Computer Model for Gas Diffusion from Nests of Burrowing Animals

Animals that live underground will consume oxygen and produce carbon dioxide. The soil creates a barrier to diffusion, inhibiting O_2 from entering the nest and CO_2 from diffusing out of the nest.

Because burrows vary in length and depth below the surface, we tested the hypothesis that these variables will have little effect on gas flow to or from the nest. In addition, some animals are colonial nesters, so we tested the hypothesis that several nests in close proximity will interfere with diffusion from adjacent nests. The objective of this study was to determine the variables that affect gas diffusion into or out of underground nests. To accomplish the objective, we used a computer simulation based on the principles of heat transfer through a semi-infinite solid. The equations for heat flow from a sphere (nest), heat flow along a rod (burrow), and heat flow from several underground pipes laid side-by-side (colony) were used. Gas diffusion coefficients replaced the coefficient of heat transfer, and gas concentration gradient replaced the temperature gradient.

Our results showed that burrow length and depth below the surface have little effect on gas flow when these values are greater than about 250 mm. However, soil porosity (the air filled spaces) and the distance between adjacent nests can have a large impact on gas flow through the soil.

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Introduction

Many animals nest or live underground and experience oxygen levels that are lower than normal and carbon dioxide levels that are higher than normal. Birchard et al (1984) and Wickler and Marsh (1981) found levels of CO_2 at 6.7% and 5.6%, respectively, in nests of bank swallows. The aim of our study was to create a computer simulation that would determine flow rates of gasses into or out of the nest, as well as the pattern of flow through the soil and along the burrow. The model was designed to examine the effect of soil porosity, gas concentration, nest dimensions and arrangement on the flow of CO_2 and O_2 out of and into the nest, respectively.

Methods

We constructed a computer model created by LabVIEW, a software that allows users to use symbols, boxes and equations to design science-based models. The equations were developed from heat transfer equations that have been well-established for estimating heat flow in soil. We substituted the gas coefficient for the coefficient of heat transfer and the concentration gradient of the gas for the temperature gradient. In addition to the flow equations, we used equations developed for pipelines in which several pipes were placed in the ground. These equations were used to create a pattern of interference. In other words, one nest would interfere with the ability of an adjacent nest to move CO_2 into the soil. All equations contained a variable for flow, the area available for diffusion, a diffusion coefficient, and a term for concentration gradient known as dU/dX. The dU/dX term is highly complex because the concentration of gas varies along the burrow; therefore, no simple value can be used for the concentration gradient. These equations were plugged into the model to demonstrate different diffusion rates. The factors affecting the flow rate were also included.

Results

The model allowed us to change several factors: the gas concentration, the radius of the nest and burrow, the length of the burrow, the depth of the burrow below the earth's surface, the distance between the adjacent nests, and the soil porosity. We were also able to determine the rates of flow from a single nest, or the diffusion rates of a colony of below-ground dwelling animals.

The rate of flow into or out of the nest was linearly related to the concentration difference between the nest chamber and the outside air. We also found that as soil porosity increased, there was an exponential increase in flow. Soils with a low porosity such as clay provided a greater resistance to diffusion than soils with a high porosity such as sand.

Length of the burrow and the depth below the surface of the burrow had little effect on gas flow until less then approximately 200 mm. When testing the soil porosity, the line was exponential, or the higher the porosity, the higher the flow rate, until essentially the flow rate became 100% and the gasses were diffusing into air.

Discussion

The model showed that the most important variables in determining gas flow are the concentration of gas, the porosity of the soil, and the distance between adjacent nests. This is because nests spaced close together would be attempting to diffuse gas into the same spaces, reducing gas flow from any one of these nests. This model assumed only one entrance to the nest, however some animals have two or more entrances. Multiple entrances could lead to convective flow through the tunnels.

Conclusions

In conclusion, the model demonstrated that animals living in a nest in a colony live in a much different microclimate than animals that nest in solitude. The soil porosity affected the flow rate of gases; animals living in a denser soil may have a much more hazardous microclimate than animals living in loosely packed soil. The length and depth of the soil had very little effect on the flow rates. In burrows longer than 250 mm, gases flowed out from the nest chamber into the soil, and burrows more than 250 mm deep did the same, unless the burrows became shorter than about 200 mm, and the depth became less than 200 mm, which is extremely unlikely.