Research and management priorities for mainland France soils

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Highlights

- Better manage French soils for the agroecological transition

- Reduce our footprint on soils and close the biogeochemical cycles

- Manage French soils to adapt to- and mitigate climate change

- Control soil sealing, land-take and soil contamination in French soils

- Raising soil awareness and develop transfer of technology to help decision making

1. Introduction

Relative to its rather small surface area (550,000 km^2), mainland France has one of the largest pedodiversity in Europe and in the world (Minasny et al., 2010). This is because of the large diversity of its i) past and present climates, 2) lithology and age of parent materials, 3) elevation, relief and landforms. Very ancient, recent, and diverse history in land-use and management, agricultural or forestry practices and their changes add another dimension to this diversity. Minasny et al. (2010), however, noted that for countries that have more detailed and diverse soil maps (such as France and some small countries) the calculations of pedodiversity might show that soils are more diverse.

France is obviously concerned by soil-related global issues. These issues are on the global research and policy agenda (e.g., McBratney et al., 2014; Montanarella et al., 2016; Lal et al., 2021) and France is indeed strongly committed to these. However, since many of these issues are shared by many countries, are there French specificities that require special attention, or research efforts? Here we attempt to make a short list of national and local priorities related to mainland France soils.

2. Better manage soils for the agroecological transition

Since the 1960s, France has had a long history of high-input agriculture. With increasing environmental concerns in the 1990s, the obvious need to better preserve the environment (air, water and soils) led to a paradigm shift in French agriculture towards agroecological practices promoting soil functions to deliver a range of ecosystem services (Duru et al., 2015), while reducing inputs and environmental impacts. The reduction in fertilizer use has been substantial in France over the last two decades (mainly for P and K), but further efforts are still required especially for N by including more legumes in rotations or legume-based intercropping systems. For pesticides that are still extensively used in a large part of French agriculture, the objective of drastically reducing their use still needs in-depth research, especially in soil ecology, biodiversity-based soil functioning and soil quality management. A large part of French soils is still managed under intensive agriculture with large inputs, especially in the northern loams and the southwestern plains. The transition to more biodiversity-based agriculture, both at plot and landscape scales requires to better account for soil spatial heterogeneities, and make use of these.

3. Reduce our footprint on soils in mainland France and overseas and close the biogeochemical cycles at a local scale

Mainland France is pointed to get beyond planetary boundaries when considering nitrogen and phosphorus flows, as related to its fertilizer-intensive agriculture and their impacts on climate change(N_2O) and air (NH_3 emissions) and water quality (eutrophication, particularly at stake in Brittany). French agriculture is also characterized by a strong specialization of vast areas and disconnections between crop and animal productions (Senthilkumar et al., 2012). The latter are largely reliant on imports of products such as feed, which result in a large environmental footprint, beyond our national territory. This is typically the case in Brittany, where a high livestock concentration results in large imports of South-and North-American products for animal feed. There is a need to reduce the dependence to foreign soils for feeding animals, to increase the use/length of grass and forage legumes in rotations, and to better reasoning pasture intensification. The stronger integration of animal, crop and forest productions in order to better close biogeochemical cycles at a local scale and better recycle wastes and biomass are major drivers for achieving an efficient circular bioeconomy, raising however many questions of trade-offs for achieving sober use of resources. The agroecological transition of agriculture and food production comes again into play, as well as the transition of food systems, e.g. the proportion of animal versus plant-based proteins in our food, with its potential impacts on the biogeochemical cycle of nitrogen.

4. Better manage soils to adapt to climate change

French climate exhibits a strong South-North contrast, with extension of the Mediterranean and drought-sensitive areas. The challenges about water use efficiency differ between Mediterranean, Oceanic and semi-continental climatic zones. There are major adaptation issues for some perennial crops (especially vineyards) and forest tree species that are major components of the rural industry and landscapes in France, as well as French economy. In this respect, it is necessary to increase our knowledge of the spatial distribution of soil hydraulic properties and rooting depth potential, in order to better identify adaptation needs. All facets of water use should be re-thought, including irrigation and emerging practices related to the ongoing agroecological transition: with more diverse and permanent plant cover, that may either increase water losses through enhanced transpiration or decrease water losses through reduced runoff. Soil properties and management are also important drivers to limit catastrophic events (e.g. flooding and landslide) that are another feature of present-day and future climates in many regions of mainland France.

5. Better manage soils to mitigate climate change

Soil organic carbon (SOC) stocks and SOC sequestration potential are diverse and contrasted in French soils (Figure 1), because of the great diversity of climate, soils, land use and management practices.

<Insert Fig.1 about here>

There are approximately 3.6 Pg of SOC stored in the 0.3-m topsoil of French mainland soils (Martin et al., 2021). There are, however, very strong differences between forest (31% of mainland France surface area), mountain pastures (3%), grasslands (23%) and croplands soils (30%). French scientists and policy-makers have been instrumental in designing and launching the 4/1000 initiative but its ambitious objective is not reachable everywhere, and it will be necessary to adapt practices locally, both to increase and preserve low and high SOC stocks respectively (Martin et al., 2021). Launay et al. (2021) have been showing the potential of the inclusion of cover crops or temporary grassland in rotations for instance, while agroforestry is bearing promises as it currently represents only a minor fraction of French agroecosystems. French agriculture accounts for 19% of the French emissions of GES and researches should be pursued, e.g. on deep SOC sequestration, N_2O emissions, and the effect of climate change and agroecological transition on SOC dynamics (Bertrand et al., 2019; Chenu et al., 2019; Guenet et al., 2021). France is coordinating an ongoing large European project (EJP Soil) with this aim, and will be launching a large national project (PEPR FairCarboN) to tackle these issues, beyond agriculture. In comparison, soil inorganic stocks (0-0.3 m) are much lower, (about 1 Pg, see Marchant et al., 2015) and hardly manageable to mitigate fossil fuel emissions.

6. Soil Sealing and land-take, urbanization

Soil sealing and land-take issues in France call for including soil ecosystem services in land use and urban planning, developing indicators of soil functions/services (Fossey et al., 2020), and improving our knowledge on sealed soils (about 6%), urban non-sealed soils (about 3%) and on the rehabilitation of brownfields (about 0,5%). The Biodiversity Plan, presented by the

French Government in 2018, sets the objective of "limiting the consumption of natural, agricultural and forest areas to achieve the objective of zero net land-take by 2050”.

7. Soil diffuse and local contamination

France has a long industrial and agricultural history, which led to the accumulation of diverse trace elements and xenobiotics in soil. These can represent concentrated pollutions (about 9,000 contaminated sites are clearly identified and under rehabilitation, while about 250,000 more may be locally contaminated e.g. former gas stations) or diffuse ones, which for pesticides or some trace elements applied in agriculture, e.g. cadmium and copper, are concerning extensive areas of agricultural soils, as evidenced through the French Soil Monitoring Programme (RMQS) launched more than 20 years ago. For trace elements, the pedodiversity also holds for the pedogeochemical background, which shows substantial variations, with some soils exhibiting naturally high levels of e.g. cadmium or nickel. The rehabilitation of contaminated hot-spots, as well as monitoring diffuse contaminations and reducing their impacts, are prerequisites to secure the food-chain safety, water and air quality, human and environmental health.

8. Conclusion

French priorities stress the need to progress in local soil mapping and modelling soil functions in space and time. This should include efforts in high-resolution digital soil mapping (Voltz et al., 2020), soil monitoring, maintaining and developing long-term experiments and observatories, and increasing interdisciplinary and participatory approaches. An overall objective should be to better predict/anticipate potential changes of soil quality and functions, hence associated services on mid- to long term scales (one to several decades), as related to global changes and agroecological or energetic transitions.

Such efforts will be impeded or useless if France fails to increase soil awareness for various stakeholders at local, national and international levels. A recent review (Arrouays et al., 2020) showed that digital soil mapping in France had substantial impact on various categories of end-users, especially on stakeholders, and policymakers. Raising soil awareness should include implementing education programmes on soils from kindergarden to university levels, developing easy to understand and measure indicators, and upscale their use and uptake through participatory research and science projects.

Overall, communication and transfer of technology tools are essential to help decision-making at all levels (farmers, foresters, advisers, local stakeholders, national and EU policy makers…). This is in line with the EU mission area “Soil Health and Food” and the framework for a new EU soil strategy.

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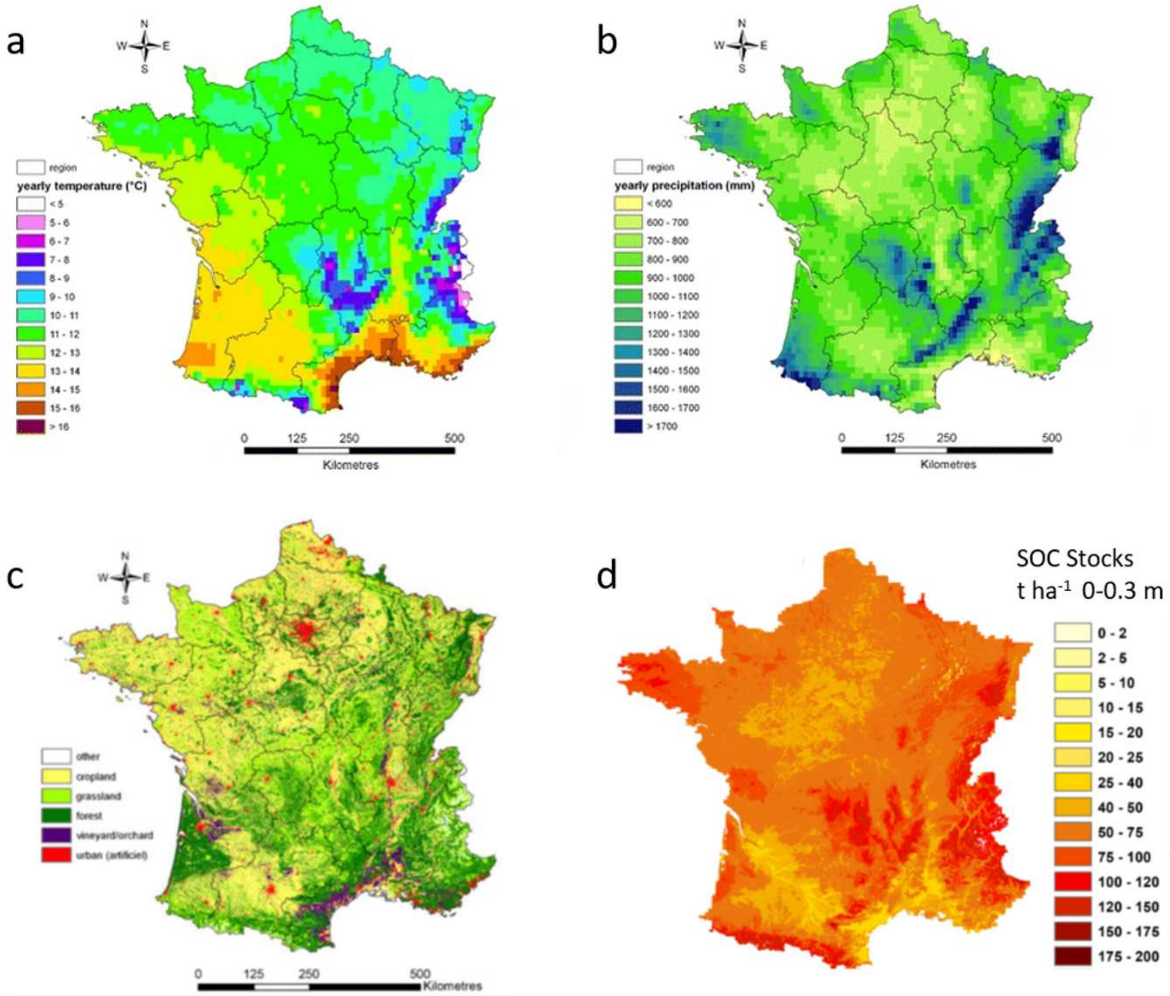
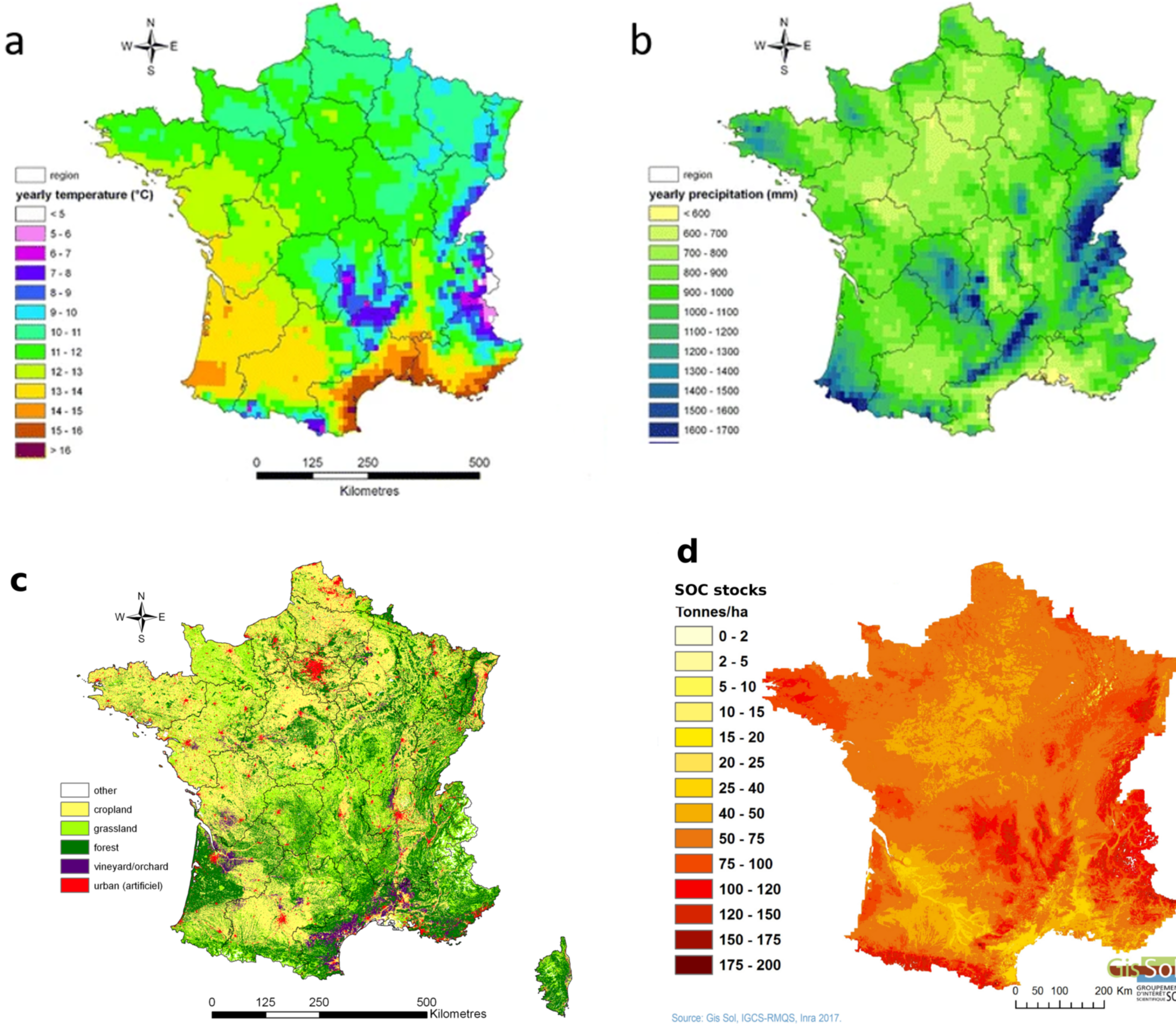


Figure 1. a) yearly temperature (°C); b) yearly precipitation (mm); c) land use in six classes; d) SOC stocks 0-0.3 m (t ha^{-1}). Sources a)&b) Meteo France; c) Corine land Cover; d) https://doi.org/10.15454/JCONRJ, Portail Data INRAE, V1.


a
N
W
E
S
region
yearly temperature (°C)
< 5
5 - 6
6 - 7
7 - 8
8 - 9
9 - 10
10 - 11
11 - 12
12 - 13
13 - 14
14 - 15
15 - 16
> 16
0
125
250
500
Kilometres
b
N
W
E
S
region
yearly precipitation (mm)
< 600
600 - 700
700 - 800
800 - 900
900 - 1000
1000 - 1100
1100 - 1200
1200 - 1300
1300 - 1400
1400 - 1500
1500 - 1600
1600 - 1700
c
N
W
E
S
other
cropland
grassland
forest
vineyard/orchard
urban (artificiel)
0
125
250
500
Kilometres
d
SOC stocks
Tonnes/ha
0 - 2
2 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 40
40 - 50
50 - 75
75 - 100
100 - 120
120 - 150
150 - 175
175 - 200
0 50 100 200 Km
Gis Sol
GROUPEMENT D'INTÉRÊT SCIENTIFIQUE SOL
Source: Gis Sol, IGCS-RMQS, Inra 2017.