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How many factors of global change affect soils

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ABSTRACT

It is very difficult to study many factors of global change at the same time. We did this using a trick: we asked what happens if you steadily increase the number of factors that influence a soil, ignoring factor identity. This way we found that just the number of factors can explain general trends in soil properties and biodiversity.

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We often hear about how the warming climate is affecting the natural world around us. But the human-made global change is a tremendously more complicated problem than 'just' a changing climate. It captures pollution, invasive species, biodiversity loss, excessive use of species or land, all of which reduce the benefits we receive from nature. As scientists, we need to understand what happens when many such factors of global change act at the same time.

Soils are the natural target of global change questions. Soils determine how ecosystems on land will respond to global change. Soils support important processes such as decomposition, respiration and the ability to form soil crumbs, aggregates; without these, nutrients would not get recycled for use by plants, and soils would more easily erode. Without a healthy soil we would also be unable to grow our food. Besides, soil harbors countless life forms known as soil biodiversity.

The vast majority of studies on how global change affects soil look at one factor only. For example, researchers examine how warming affects soil biodiversity. We counted the number of studies that look at more than two factors to be incredibly low - only two percent. Why is this? Ecologists examine

the effects of combinations of factors in so-called "factorial experiments". Say you have two factors: warming and microplastic pollution. You establish two levels of each of the factors - ambient and future temperature, or absence of a pollutant and its projected future concentration - and combine them in all possible ways. For two factors that gives four different combinations. If you expand the experiment to three factors with two levels of each, you'll have eight different combinations. Such experiment becomes much more difficult already, keeping in mind that you also need to replicate each combination. If you have ten different factors, you would need 1024 different combinations - a number too large for experiments. And global change includes many more than ten factors. It would be also interesting to look at more than just two levels of each.

How can we study responses to a large number of factors? One option is to let go of the idea that each interaction between factors needs to be studied. Instead we asked: what happens if we look at just the *number* of factors, ignoring what these factors actually are. We used this trick: we created a pool of ten global change factors. When we wanted to study what happens with three factors, we picked them from the pool completely randomly. We repeated this procedure many times, which means that most likely all the scenarios in our experiment combined different factors, for example, "warming, copper and microplastic", or "drought, warming and salinity". We followed this procedure of random draws for up to ten factors.

Then we set up small experimental systems, containing about 30 grams of soil each. We applied the factors according to the recipes and measured what happened. We saw that with an increasing number of global change factors the quality of soil declined progressively. Astonishingly, we found that just the number of factors, and not the actual identity or combination of factors, would predict some of the effects we observed. In most cases, we could predict in which direction a parameter would change as we increased the number of factors. But there were also some surprises - phenomena that occurred 'without warning'. In our case, we observed the soils becoming water-repellent. This property increased impressively at higher factor levels (five, eight and ten factors), while there was no indication that this would happen when looking at the effect of just one or two factors.

Our results give hope that we can understand some effects of global change involving many factors. Even though the effects became more negative as we added more factors, there is a silver lining: everything helps! We can make progress by reducing any single factor. And many of these factors are related, for example different forms of pollution. Going forward, we need to continue to study all factors of global change in a more integrated way rather than stay within individual effects.