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Management of Crop Pruning Assisted by Computational Experiment

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Abstract - **Pruning of fruits, leaves or branches is a very common management in horticulture. Traditionally such management depends on the knowledge and experience of the grower. On the other hand, functional-structural plant model make it possible to interact with virtual plants which feedback in a similar manner as the real plants. In this paper, we present such an example using GreenLab model as the support for displayed virtual plants. A computational example on cucumber plant gives better fruit yield and more homogeneous fruit size when regular pruning is applied. Another example of removal of early fruit set gives taller plants and better fruit yield as well. These realistic results prove the computation experiment a promising tool for crop management.**

I. INTRODUCTION

Pruning of fruits, leaves or branches is a very common management in horticulture. The timing and policy of pruning is generally based on the knowledge and experience of the grower. Although such management can be well done by an experienced farmer, the job can be better fulfilled if the underlying mechanism is understood. For a new-hand, quick and cheap experiments can be desirable to learn quickly how to master the agriculture system. Moreover, to obtain better yield and fruit quality, easily repeated experiments can give reference for the management on real plant.

In the domain of plant modeling, functional-structural plant models (FSPMs) [1] has appeared as a versatile tool for integrating plant knowledge of different level. As 3D plant is an output of the model, users can see their plants in computer, which can generally attracts their interest. On the other hand, in FSPM, plant structure, both topologically and geometrically speaking, can take effect on plant growth [2], thus interactive management from users can change the behavior of virtual plant. Theoretically speaking, if crop and their environment are both well simulated in a computer system, user can make management and see its result immediately, and compare with plants in real situation.

However, developing such a crop-environment system is of great challenge, and it is currently an on-going a research domain jointly worked by computer scientist, plant scientist, mathematician, etc. While several models simulating plant development and growth [3] [4], there is few modeling work on crop management, and among them, the interactive pruning, which plays an important role for final yield, is hardly implemented. In this paper, we propose a model-based interactive crop growth system where user can make experiments on different pruning strategies on crops. The paper is organized as follows: firstly we give a brief introduction to the mathematical plant model giving the behavior of the virtual plant; secondly an example is given on pruning of the cucumber plant. Conclusion and discussions are given briefly in the end of paper.

II. METHOD

For modeling the reaction of plant to pruning, we use a mathematical model, GreenLab, which simulates the dynamic process of plant development and growth as well as their interaction [5]. Fruit set is simulated based on the hypothesis that it is regulated by source-sink ratio, as claimed in many literatures. In GreenLab, growing organs in plant are supposed to compete biomass from a common pool, which is computed from the leaf area. Each type of organs share the same relative sink strength and sink variation function, i.e., change of sink strength according to organ age [6]. Therefore, according to appearance time of an organ in plant structure, its age, and consequently its sink strength, are know precisely, and we can compute plant demand as the sum of all organ sink strength at a given cycle. The ratio between the amount of biomass available and plant demand is defined as source-sink ratio [7].

To conclude, at each time step (cycle), the following steps are needed in GreenLab model:

- compute new organs according to the organogenesis model and plant source to sink ratio;
- allocate available biomass to growing organs according to their sink functions;
- update the size of organs according to the relationship between size and biomass of individual organs; update the geometrical information of plant;
- compute new biomass production for next cycle.

There are topological, geometrical and functional parameters in GreenLab model, the last one being obtained by inverse method, i.e., by fitting the model output with corresponding measured data [6] [8]. Using a set of model parameters, the full dynamics of plant structure from seedling to mature stage can be simulated.

To be able to have interactive management, especially pruning, it is desirable that user can run the model interactively and remove leaves, fruits or branches at any time. Such function has been implemented in *QingYuan*, a versatile software simulating plants with interaction between plant development and growth [9]. To allow user interaction, dedicated GUI and data structure are designed so that data exchange between user and growth engine on plant topology is possible [10].

III. CASE STUDY

We selected cucumber as the example plant for our study. As observed in many other horticulture plants like sweet pepper, it exhibit rhythmic fruit set pattern, which is unexpected from marketing point of view. Through the computational experiment, we want to find a pruning policy that can decrease the waves of fruit set. On the other hand, removal of early fruit is a common strategy in cucumber management. Through the computational experiment, we will test its validity. As mentioned above, fruit set is controlled fully by the source-sink ratio.

The source and sink parameters need to be set in order to simulate a cucumber plant in *QingYuan* software. For topological parameters, cucumber plant is set to be a sing-stem structure consisting of phytomers. Each phytomer is composed of an internode, a leaf and a female flower (the male flowers are not considered). The plant ages is set to 70 cycles. The sink strength of fruits is set to be much higher than those of leaves or internodes, with a delay of four cycles from appearance to start of growth, corresponding to flowering stage. The expansion duration of organs are all 20 cycles. Fruit set can take place only when source sink ratio is greater than a given threshold. All the parameters were the same four all pruning treatments.

Four treatments were compared on the same virtual cucumber plant. The first one grew naturally without any pruning (called *no pruning*); in the second case, female flowers on the first ten phytomers from base of plant were all removed (called *first ten*); in the third case, female flowers on the first fifteen phytomers were removed (called *first fifteen*); in the last case, pruning were made periodically so that one fruit is kept every ten phytomers (called *periodic*).

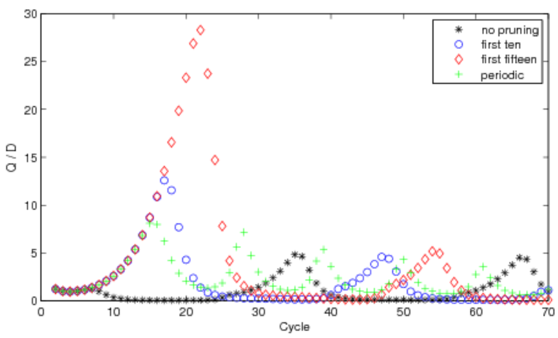

Fig. 1 Dynamic source sink ratio of four pruning treatments on cucumber plant.

In all treatment, cyclic pattern of source sink ratio (*Q/D*) were observed, as shown in Fig. 1. It is caused by the interaction of fruit set and *Q/D* value: when a cluster of fruits is set, *Q/D* value decreases because of increased demand by fruit, thus fruit set event paused in following phytomer, which will increase *Q/D* again with end of expansion of existing fruits, and lead to new fruit set. Among four treatments, arising of *Q/D* is much slower in the case of no pruning than the other three, because of heavy fruit load in the beginning. The peak of *Q/D* is highest in the case of first fifteen, because of pure vegetative growth during first 15 cycles. While two obvious peaks of *Q/D* were in three treatments, in the last periodic treatment, five peaks were observed, which means five times of fruit set in the same duration.

The total fruit weight, average individual fruit weight and its coefficient of variance were compared for the four treatments. Among all treatments, total fruit weight per plant, or yield, was highest in the treatments of *first fifteen*, while the case without pruning gave lowest yield, which proved the usefulness of pruning in horticulture crops. Average individual fruit weight (average FW) increased from the first to the last case, which is an index of fruit quality. Interestingly, coefficient of variance of individual fruit weight (CV), another index of fruit quality indicating the homogenous level of individual fruit, was lowest in the case of periodic pruning and highest in the case of pruning the first fifteen female flowers. In above three indices, the periodic treatment gave the best result both from quality and quantity point of view on yield.

TABLE I
RESULTS UNDER DIFFERENT TREATMENTS

Treatment	Yield	Average FW	CV
No pruning	360.6	20.0	70.7%
First ten	873.5	39.7	80.4%
First fifteen	1340.7	67.0	92.0%
periodic	1081.2	216.2	30.8%

Fig. 2 gives a 3D view on the cucumber plants under the four treatments. It can be seen that plant without pruning is smallest. Interestingly, the treatment gave the best yield is not the tallest plant, which proves a balance between vegetative and generative growth is necessary to get optimal yield.

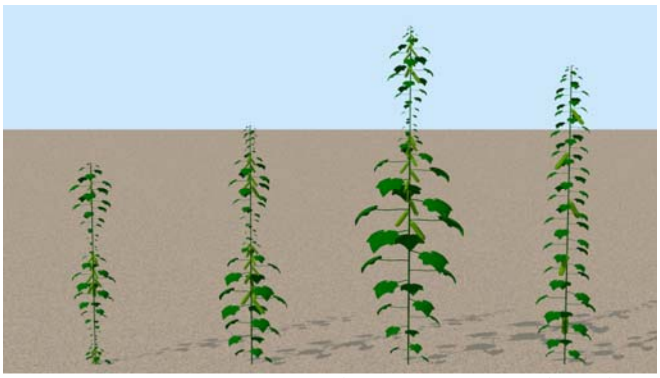

Fig. 2 Cucumber plants obtained with four pruning treatments, from left to right: no pruning, first ten, first fifteen and periodic.

IV. Conclusion and Discussion

In the paper, we have presented a pruning exercise on a virtual cucumber plant based on GreenLab model. The result is realistic: the plant without pruning was smallest, plants with removal of first female flowers gave better yield, and best yield was obtained by periodic pruning. While such results confirm the usefulness of common management in reality, they hint further advantages: compute of optimal pruning strategy for best quantity and quality of yield. In case that labor should be taken into account as a cost, which need to be changed is just the cost function of an optimal control problem. Actually, research on optimal control on virtual plants has been started on a water supply problem [11]. To start from theoretical work to application, first the model should be calibrated for a certain cultivar to get its source and sink parameters, secondly the threshold of *Q/D* controlling fruit set need to be obtained by making different pruning treatments. Fortunately, for a given cultivar, there is probably only one certain relationship between *Q/D* and fruit set [7]. The current work shows a promising and highly computable way of crop management regarding pruning.

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