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Modelling nitrate transport under row intercropping system: Vines and grass cover

J. Tournebize [a,*], C. Gregoire [b], R.H. Coupe [c], P. Ackerer [b]

[a] UR "Hydrosystems and Bioprocesses", Irstea, 1 rue Pierre-Gilles de Genne, CS 10030, 92761 Antony Cedex, France
[b] UMR 7517 LHYGES, CNRS/University of Strasbourg/ENGEES, 1 quai Koch BP 61039, 67070 Strasbourg, France
[c] US Geological Survey, 308 South Airport Road, Pearl, MS 39208, USA

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SUMMARY

In the context of reduction of agricultural non-point source pollution, an associated crop system often presents several advantages. The difficulty resides in the characterisation of each species' contribution (dominant and dominated). This paper deals with the particular case of voluntary grass cover management between rows in a vine plot. We evaluate the spatial and temporal changes in the development of both crops: vine/grass cover system, in their ecological functioning and in the influences on water and nitrogen balances. We modify the SWMS_3D model to incorporate separate distribution of water and nitrogen demands for the two coexisting plant species. The parameterized model is then assessed using the measured data (water content, matrix potential and nitrogen content of the soil solution at depths of 30, 60, 90 and 120 cm) acquired from two monitored vine plots (vine "Tockay-Pinot Gris" plot grass covered every second row compared to a control plot that was chemically weeded vine "Riesling" plot, France, Alsace, Rouffach) between October 1998 and September 2000. The main results are the following. The vine's mean total transpiration over the two growing seasons of 1998/1999 and 1999/2000 is simulated of 355 ± 9 mm per season. The matrix potential is reproduced accurately especially improving with depth and under the interrow. Despite a high variability due to soil heterogeneity, the nitrogen mass variations between measurements and simulations with the adapted model are coherent. Nevertheless we note that the model slightly underestimates the nitrogen mass for both types of observed cropping patterns, however the ratio between the two itineraries remains similar, yielding a reduction in nitrogen loss by at least 4-fold in favour of grass cover every second row plot during the period observed from 10/01/1998 to 09/30/2000.

0. Introduction

In Alsace, in north-eastern France, the nitrate deterioration of ground water quality over the past 30 years has alerted communities, public authorities and associations of wine professionals (Alsace, 2001). Grass cover of vine plots every second row has been favoured since the 1980s to reduce erosion, but since then it has also been associated with its potential impacts on nitrate retention, especially during winter. However, the two associated species compete, which might lead to economic decline and therefore affect its acceptance by farmers.

The associated crop technique – defined as the combination of at least two cultivated species in alternate rows, simultaneously on the same plot (Miller et al., 1989) – is often suggested as a technique to improve the environmental impact of water transfer and agricultural non-point-source pollutant transport. However, knowledge of the impacts of this system is often limited to the agronomical, economic (Morlat et al., 1984; Jose et al., 2000; Odhiambo et al., 2001; Vervoort et al., 2001; Morlat and Jacquet, 2003), or erosion aspects (Ballif et al., 1991; Gay et al., 2004; Goulet et al., 2004). A global study of vegetative multicomponent system dynamics at the root level needs to be conducted. This involves understanding the environmental variables (water and nitrate) and transport phenomena as well as implementing this method, aiming for sustainable development (Huxley, 1996). These associated systems are more difficult to characterise than single-crop farming. Indeed, at the level of an agricultural plot, the association of two plants with staggered growing seasons, heterogeneous covers and different root exploration systems all need to be taken into account in considering the spatial and temporal aspects so as to understand ecological functioning (Gillespie et al., 2000). The interactions of one dominant crop over the other depend upon the distribution of resources such as light, water and nutrients, above ground as well as below. These interactions imply competition phenomena concerning these resources and the success of such a complex system then depends mainly upon the minimisation of negative effects between dominated and dominant species (Jose et al., 2000).

* Corresponding author. Tel.: +33 1 40 96 60 38; fax: +33 1 40 96 61 99.
E-mail address: Julien.tournebize@irstea.fr (J. Tournebize).

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"Managing the grass cover" in a vine-growing context therefore means "choosing species for the grass cover whose growth cycle is staggered in relation to the vine's, and whose growth is maximised in the autumn and winter, and minimised during the rest of the year." The vine is here defined as the dominant plant, while the grass cover (mainly graminaceae or poaceae) is the dominated crop. This study concerns a grass cover in the inter-row of a vine plot in a Piedmont vineyard under a continental climate. The objective of this paper is the implementation of a model which is adapted to an associated crop system of vines/grass/bare soil to evaluate environmental outputs.

The goals of this study were therefore to gain better knowledge of water and nitrate uptake efficiency for the vine/grass cover/bare soil associated system as well as an improved understanding of how the "vine/grass" ecosystem functions, through a three-dimensional adapted model called SWMS_3D, (Simunek et al., 1995). Because of the complexity of an associative system and considering the spatial scale (the plot scale), a physically based approach was chosen. In order to examine the effects of the grass cover on the vine and vice versa, it was necessary to model the horizontal as well as the vertical movement of water and nitrate. This approach shows the degree of complementarity of the agricultural cycles (Ozier-Lafontaine et al., 1998; Lafolie et al., 1999). Moreover, along a row of vines, the influence of one vine trunk over another adds an extra dimension to the system being studied (Morano and Kliewer, 1994), leading to three-dimensional modelling. The results of the simulations are compared to a series of experimental measurements from the monitored site in Rouffach (Alsace, France). The soil properties (water content, matrix potential and nitrate concentration in the soil solution) were monitored weekly between October 1998 and September 2000 on two experimental plots.

1. Materials and methods

1.1. Experimental site

The experimental site is located in the heart of the Alsatian vineyards on the Hohrain domain. The property belongs to the Agricultural and Viticultural College of Rouffach (Alsace, France, latitude 47°57′9 N; longitude 007°17′3E; altitude, 284 m).

The analysis of interannual climatic characteristics at the Rouffach site shows a mean annual temperature of 11 °C and mean annual rainfall of 583 mm. Generally, precipitation is 35% more abundant in summer than in winter. The 1998 climatic year falls within average values (precipitation, 542 mm); the 1999 and 2000 climatic years had greater annual precipitation: 813 and 648 mm, respectively. The experimental plots are situated on calcareous loess, which has been remodelled by siltage from the bottom of a carbonated slope. The soil from both plots is a Calcosol, (classification FAO-UNESCO, 1981). It has a loamy particle size distribution, which becomes loamy–clayey deeper down.

The field is equipped to experimentally evaluate the impact of grass cover every second row on a vine plot (the most frequent cropping pattern used in Alsace) on nitrate transport as opposed to a plot where weeds are chemically managed. The plot where grass grows every second row (hereafter called the GCP for grass cover plot) is cultivated for a *Vitis vinifera* vine cp. Tokay Pinot Gris, and by a managed, natural grass cover consisting mainly of *Festuca pratensis*, *Bromus sterilis*, *Poa pratensis* and *Lolium perenne*. A plot where the weeds are chemically managed (called the WP for weeded plot) serves as a control reference: vine on the Riesling variety grapes (*Vitis vinifera* cp. Riesling). Both plots, whose characteristics are given in Table 1, were supplied once a year until May 1998 with nitrogenous fertiliser (from 60 before 1995 to 22 kg N ha^{-1} $year^{-1}$ between 1995 and 1998). During monitoring, in 1999 and 2000, no fertiliser was applied and all agricultural practices on vine trees such as leaf trimming or branch clipping, were done similarly on the two plots. It was assumed that water and nutrient demands for the two vine species were similar, leading to a similar yield. The organic matter content of the topsoil (0–30 cm) is 1.3 and 1.5 g kg^{-1} respectively for the WP and the GCP. The C/N ratio is 8.7 for both plots. The total measured nitrogen amounts to 0.9 and 1 mg g^{-1} of dry soil, respectively, for the WP and the GCP.

The site is instrumented to monitor matric potential, water content and nitrate concentration: the matric potential of the soil using tensiometers, variation of water storage over time by measuring water content through time domain reflectometry (TDR, TRIME by IMKO) and nitrate concentration in the soil solution sampled with ceramic porous cups. Four measurement stations (Fig. 1) enable the monitoring of these variables under the row of vines and in the interrow, along the 107 m of rows, at depths of 30, 60, 90 and 120 cm. The system also includes a weather station belonging to the MétéoFrance network, measuring five climatic parameters (temperature, wind, precipitation, total radiation and atmospheric water content).

1.2. The SWMS_3D model

1.2.1. Model description

SWMS_3D (Simunek et al., 1995), proposed in the HYDRUS package (for details see Simunek et al., 2008), is a three-dimensional physically based model for water flow and solute transport in a variably saturated medium. The model numerically solves Richards equations for a saturated/non-saturated flow (Eq. (1)) and the advection–dispersion equation, (Eq. (2)), and zero- or first-order reactions.

$$\frac{\partial \theta}{\partial t} = \nabla \cdot (\overline{\overline{K}}(h) \cdot \vec{\nabla}(h + z)) + S_h \qquad (1)$$

$$\frac{\partial \theta c}{\partial t} = \nabla \cdot (\theta \overline{\overline{D}} \cdot \vec{\nabla} c) - \vec{\nabla} \cdot (\vec{q} c) + S_c(t) \qquad (2)$$

considering θ: water content [−]; t: time [T]; $\overline{\overline{K}}$: hydraulic conductivity tensor [L T^{-1}]; h: matric potential [L]; z: elevation [L]; S_h, S_c, sink terms of water and nitrate uptake [T^{-1}] and [M L^{-1} T^{-1}]; c: nitrate concentration [M L^{-3}]; $\overline{\overline{D}}$: dispersion tensor [L T^{-2}]; $\vec{q}$: Darcy's velocity [L T^{-1}].

The model uses the relationships of Van Genuchten (1980), between water content and matric potential, and Mualem (1976), between hydraulic conductivity and water content.

The term S_h in Eq. (1) represents water uptake through the roots. The approach chosen in SWMS_3D is based on the stress response function defined by Feddes et al. (1976) where:

$$S_h = r(h(x, y, z, t)) \times S_{\max} \qquad (3)$$

respecting for every time step $\int_\Omega S_h(x, y, z, t) d\Omega = TR(t)$ and $\int_\Omega S_{\max}(x; y; z; t) d\Omega = TP(t)$, $S_{\max}(x, y, z, t) = TP(t) \cdot \rho(x, y, z)$, $\int_\Omega \rho(x, y, z) d\Omega = 1$, with $S_{\max}$: maximum uptake rate; r(h): dimensionless function varying between 0 and 1 depending on soil matric potential. $S_{\max}(t)$ is dependent upon the temporal value of the vegetation potential transpiration TP(t) as well as upon the spatial distribution (x, y, z) of the normalised root density (assuming that this is equivalent to active roots) over the domain Ω. TR(t) corresponds to the vegetation's actual transpiration.The term S_c in Eq. (2) represents the variations in concentration due to chemical or biological reactions involving nitrate (soil production and denitrification) as well as the plants' nitrate uptake, described below.