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Sustainable intensive agriculture: evidence from aqueous geochemistry

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Abstract

Geochemical and crop models allow for simulating the concentration of irrigation water (Durance River) by evapo-transpiration, equilibration with soil pCO_2, dissolution / precipitation of calcite, dissolution of fertilizers (P-K, no N), and apatite precipitation. Nutrient absorption is simulated as removal of the corresponding ions from the solution. The results show that the crop system in the Crau plain has thus protected and ameliorated soils since the XVI[th] century, while sustaining production of high quality crops and a correct income for farmers. This has been made possible by investments in water control (irrigation and drainage). It is now endangered by urban sprawl.

Keywords: agriculture; soil; irrigation; Crau; PHREEQC; sustainable development.

1. Introduction

Irrigation is necessary to ensure food production and meet the requirements of increasing world demand. Little attention has been paid to the influence of water quality in irrigated systems, except in salt-affected soils. However, nutrients supplied by irrigation water are not negligible, though they are overlooked in calculations of nutrient balances. In Mediterranean regions, water scarcity and increase of costs of fertilizers make a more rigorous evaluation of water use in agriculture necessary. Crop models and geochemical models can be used together to this end. This allows for evaluation of ecosystem services supplied by agriculture to cities: food production, soil and groundwater quality protection. This

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study is part of a larger project aimed at evaluating these services and the vulnerability of territories to urban sprawl [1].

2. Study site, material and methods

The Crau plain, in the South of France, east of Rhône river delta, is subject to a Mediterranean climate with a steppe-like microclimate and consists of surface formations deposited by Durance River before it is captured by Rhône river. These deposits are dominated by pebbles indurated by calcite of pedogenetic origin and fractured. In the present climatic conditions, calcitic cement tends to dissolve and the topsoil tends to be decarbonated. Traditional land use is extensive grazing. Since the XVIth century, part of the natural steppe (locally called « coussoul ») has been irrigated and transformed into grassland.

Soil data (thickness of horizons, texture, density…) were taken from soil map [2]. Moisture at field capacity and wilting point were computed from texture data, by using pedotransfer functions; apparent density was taken as 1.45 for cultivated topsoil and 1.6 for deeper non-cultivated horizons. "Active limestone" is present in the topsoil of most (2/3) irrigated grasslands, while it is absent in most (2/3) of non irrigated steppe-like topsoils ("coussoul"); this reflects both the general tendency of soils towards decarbonatation under north Mediterranean climate and the partial "recarbonatation" of topsoils under irrigation [1].

Meteorological data for 2000-2010 from INRA (Agroclim, Avignon) measured in the Domaine du Merle (Salon-de-Provence) were used. Parameters for crop model STICS [3] (inputs of N fertilizers and manure, frequency of irrigation, dates of cutting) were obtained by enquiries. Mineral composition of hay was given by professional organization Comité du Foin de Crau. Groundwater analyses were taken from the database Ades [4]. Irrigation water was sampled on April 6th 2010 ; pH, Eh and temperature were measured *in situ* ; samples (n=16) were filtered at 0.2 μm in the field, and analyzed for cations (Al, K, Na, Ca, Mg) by ICP-AES, for anions (fluoride, chloride, nitrate, sulphate, phosphate) by Ion Chromatography, for alkalinity by Gran's method and for silica by the molybdate-blue method.

Activities and Saturation Indexes (SI = log Q – log K) were computed by using PHREEQC [5], using phreeqc.dat database: activity coefficients were computed with Debye-Hückel extended law, as ionic strength is small enough (*ca*. 0.01 M). The reaction of reduction of nitrate into ammonium was removed from the database as it is biologically mediated and N(III) and N(V) were considered as distinct elements separated by a kinetic barrier. Inorganic fertilizers (P-K) consist of gypsum $CaSO_4.2H_2O$, calcium phosphate $Ca(H_2PO_4).2H_2O$, arcanite K_2SO_4, and sylvite KCl. The last three minerals were introduced in the database, with their thermodynamic properties [1]. Dissolution of fertilizers was simulated by PHREEQC as the dissolution of a mixture of the above minerals.

P absorption by plants was simulated as the removal of calcium phosphate from the solution, S absorption by plants as the removal of gypsum, calcium being absorbed in excess of the sum of P and S; the remaining Ca absorption was simulated as CaO removal from the solution ; Na, K and Mg absorption by plants were simulated as the removal of Na_2O, K_2O and MgO from the solution. Na_2O, K_2O, CaO (lime) and MgO (periclase) were introduced in the database phreeqc.dat. Removal of elements from the simulation is simulated by PHREEQC as dissolution with negative coefficients, in the same way as evaporation is simulated with a negative coefficient for water. To avoid transient negative concentrations, fertilizer dissolution was simulated before absorption by plants. All simulations are computed at the average temperature of groundwater (17 °C).