Extreme excavation: Fire ant style

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Fans of The Lord of the Rings may disagree, but when it comes to exquisite excavation, the dwarves of Moria have nothing on the mighty fire ants of Georgia Tech. But Dan Goldman and Michael Goodisman aren't fascinated by the aesthetics of fire ant architecture alone. "I have an interest in animals interacting with complex materials", explains Goldman, who has studied creatures such as sidewinder snakes and sandfish lizards moving through and across sand. With the ants on their doorstep, Goldman and Goodisman were intrigued to learn more about how the insects work together and the mechanical factors that affect ant nest construction in soils ranging from wet clay to coarse sand.

They publish their discovery that fire ants are successful invaders because they are able to construct nests regardless of grain size in *The Journal of Experimental Biology*.

However, producing consistent simulated soil conditions for the ants to excavate was not as simple as stirring soil into water - "Different people got different conditions", Goldman recalls - until Nick Gravish, Daria Monaenkova and Sarah Sharpe came up with the idea of sieving mixtures of sand and water to create uniform distributions of water through the soil. Then, everything was ready for Monaenkova to take 14.5cm long plugs of the uniform soil samples - ranging from minute clay-like particles to ant head-sized grains of sand with a moisture content ranging from complete saturation to perfectly dry - drop mini-colonies consisting of 100 ants on the top and leave them to their excavations for 20h. The challenge then was to visualise the nests without destroying them, so Monaenkova meticulously scanned the plugs with X-rays - taking 400 shots per nest - and laboriously reconstructed the 3D structures with Greggory Rodriguez and Rachel Kutner to see what the industrious insects had achieved.

Analysing the structures, Monaenkova could see that no matter how large or small the grains of soil, the ants were able to excavate tunnels. And she noticed that above 5% saturation, the wetness of the soil had little effect on the ants' ability to construct nests. However, in dry soils, the ants could barely dig at all. Although Goldman admits that even these puny efforts were very impressive: when Monaenkova attempted to repeat the ants' efforts by driving a small steel rod into the relatively dry soils, even the shortest tunnels collapsed. Goldman suspects that the microengineers are building networks like Jenga puzzles to stabilise their structures.

Monaenkova also noticed that on average the ants built tunnels faster in coarser soils, although they forged ahead at an impressive 0.3cm3 per hour during the early stages of construction in the optimally hydrated fine soils. In addition, the team found that as hydration increased the ants went deeper in the finer soils, although they built more complex branched structures in moister coarse soils. The team suspects that the soils at intermediate levels of hydration yielded the most robust tunnels because the granules were bonded by strong capillary forces provided by minute droplets of water bridging the particles - although the stronger attachment did not impair the ants' excavation.

Next, Monaenkova investigated the mechanics of ant excavation by enticing them to burrow against a glass cylinder wall while she filmed their Herculean efforts, revealing that the animals used two tactics to remove the spoil. When the soil was coarse, they grasped a single grain and shuffled backward up the tunnel, dragging it with them. However, when the soil was fine and the ants could grasp multiple grains, they gathered them into a pellet and marched upward. Goldman was most surprised by the ants' inventiveness, moulding bulky pellets like snowballs with their forelimbs, mandibles and even their antennae.

Reflecting on the ants' engineering, Goldman says that he is impressed by their ability to work in a completely dark and confined environment while continually colliding with their nest mates. "It is just mind blowing how they can dig so well", he says.

More information: Monaenkova, D., Gravish, N., Rodriguez, G., Kutner, R., Goodisman, M. A. D. and Goldman, D. I. (2015). Behavioral and mechanical determinants of collective subsurface nest excavation. J. Exp. Biol. 218, 1295-1305
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