 1000m^2 surface at Ise City, Mie Prefecture, Japan

The field of synecoculture is composed of a productive surface raised as ridges about 30cm high, paths for harvest and maintenance work, 1-3m high fruit trees, and fences around the field for climber plants. (Picture taken in late November 2010)

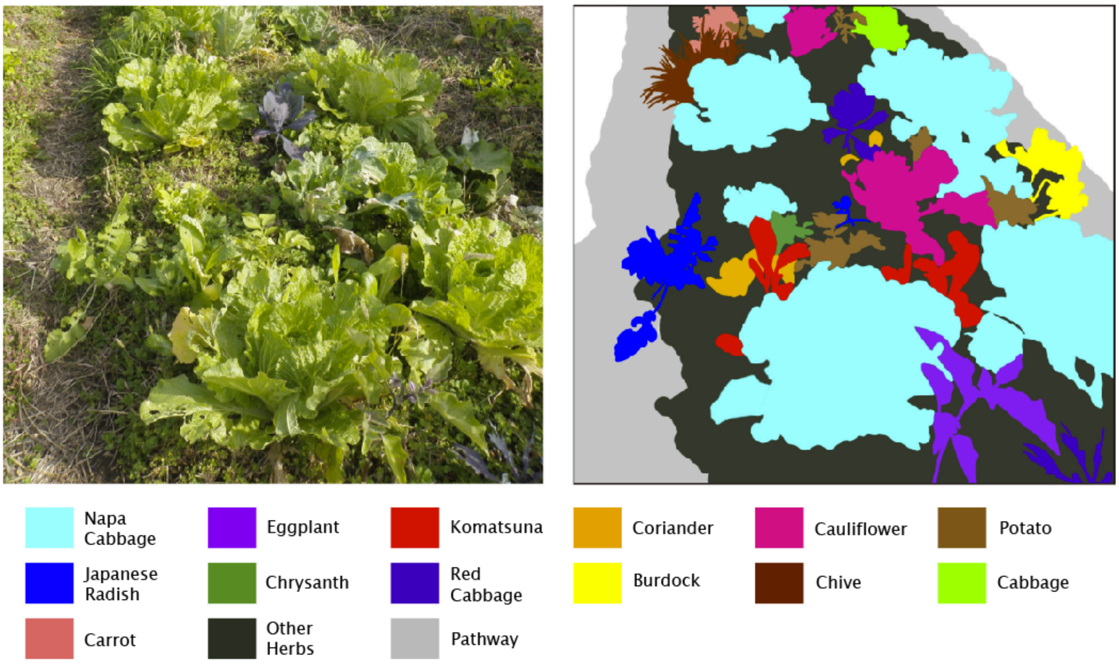

Figure 2. Example of productive surface of synecoculture (Ise City, Mie Prefecture, Japan)

Close-up of productive surface of synecoculture. In this surface of 2m2, 13 different kinds of vegetables cohabit. "Other plants (autre herbes)" zones also contain seedlings of vegetables waiting for their turn to grow after the harvest of bigger plants. (Picture taken in late November 2010)