Designing mixed horticultural systems

MARC TCHAMITCHIAN[1], EMMANUELLE GODIN[2]

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Abstract

In the abstract should be a short introduction and the main results resp. conclusions. It should be understandable without the rest of the paper. The abstract should not exceed 1000 letters (incl. spaces).

Introduction

Organic vegetable production systems are a solution to address the current concerns about the environmental impact of agriculture (Bellon and Hemptinne, 2012). However, these systems remain relatively specialized. Agroforestry systems mixing fruit trees and vegetable crops make a better use of biodiversity and offer a good response to economic challenges such as being able to fulfill the local market requirements, continuous provisioning of vegetable but diversified food.

Designing mixed cropping systems based on fruit and vegetable is a real challenge because they combine interactions of different nature (ecological, economical and social), which take place both in time and space. Therefore, automatically building prototypes exploiting the advantages of agroforestry would be of great help. The goal of this study is to assess the validity of the methodological choice to design mixed fruit-vegetable cropping systems by automatic inference using the constraint satisfaction problem approach. The following part surveys the knowledge necessary to describe such mixed systems and how it has been modeled as constraints. The next part presents and discusses the results obtained so far.

Material and methods

Knowledge base

The necessary knowledge encompasses the agronomic knowledge concerning the potential crops, fruit trees and vegetable crops. We have chosen to focus on only one fruit tree variety, apple, and on a selection of vegetable crops that would allow for variable planting dates along the year and would need different cropping duration: lettuce, tomato, onions, melon and carrots. We have added a green manure, as it is a required practice for the restoration of the soil fertility. This knowledge has been augmented with the necessary information concerning the potential interactions: root extension dynamics and crop sensitivity to shade and microclimate modifications. In many case, it has not been possible to obtain a quantitative description of these effects. In such cases, local agricultural advisers' knowledge has been used. Other interactions represented were in relation to the development of the roots of the different crops, leading to competition or sharing of water and trophic resources.

Model formalism

The main inference challenge in the present study is linked to the combination of time and spatial dimensions in the problem. Recently such a problem has been solved using the Weighted Constraint Satisfaction Problem (WCSP) methodology (Akplogan et al., 2011). It consists in representing the problem to solve in a set of variables, which can take a finite number of states, and a set of constraints, algebraic relations linking variables. In the WCSP approach, the search for a solution tries to minimize the sum of these weights (or costs), and finally proposes all solutions associated to this minimum.

The problem being to allocate crops (annuals and perennials) on a piece of land, is has been represented as a set of variables representing a unit land area at a given time (a cell). Visually, it results in a set of matrices of cells, each matrix corresponding to the same cultivated plot, the sequence of matrix giving the evolution in time of its occupation by the crops. The inference engine used is an open-source solver, toulbar2 (de Givry et al., 2005). Because of its limitations and of the maximum size of the problem it is known to be able to handle, we have limited our problem formulation to about 1,000 (one thousand) variables. Therefore, we chose to represent the piece of land of interest as a square grid of 10x10 cells. We also divided time into four

[1] INRA, UR 0767 Ecodéveloppement, Avignon, France. http://www.paca.inra.fr/ecodeveloppement. mailto:marc.tchamitchian@avignon.inra.fr
[2] INRA, UR 0767 Ecodéveloppement, Avignon, France. http://www.paca.inra.fr/ecodeveloppement.

seasons for the within year evolution, and in three periods for the tree growth. The first period corresponds to young trees, the second to intermediate growing trees, not yet producing fruits and the third period corresponds to their maturity. The evolution of their potential shade is presented in Figure 1. On the contrary, the roots extend progressively along these periods. Each tree growing period may last several years, however a one year rotation is represented for each period. Therefore, we have 12 time intervals, 4 seasons x 3 periods to represent. The final model consists of 12 matrices of 100 variables each.

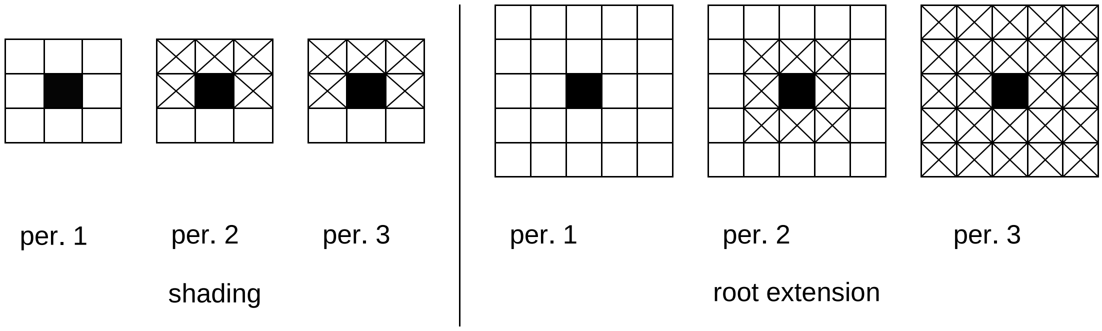

Figure 1. Evolution of the spatial influence of the trees. Dark cells host a tree, checked cells are shaded in periods 1, 2 and 3 (left) or host tree roots in periods 1, 2 and 3 (right).

Conclusion

The work described here showed that the WCSP formalism can tackle the problem of designing complex agroecosystems needing to allocate crops both in time and space in one same rationale. However, it also showed that the available mathematical tools had limitations which deprecate the interest of the proposed solutions. It also showed that some key knowledge on the interactions at play in these systems are still lacking, although they are essential to the sustainability of these mixed cropping systems, especially when grown organic. This draws line for future research, both in the agronomic domain and in operations research.

Figure 2 shows an example of a solution. Crops taking benefit from the tree proximity (tomato in summer for example) are located in the areas where they are shaded in summer. On the contrary, crops that suffer from tree shade (melon in summer for example) are placed in cells not shaded. Although no constraint expressed any necessity to diversify the system, it can be noted that the solution makes use of all the possible crops. Moreover, bare soil is a rare option; it only appears in fall where the choice of crops was very limited.

While some major interactions have been successfully represented (access to trophic resources in the soil, competition for light…), no information concerning the natural regulations have been found on these specific mixed fruit-vegetable cropping systems. Natural regulations, enhanced by a higher biodiversity within the systems, are a key element for the stability and the sustainability of mixed systems (Trenbath, 1993). Not being able to represent any of these interactions is a crucial drawback that must be addressed before any use such an approach to collaboratively design new cropping systems. Moreover, the technical limitations of the solver used, which is one of the few available, lead us to simplify the time and space description. Discretizing the time into seasons forbids for example the representation of constraints describing the work load associated to each agricultural operation, therefore depriving the solution from another key element, the manageability of the proposed prototype.

Results and discussion

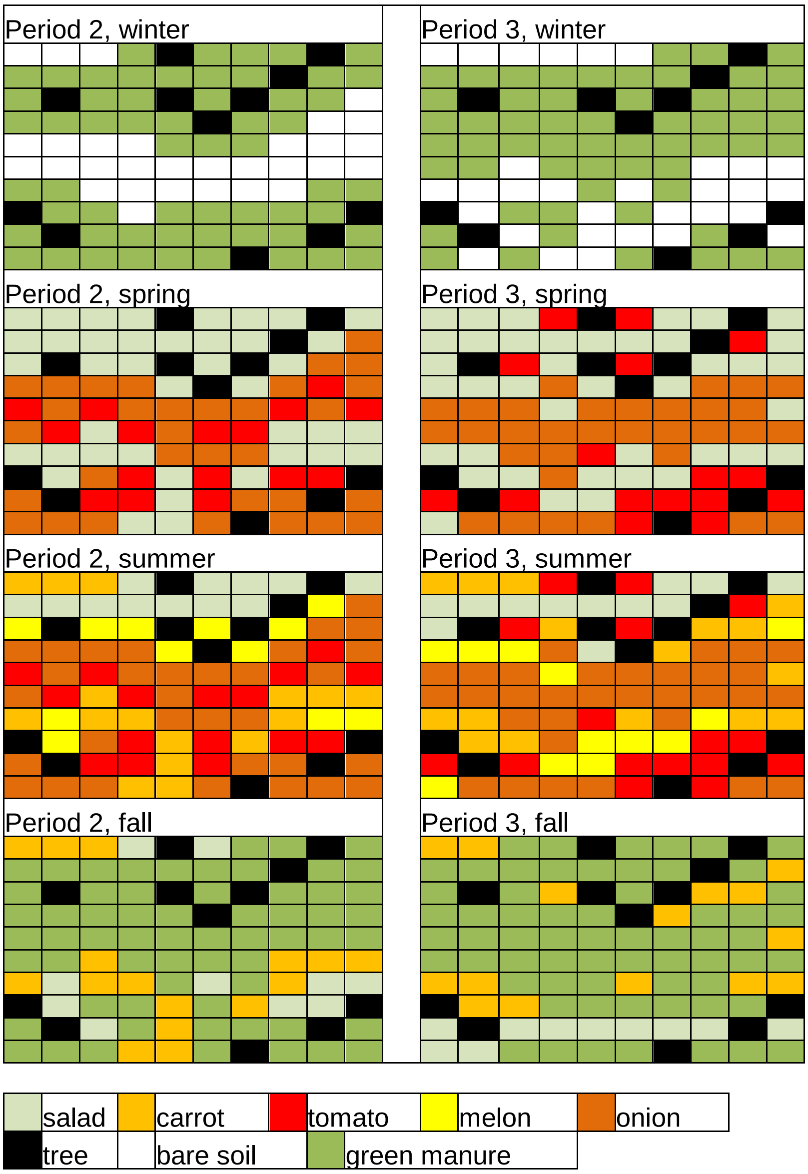

Figure 2. Mixed system prototype (period 1 is not represented because no interactions take place between trees and vegetable crops)

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