Sustainable intensive agriculture: evidence from aqueous geochemistry

Guilhem Bourrie, Fabienne Trolard, Andre Chanzy, Francoise Ruget, Rémi Lecerf, François Charron

Procedia Earth and Planetary Science (2013), Vol. 7, p. 93-96, DOI: 10.1016/j.proeps.2013.03.077,
Journal homepage: http://www.sciencedirect.com/science/article/pii/S1878522013001586

Sustainable intensive agriculture: evidence from aqueous geochemistry

Guilhem Bourrié[a]*, Fabienne Trolard[a], André Chanzy[a] , Françoise Ruget[a], Rémi Lecerf[a], François Charron[b]

[a]*UMR 1114 INRA-UAPV Emmah, Domaine Saint-Paul, Site Agroparc, 84914 Avignon, France*
[b]*SupAgro Montpellier, Domaine du Merle, Salon-de-Provence.*

Abstract

Geochemical and crop models allow for simulating concentration of irrigation water (Durance river) by evapotranspiration, 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's plain has thus protected and ameliorated soils since the XVIth century, while sustaining productions of high quality and 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

* Corresponding author. Tel.: +33 4 32 72 22 28; fax: + 33 4 32 72 22 12.
E-mail address: guilhem.bourrie@paca.inra.fr.

Procedia Earth and Planetary Science (2013), Vol. 7, p. 93-96, DOI: 10.1016/j.proeps.2013.03.077,
Journal homepage: http://www.sciencedirect.com/science/article/pii/S1878522013001586

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 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

Crau's plain, in the South of France, east of Rhône river delta, is submitted to a Mediterranean climate with a steppic microclimate and consists of surface formations deposited by Durance river before it was 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 steppic 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 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

Procedia Earth and Planetary Science (2013), Vol. 7, p. 93-96, DOI: 10.1016/j.proeps.2013.03.077,
Journal homepage: http://www.sciencedirect.com/science/article/pii/S1878522013001586

(lime) and MgO (periclase) were introduced in the database phreeqc.dat. Removal of elements from the simulation is simulated by PHREEQC as a 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).

3. Results

The average composition of irrigation water (N = 16) and statistic parameters for groundwater (N = 43) are given in Table 1.

Table 1. Chemical composition of irrigation water, statistic parameters for the chemical composition of groundwater compared with irrigation water evaporated and equilibrated with soil atmosphere (simulation 1), and seepage water after absorption of nutrients and fertilizer (P-K) dissolution (simulation 2).

Variable	pH	Alc	I	Cl^-	SO_4^{2-}	Si	K^+	Mg^{2+}	Ca^{2+}	Na^+
Irrigation water										
Average	8.29	3.469	0.775	0.447	0.628	0.100	0.043	0.457	1.953	0.482
Groundwater										
Average	7.27	4.87	11.9	0.739	1.21	0.154	0.045	0.547	3.23	0.689
Std. Dev.	0.23	0.327	0.871	0.07	0.207	0.039	0.016	0.082	0.232	0.066
Minimum	6.80	3.94	9.57	0.593	0.177	0.00	0.014	0.032	2.60	0.51
Maximum	7.74	5.40	13.8	0.906	1.49	0.195	0.085	0.700	3.75	0.827
Simulation 1: irrigation water equilibrated with soil atmospheric pCO_2 and calcite and concentrated by evaporation										
Result	7.107	4.941	10.77	0.598	0.913	0.134	0.058	0.611	2.768	0.646
Test 1 *t*	-0.69	0.21	-1.33	-2.01	-1.42	-1.46	0.80	0.78	-2.00	-0.65
Simulation 2: same as above after fertilizer dissolution and nutrients absorption										
Result	7.092	4.768	11.11	0.8665	0.986	0.134	0.045*	0.550	2.977	0.573
Test 2 *t*	-0.75	-0.31	-0.94	1.80	-1.06	-1.45	-------*	0.04	-1.09	-1.75

All concentrations and ionic strength I in millimole/kg of water. * Used for calibration of the absorption of nutrients.

Irrigation waters are oversaturated with respect to calcite (SI = 0.63 – 1.0), and hydroxy-apatite (SI = 6 –7), while groundwaters are close to equilibrium with calcite (SI = 0.09 ± 0.4, N = 43, min. = -0.9, max. = +1.15), and hydroxyapatite (SI = -0.8 to +0.22). Equilibrating pCO_2 is close to 10^{-2}atm.

During infiltration in the topsoil, irrigation water equilibrates with soil atmosphere, which tends to lower the pH, while it is concentrated by evaporation, which tends to increase the pH. The average concentration factor fc is derived from meteorological data and irrigation volumes, fc = I/D, with I = irrigation and D = drainage = I + P – E, where P = pluviometry and E = evapotranspiration. As an example for 2006, and the first cutting, I = 730 mm, P = 48 mm, E = 234 mm, hence fc = 1.343. In simulation 1, irrigation water is equilibrated with atmospheric pCO_2, concentrated by evaporation (fc = 1.34) and soil calcite is allowed to dissolve till equilibrium is reached: pH decreases from the value in equilibrium with calcite and atmospheric pCO_2 (8.29) to the value in equilibrium with calcite and soil atmospheric pCO_2 (7.11). Student's test shows that simulation 1 is statistically identical to average groundwater (t < 2.02), though for calcium and chloride, the experimental value is very close to the threshold. This implies that simply by equilibrating with soil pCO_2, and dissolving a small amount of calcite, irrigation water transforms into groundwater and drains without significant changes. The result is however better when fertilizer dissolution and nutrients absorption is taken into account (simulation 2).

Procedia Earth and Planetary Science (2013), Vol. 7, p. 93-96, DOI: 10.1016/j.proeps.2013.03.077,
Journal homepage: http://www.sciencedirect.com/science/article/pii/S1878522013001586

This implies that fertilizer application quasi-exactly compensates nutrient requirements. Some calcite is dissolved to compensate acidification due to CO_2 production by soil respiration and to proton pump, but sometimes calcite precipitates, when the concentration factor fc is large. The amount of fertilizer dissolved was fitted on the concentration of K^+ in groundwater, and it was simply assumed that the fertilizers dissolve proportionally to the average composition of the P-K fertilizer. This results in a slight excess of P addition, which is simulated as precipitating as hydroxy-apatite. Consequently, no P reaches the groundwater.

4. Conclusions

Irrigation in the Crau's plain aimed at supplying water (i) to mills for olive oil and wheat grinding, (ii) to agriculture, and at bringing loam to soils; on 52000 ha, 12000 ha have been transformed into grasslands since the XVIth century. The landscape now consists of a mosaic of a steppic area of great ecological value, and of grasslands devoted to production of high quality forrage. The Crau's groundwater mainly (70%) depends on excess of irrigation and supplies drinking water to 300000 people and industries. Aqueous geochemistry demonstrates that in addition to production of high quality forrage (AOC), agriculture contributes to production of good quality water and to the protection of soil components against natural tendency to acidification. No excess of P or N drains to the groundwater and to wetlands, so that there is no risk of eutrophication of those protected wetlands, nor additional cost for water treatment due to dissolved organic matter. This crop system dates back to the XVIth century, so that it can be considered as a remarkable instance of ecologically intensive agriculture. Nowadays, it is endangered by urban sprawl from Marseille and smaller cities, but the development of all these cities heavily rely upon ecosytem services supplied by their hinterland [1].

Acknowledgements

The support of the "Fonds Unique Interministériel de soutien aux programmes de R&D des pôles de compétitivité " and of the "Région Provence-Alpes-Côte d'Azur" (Programm Astuce&Tic) is gratefully acknowledged. The help of Monique Mayor and Houssine Er-Ray is acknowledged too.

References

[1] Mordant de Massiac JC de, Trolard F, Bourrié G. *Anticipation Sécurisée des Territoires Urbanisés, des Campagnes et de leur Environnement fondée sur les nouvelles Technologies de l'Information et des Communications (Astuce&Tic).* Rapport final, 1480 p., 2011.

[2] Bouteyre G, Duclos, G. *Carte pédologique de France au 1/100 000, Arles N-22*. Service d'Étude des Sols et de la Carte pédologique de France, Orléans; 1994.

[3] Brisson N *(et al.)* STICS: a generic model for the simulation of crops and their water and nitrogen balances. 1. Theory and parameterization applied to wheat and corn. *Agronomie,* 1998; **18**, 311-46.

[4] Ades, Portail national d'Accès aux Données sur les Eaux Souterraines: http://www.ades.eaufrance.fr/

[5] Parkhurst DL, Appelo CAJ. *User's guide to PHREEQC (Version 2) - A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations.* U.S. Department of the Interior, U.S. Geological Survey, Water-Resources Investigation Report 99-4259, Denver; 1999.