Understanding predictability and randomness by digging in the dirt

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When tilling soil, the blade of the tillage tool cuts through the dirt, loosening it up in preparation for seeding. The dirt granules are pushed aside in a way that certainly looks random—but might not be.

Now, from studying soil tilling, researchers have found a way to distinguish whether such a process is truly random, or only appears so and is actually predictable and deterministic—which can lead to a deeper understanding and the ability to precisely control the process.

This mathematical method, the researchers say, could be useful in a range of applications beyond soil, from drying and sorting grains to seismology. They describe the analysis this week in the journal *Chaos*.

During tilling, soil particles stick to and rub against one another. These interactions subject the granules to forces that oscillate in strength. Under some conditions, these fluctuations may be deterministic, which means calculations can predict how the resultant forces will behave at a later time.

For example, these fluctuations can be similar to the oscillatory behavior of a box sitting on a conveyor belt while being tethered to a spring. As the conveyor belt moves, the box pulls away, stretching the spring. When the spring force becomes greater than the friction force holding the box in place, the box slides back, only to be pulled again by the conveyor belt. This back-and-forth motion—called stick-slip dynamics—also appears in the interactions between grains and other particles, the strikeslip faults that trigger earthquakes, and even in the friction of a gecko's feet.

Stick-slip behavior is deterministic, but it also can be chaotic in certain instances. A slight change in the initial conditions of the system can lead to wildly different outcomes.

But such chaotic behavior often appears random, and knowing whether it is truly random is essential for understanding the system.

"If the system was deterministic chaos, we can expect to start to develop a method to predict and control the behavior of the system with higher accuracy," said Kenshi Sakai of the Tokyo University of Agriculture and Technology in Japan. "However, if the system was stochastic, the only thing we can do is to estimate the probability of the occurrence of the behavior."

There are mathematical tools that distinguish deterministic chaos, like in the stick-slip model, from pure randomness. But, Sakai said, those tools don't work as well when statistical noise contaminates the data—such as the noise inherent to the messy reality of soil tilling.

So the researchers sought a new technique, which they tested on a series of soil-tilling experiments. In the experiment, they used a device developed at the University of California, Davis that measures forces as it cuts through the soil. They made these measurements on Yolo loam soil under four conditions: tilled and dry, tilled and wet, untilled and dry, and untilled and wet.

By analyzing the data, the researchers calculated a parameter called the normalized deterministic nonlinear prediction (NDNP). It turns out that when this number is less than one, the system is random. But if it's greater than one, it's deterministic. Only the case in which the soil was tilled and dry was deterministic. The tilled and wet case was uncertain, with a NDNP value of one.

These results show that NDNP is a relatively simple way to determine whether a system is deterministic, Sakai said. One important use would be for analyzing seismic data and, perhaps, to better anticipate future earthquakes.

More information: "Chaos emerging in soil failure patterns observed during tillage: Normalized deterministic nonlinear prediction (NDNP) and its application," *Chaos*, DOI: 10.1063/1.4978027

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