Getting to the Root of the Problem

Using mathematics to investigate the effects of climate change on root growth in temperate forests

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Investigating the effects of elevated carbon dioxide is crucial to understanding how the world's ecosystems will behave under climate change

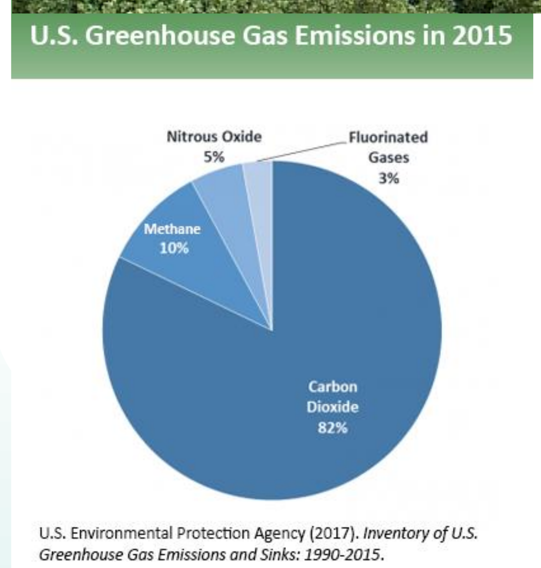

Figure 1: A pie chart showing US greenhouse gas emissions in 2015

Carbon dioxide is a major greenhouse gas, making up over 80% of greenhouse gas emissions in the US in 2015 [1]. It is also stored, or sequestered as part of the carbon cycle, which describes the exchange of carbon dioxide through photosynthesis, respiration and decomposition in plants, soil and in the oceans.

Minirhizotrons installed within the arrays allow for direct observation of root system responses to elevated carbon dioxide, with minimal disturbance to the ecosystem. Specialised camera equipment is used to capture images of roots belowground and growth data extracted using image analysis techniques.

The difficulties in non-destructively imaging roots in situ have led to a relative lack of representation of root system responses in the literature. Advances in x-ray and MRI techniques have recently allowed for imaging of lab grown plants in soil, but require plants to be grown in contained conditions [2]. Minirhizotrons are clear tubes installed in soil at a 45 degree angle, with care taken to minimise compaction of the surrounding soil. After a resettlement period, roots will grow around the outside of the tube and can be photographed. 4 minirhizotrons have been installed in each of the 6 rings at Mill Haft, allowing for direct comparison of growth between the 3 control and 3 treatment arrays.

Figure 3: Left: a minirhizotron installed in an array. Right: a root image analysed using SmartRoot [3]

The use of probabilities within a mathematical model allow for a wide variety of possible outcomes, such as is observed in real life.

As an example, the production of a new root branch is affected by many factors such as nutrient and water availability, the shape of the current root system, and biological processes within the plant. Therefore, two identical plants could produce two different root systems, and models would need to allow for this. This problem can be solved by the inclusion of probabilities, such as by giving a root a certain probability of branching within a certain timespan, rather than a constant rate at which branches are produced. Careful comparison with data is then required to evaluate the fitness of the model

Temperate forests are known to be an important absorber of carbon dioxide, however the magnitude and longevity of this affect has not been fully investigated. As a major plant organ, and understanding of the effect of eCO_2 on root systems is essential to understanding the effect on plants as a whole.

Trees take in carbon dioxide through photosynthesis, where it forms the main 'building blocks' for plants to produce new tissue. Carbon is also released from the roots into the soil, where it can be stored for long periods. Some studies suggest up to 30% of carbon released into the atmosphere by human activity is absorbed by forests [2], but the exact amount, underlying mechanisms, and length of storage time is poorly understood. Roots are an essential plant organ which provides anchorage along with water and nutrient acquisition, however they are relatively under investigated due to difficulties in data collection.

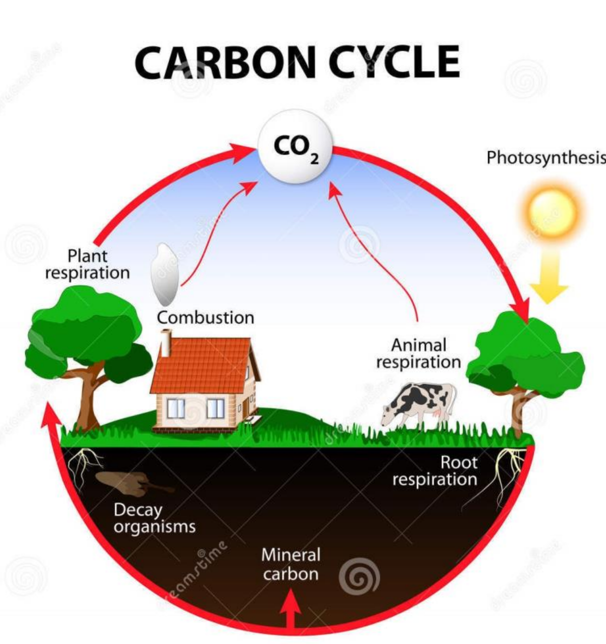

Figure 2: The carbon cycle

Initial imaging data collected since the switch-on shows around 50% more root biomass has been observed in arrays treated with increased carbon dioxide.

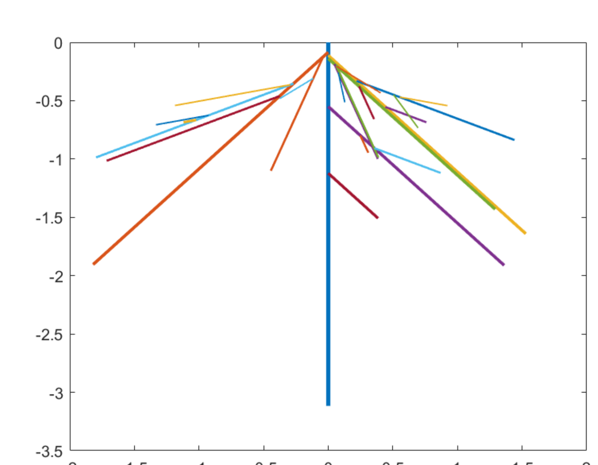

Figure 4: Example output from a root simulation

Figure 5: Section of a root system photographed at the research centre

This project aims to produce mathematical models of root growth, which can then be used to make predictions about how root systems will be affected by increased carbon dioxide.

Mathematical models can be used to capture the important processes within a complex system. Using computer simulation, we can run our models under different conditions and compare to real-world data, such as that collected from the BIFoR research site.

Approximate Bayesian Computation allows for information into the likely values of parameters such as growth and branching rates within a model

ABC provides a method for determining parameter values. If models are run with a 'guess' at the parameter values, the validity of the values can be decided by comparing the simulation output to data from the system to be modelled. ABC uses the idea that we can run a simulation many (> 1 billion) times with randomly chosen values for these parameters. By recording which values give a hit, we can produce figures that show the likely values of these parameters, as shown in Figure 6.

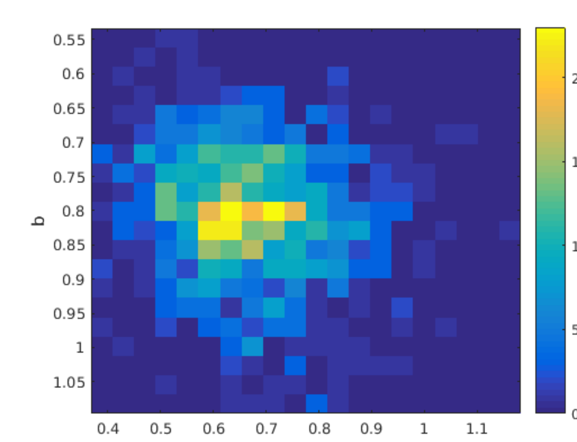

Figure 6: A contour plot showing the likely values of the branching rate (b) and growth rate (g) within a model of a root system

References:

[1] U.S. Environmental and Protection Agency (2017), *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015*

[2] Roose, T., Keyes, S. D., Daly, K. R., Carminati, A., Otten, W., Vetterlein, D., & Peth, S. (2016). Challenges in imaging and predictive modelling of rhizosphere processes. Plant and Soil, 407(1-2), 9-38.

[3] Lobet, Guillaume, Loïc Pagès, and Xavier Draye. "A novel image-analysis toolbox enabling quantitative analysis of root system architecture." *Plant physiology* 157.1 (2011): 29-39.