THE MANAGEMENT OF INTERCROPS IN VINEYARDS SHOULD BE ADAPTIVE TO BUFFER THE EFFECTS OF CLIMATE VARIABILITY ON THE GRAPEVINE PERFORMANCES

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Summary

In viticulture as in other crop productions, adaptation to climate fluctuations is needed to mitigate their possible impacts on productivity and on the quality of products. The VERDI simulation model was developed to evaluate various adaptive strategies of intercrop management at field scale. Its main purposes were to design management strategies that are responsive to the state of the soil-crop system and to climate, and to reproduce realistically the dynamic interactions between the biophysical and decision systems in varying climate conditions.

A simulation study involving various more or less adaptive strategies of soil surface management under different climate scenarios was carried out. The simulation outputs confirmed that in case of severe drought, the most flexible strategy yields the best agronomic and environmental results in the long term, in relation to its ability to trigger the removal of an intercrop according to the time-course of soil water availability.

INTRODUCTION

Submitted to inter-annual climate fluctuations, farmers tend to adapt the management of their cropping systems to maintain their agronomic and economic results as steady as possible. For perennial species such as grapevine, crop rotation is not an option but adaptation is still possible through canopy management, fertilization, irrigation and soil surface or intercrop management (Celette and Gary, 2006).

Yet, extension services and farm supply retailers often suggest standardized management plans adapted to average conditions and repeated every year. The limits of this approach were evaluated in a recent simulation-based study about soil surface management in vineyards (Ripoche et al., 2010). Various intercrop management plans combining various types of options (grass species, covered surface area, period of intercropping) were evaluated with respect to production and environmental criteria over 30 years. Finally, none of these management plans was successful over all the years and most of them exhibited low frequencies of success. These results could be explained by the normative representation of the management plans with little consideration for the climate variability and the actual state of the soil-crop system.

Therefore, more elaborate vineyard management policies should be designed in order to buffer the effects of climatic variations on the soil-crop system. Cropping systems should be dynamic and adaptive to changes in order to be more suited to the realization of farmer's objectives year after year (Sadras et al., 2003). We make the hypothesis that including the relationships between the agricultural activities, the weather (past and present) and the actual state of the biophysical system in the modelling of vineyard cropping systems can help to design efficient, robust and innovative management plans. Such a model should simulate the interactions between biophysical and decision processes, i.e., how biophysical processes affect farmer's activities and reciprocally. The management of activities is rarely explicitly represented in crop models, and crop management is often implemented as simple options represented by fixed parameters (Bergez et al. 2010). Recently, a generic modelling platform called DIESE (DIscrete Event Simulation Environment) was designed (Martin-Clouaire and Rellier, 2009); it offers an object-oriented conceptual framework under the form of a production system ontology.

In order to study the agronomic and environmental relevance of introducing flexibility in management strategies of intercropped vineyards, the DIESE platform was adopted to simulate the productive and environmental performances of fixed and flexible strategies of soil surface management under different climate scenarios.

MATERIAL AND METHODS

The VERDI model. In the DIESE platform, the vineyard cropping system was represented as the combination of biophysical and management components influenced by climate (Figure 1) in a model called VERDI (simulation of Vineyard intERcropped with DIese).

In the biophysical sub-model (Figure 2), the field could be set as a group of {Row; Inter-Row} couples, possibly differing by the soil surface management policy in the row and in the inter-row. It was defined by a proportion of area with a cover crop, and by a proportion of area treated as inter-row. Vegetation (grapevine and/or cover crop) and soil reservoirs could be linked to the row and inter-row, respectively. The main biophysical processes were those contributing to the soil water balance (runoff, drainage, soil evaporation, crop transpiration), and the crop

growth and phenological development. They were formalized as in the WaLIS model (Celette et al., 2010).

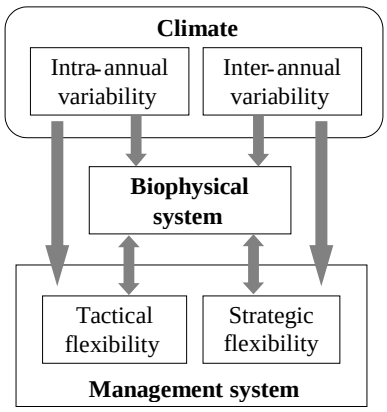

Figure 1. *Framework of the VERDI model.*

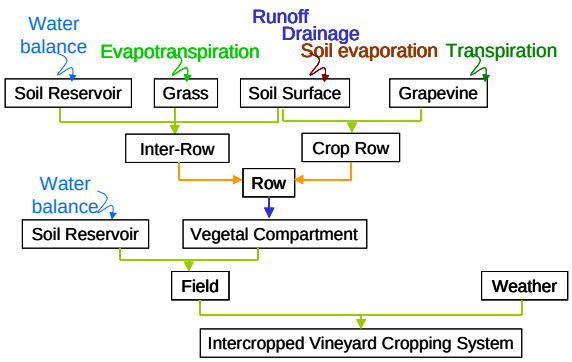

Figure 2. *Entities of the biophysical sub-system in the VERDI model and associated processes.*

In the management sub-model, five types of activities were defined: chemical pest control, chemical weeding, tillage, sowing and mowing, with various specializations for chemical weeding and tillage (e.g. autumn vs. spring tillage). Each activity was defined by (1) its opening and closing conditions in relation with climate and soil conditions, crop phenology and realization of other activities, and (2) by its earlier and latest dates in relation with calendar, crop phenology and realization of other activities. The management sub-system continuously monitored the biophysical sub-system to determine the proper sequence of operations. The opening-closing and feasibility conditions introduced tactical and operational flexibility in the management.

On these bases, three annual management plans were defined for the soil surface management in the inter-row:

- permanent intercropping, with mowing activities repeated in relation to the value of the leaf area index of the intercrop;
- permanent bare soil, with chemical or mechanical weeding;
- temporary intercropping, eventually destroyed in relation to the soil water status.

These three management plans could be combined within a 'mixed plan' in order to introduce a strategic level of flexibility (Figure 3). Basically the strategy was to introduce or to stop cover cropping according to the soil water status. In the 'mixed plan', the sowing activity could be cancelled in case of unfavourable climatic conditions or late grape harvest. When no sowing was done, the management shifted from the temporary intercropping plan to the bare soil plan. Conversely, if a sowing was done, mowing was iterated until circumstances required to destroy the intercrop as in the temporary intercropping plan. If no destruction was carried out, the intercrop was maintained throughout the year as in a permanent intercropping plan.

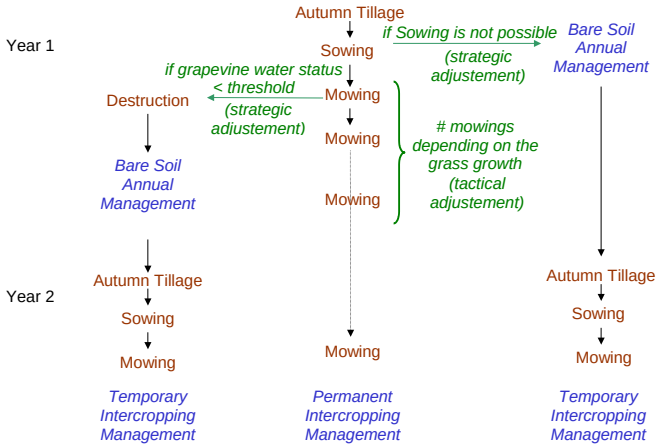

Figure 3. *Strategic and tactical adjustments in the management system of the VERDI model.*

Simulated strategies and climate scenarios. Three strategies (permanent intercropping, permanent bare soil, mixed strategy) were simulated under four years long climate scenarios either alternating rainy and dry years or observed in the region of Montpellier, France (2005-2008). The ordering and timing of activities were compared among strategies and climatic years. The possible benefits of flexibility were evaluated with respect to the agronomic and environmental performances of the strategies.

RESULTS

Sequences of activities with strategic and tactical adjusments. The sequences of activities triggered by the management model differed depending on the year and strategy. For example, in the bare soil strategy, the number of simulated mechanical weedings during the grapevine production cycle varied from two to five in relation to the amount of rain whereas in the permanent intercropping strategy, the number of mowings varied from one to five. The sequence of activities also varied in the mixed strategy. For instance, during a humid year, the soil surface management shifted from temporary to permanent intercropping (Figure 4), whereas during a dry year intercropping remained temporary, the grass being destroyed by tillage from spring to autumn.

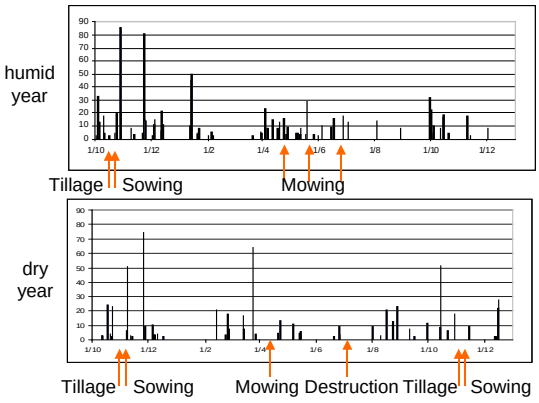

Figure 4. *Examples of simulated sequences of operations of soil surface management during a humid and a dry year.*

Agronomic and environmental impacts of continuous and adaptive strategies of soil surface management. When one rainy year alternated with one dry year, the agronomic and environmental performances of the three strategies were all high, whatever the level of adaptability (not shown). The soil water reservoir buffered the inter-annual variation in rain. In contrast, with a sequence of two dry years, the production performance of the two management plans without strategic adaptation (permanent bare soil and permanent intercropping) dropped during the second dry year (Figure 5). With permanent bare soil, runoff was higher, leading to a lower winter refill of the soil water reservoir and a higher water stress during the second dry year. With permanent intercrop, there was less runoff and more infiltration so that there was not much competition for the soil water resources with the grapevine during the first dry year, but the buffer effect of the soil water reservoir was not enough during the second dry year.

The 'mixed' strategy, which combined tactical and strategic adaptations, stayed in the same region of high production and environmental performances along the years, whatever their rain regime (Figure 5). This could be explained by shifts from bare soil during the dry years to intercropping during the rainy years.

DISCUSSION

These results showed that the VERDI model represents realistically the relationship between climate, activities and biophysical processes. The schedules of the various activities that can be observed in the field were relevant in relation to previous results (Celette, 2007; Ripoche, 2009). If all activities carried out in vineyards were not taken into account in the model, the model constitutes an interesting tool for extensionists to work with farmers in order to better anticipate the consequences of climate variations on soil surface management.

The short simulation study presented here confirms the interest of introducing more flexibility in crop management as already shown for annual crops (Tanaka et al., 2002; Sadras et al., 2003). The possibility to shift from a strategy to another depending on the climate allowed to buffer the negative effects of a severe drought. When several years of drought occurred, the cover crop destruction allowed to reduce the grapevine water stress and therefore to maintain the agronomic performances of the vineyards. Considering environnemental performances, the results of the 'mixed' strategy remained similar to those of the permanent strategies. In fact, the intercrop being destroyed only when the drought was too high, runoff was obviously low in all cases.

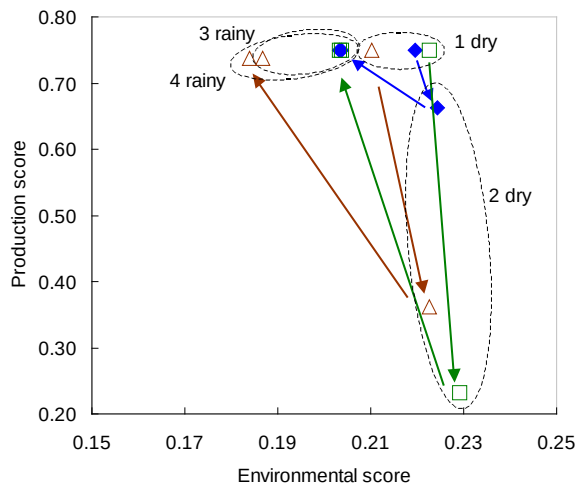

Figure 5. *Agronomic and environmental performance of three strategies of soil surface management in vineyards, over a sequence of two dry (numbered 1 and 2) and two rainy years (numbered 3 and 4). The production score aggregates criteria of vegetative development, yield and grape quality (Ripoche et al., 2010); the environmental score increases when runoff is reduced. Each criterion rated from 0 to 0.25. □ permanent intercropping, △ bare soil, ◆ 'mixed' strategy.*

Recent experimental results showed that grapevine could react rapidly to a change of soil surface management, one to two years considering vegetative development and yield, respectively (Ripoche et al., 2011). Consequently, an adaptive strategy could be a way to mitigate the variations in crop responses. As the indicators for destroying the intercrop are relatively easy to use or obtain (predicted rainfall, estimated water needs for the two crops), this strategy could be tested by farmers in vineyards. The model could allow to study the possible competition between different activities in the farm. This point was not tested here because we wanted to understand the relationships between climate, crop management and biophysical processes and study the relevance of the flexibility of the crop management to maintain the vineyard cropping system performances. Nevertheless, it remains crucial to evaluate the feasibility of this strategy regarding the farm organization as adaptive strategy could require more work to observe indicators and react in a rapid way.

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