Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Discussion

SARS-CoV-2 in soils

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ABSTRACT

Some environmental aspects are being increasingly studied in relation to the COVID-19 pandemic. Specifically, studies focusing on wastewater could be used for early warning, based on wastewater based epidemiology precepts. However, sewage sludge has been poorly studied in this regard up to now. In addition, soils have not been considered in publications related to SARS-CoV-2. In this piece, some comments are included to suggest a discussion regarding the eventual convenience of considering future studies focusing on soils receiving the spreading of wastewater and sewage sludge, as well as on plants growing on them.

1. Discussion

Since the beginning of 2020, an increasing number of works related to the COVID-19 disease and the SARS-CoV-2 coronavirus have been published. Some of them are papers covering different aspects referred to the virus and the disease in relation to environmental compartments and environmental parameters.

In a previous paper, Núñez-Delgado (2020) commented on SARS-CoV-2 and the environment, but at this moment many other relevant works have been published focusing on certain environmental and public health aspects such as:

(A) Detection and quantification of SARS-CoV-2 in water (mainly in wastewater), and its potential use as early warning, to report on the situation of current and eventual future outbreaks, most of these works taking into account precepts of the so called "wastewater based epidemiology" (WBE). Some papers in this category are those by Bofill-Mas and Rusiñol (2020), Bowser (2020), Daughton (2020), Farkas et al. (2020), Mao et al. (2020), Nabi et al. (2020), Orive et al. (2020), Race et al. (2020), Sims et al. (2020), and Venugopal et al. (2020).

(B) Relations among atmospheric variables (mostly those informing on weather condition) and incidence/evolution of COVID-19, with special relevance for studies focusing on suspended particulate matter and overall pollution in the atmosphere (for example, Bahir et al., 2020; Bontempi, 2020; Chauhan and Singh, 2020; Domingo and Rovira, 2020; Holtmann et al., 2020; Setti et al., 2020; Zhu et al., 2020).

However, regarding sewage sludge in relation to SARS-CoV-2, as per the scientific searching tools web of science (WOS) and Scopus (SP), few peer-reviewed papers have been published up to now (specifically, WOS found 2, and SP found 1, at date July 4, 2020). When carrying out the search in Google Scholar (GS) using the same searching string as in WOS and SP ("SARS-Cov-2 AND sewage-sludge"), a total of 49 results is shown, including various papers presented in repositories but not yet peer-reviewed. In addition, some of these papers do not really have a clear relation with environmental aspects, or even do not really fit simultaneously with the SARS-CoV-2 virus and sewage sludge, which is due to limitations of searching tools.

For soil, the numbers resulting from an equivalent search with the same tools are higher (15 on WOS, 3 on SP, and 851 on GS) but most of the papers are not really related to environmental aspects of soils and this virus. Refining the search string to "SARS-Cov-2-detection AND soil", no results are found by WOS and by SP, and 16 results are provided by GS, most of them being manuscript not peer-reviewed at that moment, and they are not really related to the detection of the SARS-CoV-2 virus in soils.

But, in fact, would it really needed to study soils in relation to SARS-CoV-2?

To have an answer, some aspects should be taken into consideration:

In certain cases, wastewater may be directly applied on soils. This could be treated wastewater that is recycled for irrigation purposes, or could be raw wastewater, more probably in areas where wastewater treatment facilities are scarce or absent, and where that water is really needed for irrigating/feeding crops, or where water streams are not near, promoting a direct spreading on soils. In these situations, not only soils, but also plants, may receive the application of wastewater, and in certain cases some of these plants may be exposed to grazing by cattle and/or wild fauna. In the medium term, some crops can become food for humans, although at that time virus most probably would be deactivated and not infective. To be noted that the survival of various coronavirus

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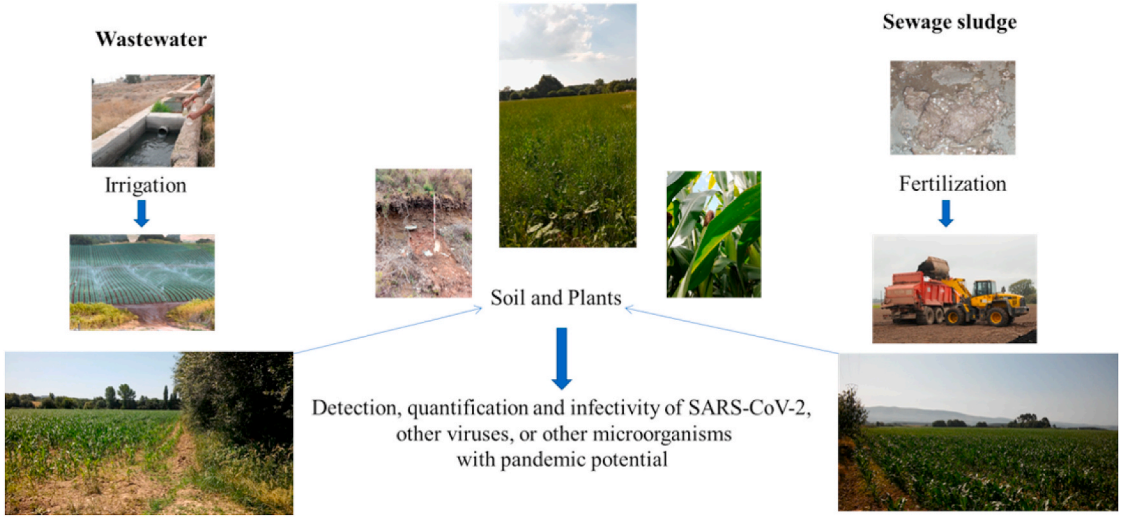

Fig. 1. Images illustrating different eventual sources for the spreading of SARS-CoV-2 and other pathogens on soils and plants, as well as indication of main samples to be taken for subsequent determination, quantification and assessment of infectivity.

has been shown to be variable in raw wastewaters, in a range going from few days to various weeks, depending on temperature (with more extended survival at low temperature), and other factors, while in treated wastewater is mostly dependent on the fact of suffering an effective tertiary treatment with disinfectants.

Just for comparison, dealing with diluted feces spread as slurry fertilizer, and just counting fecal bacteria (not viruses) Núñez-Delgado et al. (2002) detected a prolonged persistence of viable fecal microorganisms in runoff samples generated in a pastureland. Also, fecal bacteria remained viable in leachates after passing through 70 cm of soil in column experiments (Núñez-Delgado et al., 1996) and through up to 90 cm of soil in field experiments (López-Periago et al., 2002).

In addition, sewage sludge is a waste material very usually recycled as organic amendment on crop soils (and sometimes on forest soils). Once again just for comparison, Pousada-Ferradás et al. (2012) quantified fecal bacteria in leachates generated from treated sludge in laboratory columns, finding viable bacteria 4 weeks after the start of the experiment, as previously found in solid samples of treated sludge (Pousada-Ferradás et al., 2011). Focusing on viruses in sewage sludge, some selected references are the papers by Nag et al. (2020) and by Martínez-Puchol et al. (2020).

Specifically for viruses in soils, there are also several papers that can be considered a reference, such as those by Kimura et al. (2008), Williamson et al. (2017), or Kuzyakov and Mason-Jones (2018). And there are even some of them focusing on epidemic viruses, such as that by Gutiérrez and Buchy (2012).

Even if to date no peer-reviewed published papers have focused on SARS-CoV-2 in soils, the procedures that are being considered for eventual future use on samples of sewage sludge (or other more specific), could be used on soil samples in the coming future. In fact, previous papers have already studied other viruses in sewage sludge (Bibby and Peccia, 2013). As in the case of water and wastewater, these eventual procedures and techniques would have to report on the presence of the virus, its quantification, and/or its infectivity. Currently, there are techniques that allow achieving these goals for different liquid and solid substrates, and it could be also possible for soil samples. It is sure that detailed studies specific for soils could take into account many specific particularities of the edaphic environment, such as the variable distribution of a porous system constituting a certain kind of net with porous channels of a variety of sizes, subject of convective and diffusive transport for liquids containing abiotic and microscopic biotic components, as well as containing its own biome, its own "climate" (mainly at a certain depth, where the influence of the atmospheric weather is attenuated), and so on.

Some microclimates into soil could favor the survival of infective SARS-CoV-2?

Some protozoa, fungus or other microorganisms could fight these viruses (for example, by means of some exudates)?

All this would merit more exhaustive comments, in case of going ahead in this kind of studies.

In addition, direct and individualized sampling of plants (for example, grasses, or different crops) growing on soils receiving wastewater and sewage sludge would be clearly interesting, and the appropriate procedures for eventual concentration and further detection/quantification of the viruses would be applied.

Fig. 1 shows a pictographic illustration of the specific problems, and also of the starting points for the proposed workflow corresponding to the various aspects covered in this piece.

As in the previous discussion piece by Núñez-Delgado (2020), it would be noted that it is obvious that during the peaks of a pandemic situation, most effort should be directed to fight the pandemic, assisting people affected, and searching for medical treatments to cure and/or palliate the disease. However, in the medium and long term, thinking on eventual future outbreaks or on eventual future pandemics, many other aspects involving different environmental compartments, and the whole environment, should be considered to reach sustainable solutions.

Regarding soils and plants affected by the spreading of solid and/or liquid wastes containing SARS-CoV-2 and other pathogens with epidemic potential, future directions of the research would focus on the establishment of appropriate procedures for sampling of the materials, as well as on specific procedures for concentration, quantification and assessment of viability (and infectivity) of the pathogens in these kinds of samples.

In addition, with a broad view, maintaining biodiversity has been signaled as an overall way of promoting protection against pandemics (Everard et al., 2020), which otherwise, can be enunciated as "Pandemics such as Corona are an immediate consequence of destruction of nature" (Goymann, 2020), or as "There is strong evidence that ecological changes have led to increased rates of emerging and re-emerging diseases such as malaria, hantavirus lung syndrome, Nipah virus, and Ebola virus disease" (O'Callaghan-Gordo and Antó, 2020).

More specifically, soil biodiversity would be an aid in protecting against microorganism that are pathogenic for humans and have the potential for causing epidemic outbreaks (Wall et al., 2015). Soil biodiversity should be preserved (Geisen et al., 2019), as, among other beneficial effects, it would also aid to diminish the proliferation of

antibiotic-resistant bacteria, considered another heavy threat for human health now and in the coming decades.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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