Mixed Fruit-Vegetable Crop Allocation Problem using MIP

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Abstract

Agroforestry systems are one of the sustainable approaches that have received considerable research attention over the past with a view to ensure high productions, ecosystem services and environmental benefits. These systems combine two principal land-use sciences : agriculture and forestry. However, to our knowledge, none of the several studies conducted on agroforestry systems has specifically examined the combination of vegetable crops with fruit trees using a mathematical programming approach. Accordingly, the aim of the present study is to design mixed fruit vegetable cropping systems, represented as a spatial-temporal crop allocation problem. Nonetheless, unlike existing studies in which allocation concerns only annual crops [1, 2], our approach allocates both annual and perennial crops on the same land while optimizing above- and belowground interactions resulting from this combination (see Fig. 1).

To assess the validity of different modeling choices to design mixed fruit-vegetable cropping systems, we built a first prototype using a Binary Quadratic Programming (BQP) formulation of the Mixed Fruit-Vegetable Crop Allocation Problem (MFVCAP) [3]. The aim of this preliminary work was to examine the ability of state-of-the-art exact solver IBM ILOG CPLEX v12.6.1 in solving MFVCAP in order to support farmers in their crop allocation strategies. Depending on various modeling simplifications (without crop rotation nor crop dispersion) and preferences (equal importance to above- and belowground interactions), CPLEX was able to solve a small piece of land divided into 10×10 land units, each one contains either a tree or a crop (among 6 possible ones, plus bare soil), over a time horizon divided into three periods of four seasons (except the first period with only one season starting in autumn, see Fig. 3).

We further improved the results by exploiting a Benders decomposition of the problem. The master problem deals only with tree positioning and is a 0/1 linear program. The BQP objective function becomes linear in the continuous subproblem by exploiting the fact that it depends only on the quantity of crops assigned to land units having shade, root or nothing (see Fig. 2). The final spatial-temporal allocation of crops can be found in post-processing. This decomposition allows us to reformulate the MFVCAP into a Mixed Integer linear Program. The same 10×10 problem could be solved in 6 seconds compared to 405 sec. in the original BQP formulation using a 4-core computer.

Further research remains to be done in order to extend our model, e.g., by taking into account crop rotations in order to avoid soil depletion and to increase pest and disease natural regulation, and to solve larger instances (going from 15-by-15 to 100-by-100 land units).

Références

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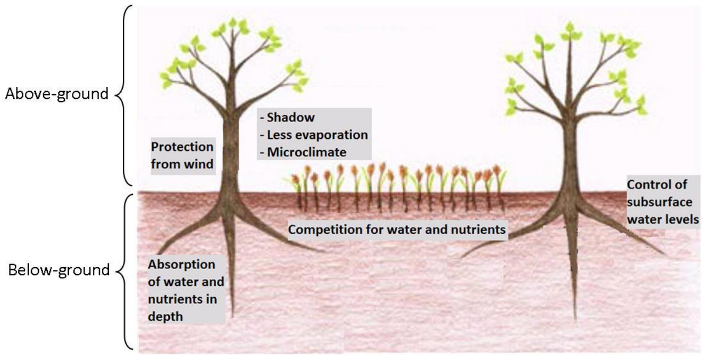

FIG. 1 – Example of above- and belowground interactions between crops and trees

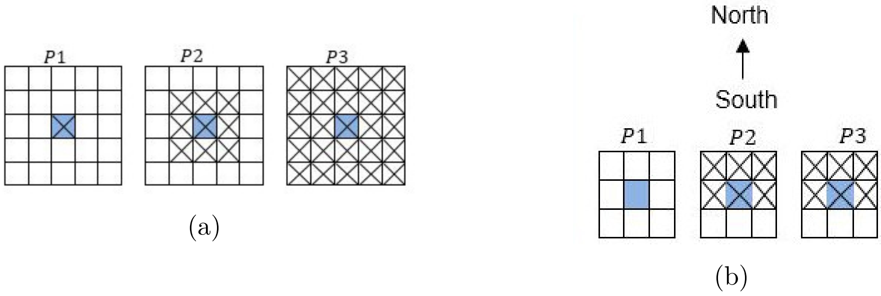

FIG. 2 – Surface view of root (a) and shade (b) extensions. Blue cells host trees, and checked cells host roots/shade in periods P1, P2 and P3

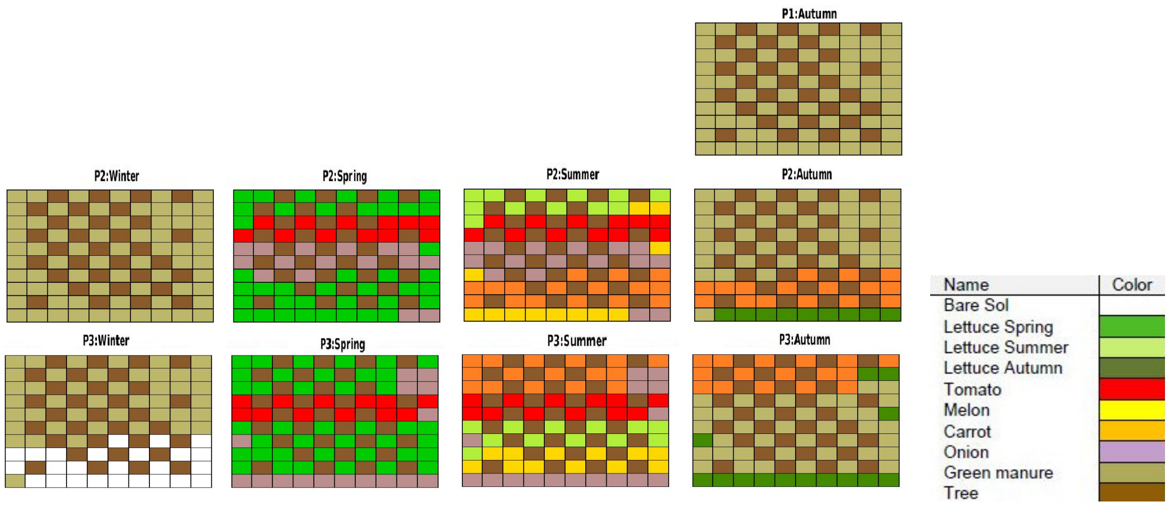

FIG. 3 – Allocation of trees and crops on 10 × 10 land units over three periods and 9 seasons

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